EFFECTS OF RETEMPERING WITH SUPERPLASTICIZER ON PROPERTIES OF PROLONGED MIXED MINERAL ADMIXTURE CONTAINING CONCRETE AT HOT WEATHER CONDITIONS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

KAZIM YAZAN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
THE DEPARTMENT OF CIVIL ENGINEERING

NOVEMBER 2005

Approval of the Graduate School of Natural and Applied Sciences

Prof.Dr. Canan ÖZGEN
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof.Dr. Erdal Çokça
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assoc.Prof.Dr. Lutfullah Turanlı
Supervisor

Examining Committee Members

Prof.Dr. Mustafa Tokyay	(METU, CE)	
Assoc.Prof.Dr. Lutfullah Turanlı	(METU, CE)	
Prof. Asım Yeğinobalı	(TÇMB)	
M.Sc. Fatih Kocabeyler	(DSİ)	
M.Sc. Şeref Topkaya	(A4 A.Ş.)	

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name : Kazım YAZAN

Signature :

ABSTRACT

EFFECTS OF RETEMPERING WITH SUPERPLASTICIZER ON PROPERTIES OF PROLONGED MIXED MINERAL ADMIXTURE CONTAINING CONCRETE AT HOT WEATHER CONDITIONS

YAZAN, Kazım
M.Sc., Department of Civil Engineering
Supervisor: Assoc. Prof. Dr. Lutfullah TURANLI

November 2005, 125 pages

Concrete which is manufactured in a mixing plant to be delivered to construction site in unhardened and plastic stage is called ready-mixed concrete. Because of technical and economical reasons, many mineral and chemical admixtures are used in ready-mixed concrete production.

As a result of extra mixing and delayed placing of ready-mixed concrete (especially at hot weather conditions), there can be many problems about concrete, like slump loss.

Addition of water for retempering concrete is the usual procedure, but addition of water without proper adjustment in mixture proportions, adversely affects compressive strength.

During this study, effects of prolonged mixing and retempering with superplasticizer on properties of fresh and hardened concrete at hot weather

conditions are observed. Some of the properties of concrete inspected are compressive strength, splitting tensile strength, slump and air content. All mixes contain air entrainer and water reducer at a standard amount. The difference between mixes comes from kind and amount of mineral admixture which cement is replaced by. During the study, fly ash, blast furnace slag, ground clay brick and natural pozzolan are used at amounts, 25% and 50% of cement. Also, a mixture of pure cement is prepared as control concrete.

15 cm initial slump is planned in the experimental work. After five minutes and at the end of first, second, third and fourth hours of mixing process, if needed retempering process is proceeded with superplasticizer and samples are taken. As a result of retempering with superplasticizer, the aimed slump values are obtained. The effects are than, observed.

As a result of this study, it has been observed that replacing Portland cement with certain mineral admixtures, especially fly ash at certain amounts, can be a solution for slump loss problem, by retarding the slump loss effect of prolonged mixing. Also it has been seen that ground clay brick causes better performance for slump values at lateral stages of mixing with respect to pure Portland cement. Another important observation has been about the increase in the amount of air caused by air entraining admixtures in fresh concrete based on prolonged mixing at hot weather conditions.

Key Words: Air Entrainment, Hot Weather, Mineral Admixture, Prolonged Mixing, Ready Mıxed Concrete, Retempering, Superplasticizer.

ÖZ

SICAK HAVA KOŞULLARINDA SÜPER AKIŞKANLAŞTIRICIYLA KIVAM DÜZELTMESİ İŞLEMİNİN, UZUN SÜRELİ KARIŞTIRILMIŞ, MİNERAL KATKILI BETONA ETKİLERİ

YAZAN, Kazım
Yüksek Lisans, İnşaat Müh. Bölümü
Tez Yöneticisi: Doç.Dr. Lutfullah TURANLI

Kasım 2005, 125 sayfa

Hazır beton, bir karıştırma ekipmanında karıştırıldıktan sonra inşaat sahasına plastik ve sertleşmemiş bir durumda sevk edilen betondur. Ekonomik ve teknik nedenlerden dolayı günümüzde pek çok mineral ve kimyasal katkı hazır beton üretiminde kullanılmaktadır.

Hazır betonun mikser içerisinde uzun süreli karıştırılması ve yerleştirme işleminin gecikmesi nedeniyle sahada kıvam kaybı gibi problemler yaşanabilmektedir.

Kıvam kaybını gidermek için su eklenmesi, genelde karşılaşılan durumdur. Ancak karışım oranlarında uygun şekilde ayarlama yapılmadan eklenecek su betonun basınç mukavemetini olumsuz şekilde etkileyebilmektedir.

Bu çalışmada, sıcak havada uzun süreli karıştırma ve süper akışkanlaştırıcı kullanarak kıvam düzeltmesi yapma işlemlerinin taze ve sertleşmiş beton

üzerindeki etkileri gözlenmiştir. Betonun mukavemeti, kıvam kaybı, hava muhtevası incelenen özellikler arasındadır. Çalışmadaki bütün karışımlar standart bir miktarda hava sürükleyici katkı ve su kesici-priz geciktirici katkı içermektedir. Hazırlanan karışımlar arasındaki temel fark, çimentonun belirli bir kısmı yerine kullanılan mineral katkının cinsi ve miktarıdır. Çalışmada kütlesel olarak %25 ve %50 oranlarda çimento sırasıyla uçucu kül, yüksek fırın cürufu, tuğla tozu ve doğal pozolan ile yer değiştirilmiştir. Ayrıca, bağlayıcı malzeme olarak sadece çimentonun kullanıldığı bir kontrol betonu hazırlanmıştır.

Çalışmada karışımlar için hedef kıvam değeri 15 cm olarak belirlenmiştir. Beş dakikalık ilk karıştırmadan sonra ve karıştırma işleminin birinci, ikinci, üçüncü, dördüncü saatlerinde gerekli olduğunda süper akışkanlaştırıcı kullanarak taze beton deneyleri yapılmış, numuneler alınmıştır. Süper akışkanlaştırıcı kullanılarak kıvam düzeltmesi işleminin sonucunda hedef kıvam değerlerine ulaşılmış, daha sonraki işlemlerle bunun beton üzerine etkisi incelenmiştir.

Çalışma sonucunda belirli mineral katkıların özellikle uçucu külün belirli oranda kullanılmasının uzun süreli karıştırmanın kıvam kaybını arttırma etkisini geciktirdiği gözlenmiştir. Ayrıca tuğla tozunun da mineral katkı olarak kullanılmasının saf Portland çimentosu kullanımına göre daha avantajlı olduğu kaydedilmiştir. Çalışmadaki diğer önemli bir gözlemse sıcak havada, hava sürükleyici katkı kullanıldığı durumda uzun süreli karıştırma işleminin hava miktarında ciddi artışlara sebebiyet verebildiğidir.

Anahtar Kelimeler: Hava Sürükleme, Hazır Beton, Kıvam Düzeltmesi, Mineral Katkı, Sıcak Hava , Süper Akışkanlaştırıcı, Uzun Süreli Karıştırma

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my supervisor, Assoc. Prof. Dr. Lutfullah Turanlı for his suggestion about the thesis subject and supporting supervision.

I am also thankful to my friends Mr. Raci Bayer, Mr. Burak Uzal and Dr. Tahir Kemal Erdem for their supports and encouragements during my thesis study. Also I want to thank my brother, Mr. Ömer Yazan for his mental support when I need.

I wish to thank Gülermak A.Ş. for their support at constructing the isolated room where experimental study has been proceeded and the administrators of Çimsa Çimento Sanayi Ticaret A.Ş, the firm where I have been working, for their support at preparation of this thesis.

Thanks are extended to the laboratory staff, Ali Yıldırım, Harun Koralay and Cuma Yıldırım for their physical assistance during the experimental study.

TABLE OF CONTENTS

LIST OF TABLES

TABLE

LIST OF FIGURES

FIGURE

LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
CEB	European Concrete Committee
GGBFS, BFS	Ground Granulated Blast Furnace Slag
GCB, CB	Ground Clay Brick
FA	Fly Ash
NP	Natural Pozzolan
PC	Portland Cement
PKÇ	Portland Composite Cement
TS	Turkish Standards
w/c	water/cement ratio
c/w	cement/water ratio

CHAPTER 1

INTRODUCTION

1.1 General

Concrete which is produced and delivered to the site in fresh and unhardened state is called ready-mixed concrete. The production and delivery processes of ready-mix concrete is proceeded by supplier who is using standard operational methods, so it is easier to control quality and standards of ready-mixed concrete with respect to concrete produced at site. Ready mixed concrete is also more advantageous and practical than conventional concrete produced at site, when "difficulties at production process of concrete is thought", especially for smaller sites.

With the use of ready-mixed concrete, concrete industry is able to use more technical methods which are based on material science, mechanics of materials and chemistry. Many materials other than cement, aggregates and water, are begun to be used in production process of concrete for economy and to improve the properties of concrete. The general name for these materials is admixture.

ASTM C125 and ACI SP-19 defines admixtures as "materials other than, water and hydraulic cements which are added to concrete mix immediately before or during mixing operation".

Generally admixtures have been used for certain beneficial effects on fresh and hardened concrete. But with these desired effects they can bring some other desirable and undesirable effects on concrete, so these additional effects should also be taken into account for the best performance at fresh and hardened concrete.

Producing ready mixed concrete needs close control under production processes, especially when admixtures have been used. As stated above different admixtures used at different conditions can result in unwanted effects in concrete.

Generally quality control systems have been applied in competent ready mixed concrete plants. The internal quality control of plant results in good quality concrete at desired strength and durability. But investigations at site show that after loading concrete to mixer-truck, the concrete to be processed in site operations has been left to personnel at truck and site, since an engineer can not be placed for each truck. The usually seen point that can result unwanted effects at this step is prolonged mixing of concrete. Especially at hot weather the prolonged mixing of concrete results in decrease in strength and loss in slump value of concrete, which are two of main important points in design of concrete. Depending on high temperature and high heat of hydration of concrete, the temperature of fresh concrete increases which results in slump loss of concrete.

The mixing operation can be described as three types depending on process and place of mixing. These are plant mixing, truck mixing and shrink mixing. By using appropriate one of last two methods, ready mixed concrete can be avoided from the unwanted effects of prolonged mixing. On the other hand these methods have some disadvantages, because of some economical and technical aspects.

The retempering of prolonged mixed concrete which is produced at plant can be said to be the most economical solution for the problem. For this method the best performance from concrete is taken with minimum hauling time. But sometimes delays being caused by site conditions and other environmental reasons do not permit this.

Based on agitation of concrete, loss of water gets unevitable, especially at hot weather. This can result in increase in water demand, decrease in slump value and workability.

At this situation, if water has been used in retempering process, strength loss can be seen depending on increase in water/cement ratio, since precise calculations generally can not be made for retempering. To avoid this figure some methods have been used by producers. The use of superplasticizer with or without water as retempering agent is one of these methods.

Although there are many studies for the effects of mineral admixtures, retarders and superplasticizers on concrete, at hot weather, the effect of prolonged mixing and retempering on hot weather concrete which is produced with admixtures stated above is not clear. In this study, this matter is focused and examined.

1.2 Object and Scope

As mentioned previously, the stiffening of concrete with water reduction and slump loss is seen with prolonged mixing of concrete. Especially for hot weather, the increased rate of hydration and evaporation of water, and in some cases the absorption of water by dry aggregates can result in this. In practice generally some water is added to concrete, in order to overcome the effect of slump loss. However, inclusion of extra water may change the water/cement ratio in an increasing direction. This results in lower strength of concrete.

Because of this effect of water as a retempering agent, superplasticizer may be used as a retempering agent instead of water which results in retempering without any change in water/cement ratio at the time of addition process.

The object of this study is to determine the effects of using superplasticizer without water as a retempering agent on concrete, produced with different mineral admixtures at different ratios and at hot weather conditions. The most important objective is considered to be determination of reaction of the compressive strength of concrete to the retempering action.

In this thesis, different amounts of superplasticizer have been used in different types of concrete (concrete prepared with different mineral admixtures at different ratios) for retempering purpose. The amount of superplasticizer is adjusted according to slump value of prolonged mixed concrete. The slump value of prolonged mixed concrete is aimed to be at the value 15±2cm.

The types of concrete, used in the study are changing in a large scale with different parameters but the starting design parameters of all these types are same. The slump value, water/cement ratio (small adjustments has been done at w/c ratio for different mineral admixtures to make the starting slump value, 15cm, of different concretes same) and maximum aggregate size are same for all concrete types . The aimed strength at the end of 28 days for control concrete which does not include any mineral admixture is 30 MPa.

The mineral admixtures added to different types of concrete are fly ash, blast furnace slag, ground clay brick and natural pozzolan. All of these admixtures has replaced the same amount (weight) of cement, at the ratios 25% and 50% of cement. As a result of this, totally 9 different starting concrete mixtures are obtained.

An important point in the study is that, all the work has taken place at an ambient temperature of 40°C, which is a very usual temperature under sun for many regions at Middle East and South Part of Turkey in summer time.

A certain type of air entrainer and superplasticizer are also added to the all concrete mixtures depending on long mixing duration. Since the stiffening amount of different concretes at the end of mixing time is not definite, same amount of these admixtures are added to all concrete mixtures. By this way the effect of mixing on air entrainment at different mixtures is also observed.

For all concrete types same procedure is applied. After initial mixing of concrete for five minutes, 20% of concrete has been taken to produce specimens. The remaining part of concrete has been continued to be mixed for one hour. Then another 20% has been taken and slump value is determined. If it is less than the value, 13cm, the superplasticizer has been used as a retempering agent at an amount that will supply the value of slump between the limits 13cm and 17cm and specimens have been taken. If the slump value is in the prescribed limits, no retempering process is proceeded. This procedure has been repeated at second, third and fourth hours.

The size of cylindrical specimens obtained have been smaller than the standard specimens, because the capacity of mixer has been about 450kg for fresh concrete and it has not been enough for size of standard cylinder specimens (15*30cm) on which many tests are thought to be applied. The specimens that have been used to determine the setting time of different concrete mixtures are standard cubic specimens.

The specimens have been cured under two different cure conditions, at 23±2ºC (standard cure temperature) and 50±5ºC to understand the full effect of high temperature on prolonged mixed concrete.

The tests made on fresh and hardened concrete are on determination of slump, air content, compressive strength of concrete at 7, 28 days and splitting tensile strength at 28 days.

CHAPTER 2

THEORATICAL CONSIDERATIONS

2.1 General

The concrete which is manufactured and delivered to the site by a certain supplier is called ready mixed concrete [1,2,3]. Since the supplier executed all the work, the concrete is “ready” for any operation on site.

The most important property of ready mixed concrete is better quality control than conventional concrete produced at site. The standard deviation of compressive strength of concrete produced at site is generally very high. In 1960 Entroy studied 1600 test values of compressive strength of ready mixed concrete and found that average standard deviation result is 5.5MPa [4]. In 1970 Metacalf passed over 4000 specimens produced at a ready mixed plant in Britain in which quality control restrictions are applied and he reached a standard deviation of 5MPa [5]. These are very low values, with respect to standard deviations as high as 10-15MPa seen at concrete produced at site.

The materials used for ready mixed concrete are selected according to standards and stored specially at plant. The batching and mixing operations are made with special equipment. The staff at plant is experienced and permanent. All these factors result in concrete at higher quality and uniformity with lower standard deviation [1].

Depending on mixing and delivery operations of ready mixed concrete, the ready mixed concrete is divided into three types. These are:

- Plant-mixed concrete
- Truck mixed concrete
- Shrink mixed concrete [4]

Plant mixed concrete: This type of ready mixed concrete is mixed at a stationary mixer. The concrete is carried to the site by mixers or agitator trucks. The mixing operation in the delivery equipment takes place with a speed of 1-4 revolutions per minute [10].

Truck-mixed concrete: In this method the concrete making materials (except water) are proportioned separately and placed into the mixer at the plant, but any mixing operation with water is not proceeded at the plant. After placing of dry material to the mixer, the dry mix is delivered to the construction site. There, the weight of water and if needed the weight of concrete admixtures for the concrete mixture are measured (these values are determined previously during the design stage) and they are added to the dry mix.

This kind of mixing operation permits longer delivery and mixing time. But it is disadvantageous from the point of the carrying capacity of mixer. According to ASTM C94 the amount of truck-mixed concrete carried by a mixer truck should be less than 63% of maximum capacity of mixer truck [4].

Shrink-mixed concrete: Concrete is partially mixed at the plant for about 0.5 minutes. Then the concrete mixture is transferred to the mixer truck and mixing process is completed in the truck. In this method the maximum amount of concrete in the truck mixer is again limited with 63% of maximum capacity of truck mixer [4].

The most widely used method for production of ready mixed concrete is plant mixing because of many advantages. All the mixture is produced in the same stationary mixer with the same proportions. By this way a more uniform concrete can be obtained. The water/cement ratio of plant mixed concrete is same and under control for all mixtures. Also mixing process until delivery stage of concrete is controlled and same for all mixture. The method is more economical depending on higher concrete capacity of mixers and less transportation costs.

However, there are some problems about plant mixed concrete caused by prolonged mixing and hot weather conditions. Normally, the concrete stiffens with time and this effect is seen with a reduced slump loss. Under normal weather conditions, there is not much difficulty about this aspect. On the other hand in hot weather environments, the stiffening is accelerated especially with long transporting durations [32].

In hot weather conditions, the retempering operation using superplasticizer, water or cement paste may be necessary to retemper the concrete for the desired workability [6].

2.2. Effects of Prolonged Mixing on Concrete

The time passed for mixing operation of concrete components is called mixing time. The mixing time of concrete is limited with maximum and minimum values of time and revolution by standards.

The optimum mixing time depends on type of mixer, condition of the mixer, speed of rotation, size of the charge and nature of the constituent materials [18].

According to ASTM standards the minimum mixing time for a mixture of concrete at an amount of $0.75m^3$ is 1 minute. For every extra $0.75m^3$ of concrete, this time increases 15 seconds [4]. The operational carrying capacity of mixer is limited to 80% of maximum capacity of mixer in this kind of operation [4].

According to ASTM standards, the mixing time in mixer is limited to 1.5 hours or totally 300 revolutions which is reached earlier [4].

Although maximum mixing time and maximum revolution of mixer is defined by concrete standards, prolonged mixing can be generally seen on site operations due to long delivery distances and delays, depending on traffic and hard site conditions.

2.2.1 Effects of Prolonged Mixing on Slump Loss

The most important result of prolonged mixing is on slump value of concrete. Fresh concrete mixes stiffen with time, particularly if continuously mixed. This stiffening effect is reflected in a reduced slump and accordingly, this phenomenon is reflected as slump loss [9] .This loss of slump value at prolonged mixed concrete is caused by a number of reasons. The main reasons are simply that some water from the mix is absorbed by the aggregate if not saturated, some is lost by evaporation and some is removed by initial chemical reactions [10].

The higher water absorption rate of aggregates as a result of longer mixing time is a reason for slump loss of prolonged mixed concrete [9]. The grinding effect caused by extra mixing of fresh concrete causes greater amount of fine aggregate than the one determined during design process. This situation results in a decrease in slump value, since increase in finer aggregate increases the water demand for same consistency of concrete [1]. The aggregates, where grinding effect is mostly seen are, limestone and weakly cemented sandstone [10].

Prolonged mixing also causes higher temperature values of concrete because of mechanical effect of mixing and heat of hydration of concrete. With the increase in concrete temperature, the hydration rate of cement and evaporation rate of water in concrete increase. This makes the water demand of concrete higher for the same slump value and decreases the slump value for same amount of water [17].

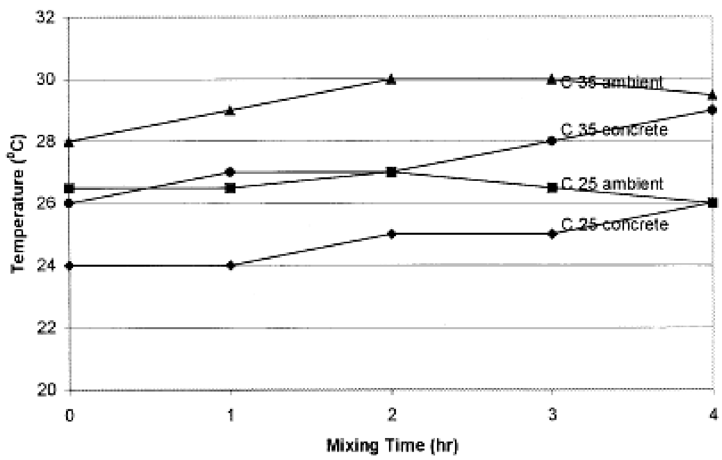

Figure 2.1 Effects of prolonged mixing and ambient temperature on concrete temperatures [7].

The slump loss is also affected by the ambient temperature depending on effect of outside temperature on concrete temperature. At high temperature conditions slump loss and stiffening of concrete is accelerated. Higher ambient temperatures cause higher concrete temperatures and higher water loss due to prolonged mixing with the result of higher slump losses [9]. Ravina et al. stated that "The cement hydration rate increases with the rising of temperature following Arrhenius equation, which states that the rise in the hydration temperature from 20°C to, say, 40°C in the first few hours, make the hydration rate enlarged by a factor of 2.41." Shortly, the accelerating effect of temperature on the hydration rate of Portland cement is very significant, resulting in shorter setting times and a higher rate of slump loss. Excess loss of water through evaporation at high temperature has further affected slump loss. The reduction in the free water content increases friction between the cement and aggregate particles and brings stiffening of the fresh mix [9]. Figure 2.2 shows the relationship between the slump loss and the ambient temperature.

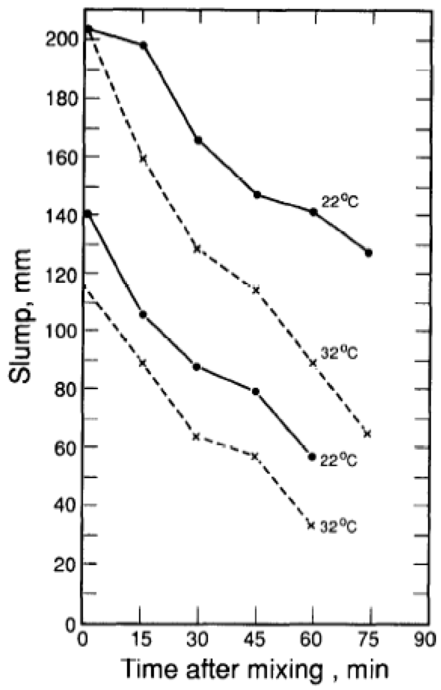

Figure 2.2 Effect of temperature on slump loss of concretes at the temperatures of 22°C and 32°C [8].

Concrete mixes with lower cement ratio has lower slump loss than the concrete mixes which are rich from cement ratio point of view, since the temperature rise in these mixes is less [11]. This is illustrated in Fig 2.3.

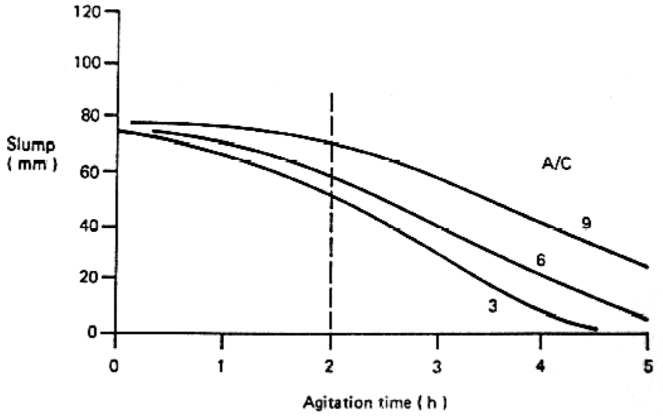

Figure 2.3 Effect of aggregate-cement ratio on rate of loss of workability with time [11].

In addition to cement ratio, cement type also affects the slump loss. The rate of slump loss is higher if the alkali content of cement is higher [15] and the sulfate content is too low [78].

Larger volumes of concrete proceeded to prolonged mixing has lower surface area proposed to evaporation of water, whereas it has higher heat of hydration which causes higher temperatures. The experiences say that lower surface area of larger volumes is more effective on slump loss and larger the volume of concrete, less the slump loss [12].

Another concept about slump loss of concrete, depending on prolonged mixing is initial slump value of concrete. The slump loss is proportional to the initial slump value; higher the initial slump level; higher the slump loss [13].

Figure 2.4 and Figure 2.5 show increased number of retempering process and higher temperatures make the slump loss increase [11].

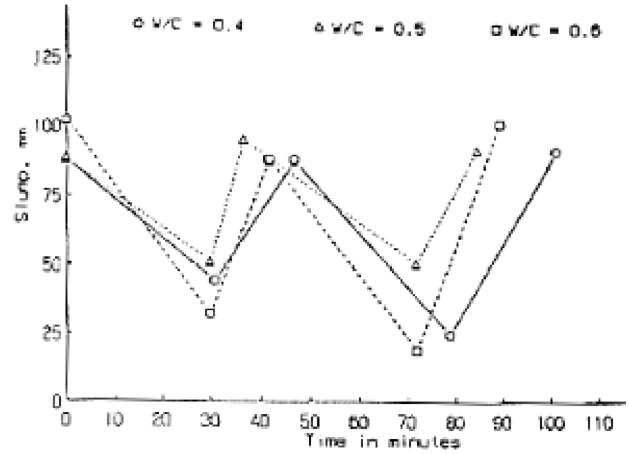

Figure 2.4 Slump, time, retempering study at 30ºC [11]

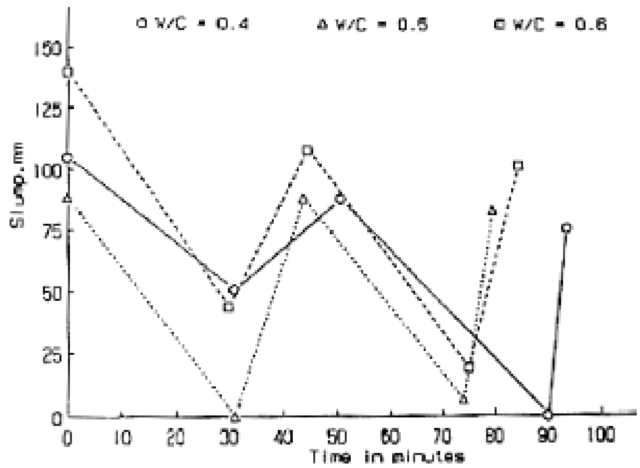

Figure 2.5 Slump, time, retempering study at 60ºC [11]

Water reducing admixtures delay the initial stiffening of concrete, but in addition to this effect on concrete, they often cause increased rate of slump loss with time [17]. It can be seen on Figure 2.6 Figure 2.7, accelerated slump loss can occur when water reducing and set retarding admixtures are used, even when the setting times are increased. It was pointed out by Ravina that retarders, although accelerating the rate of slump loss, may be beneficial to resist the possible formation of cold joints, etc under hot weather conditions [9].

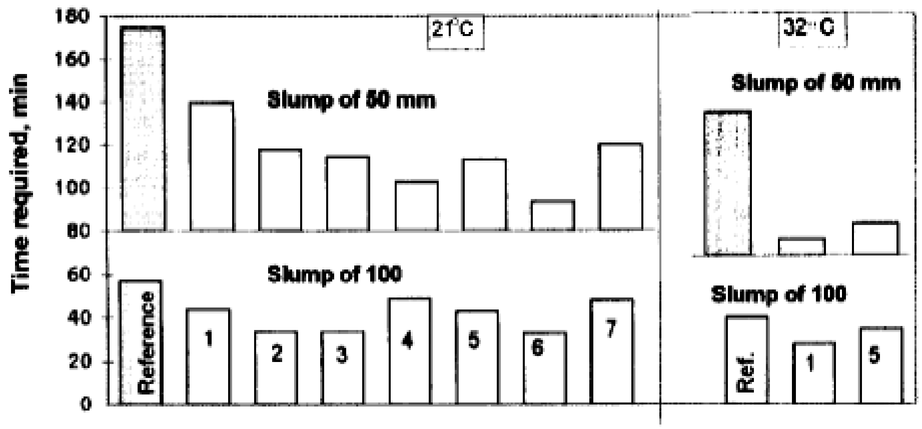

Figure 2.6 Effect of type D admixtures (1-4) and type G high-range water reducing admixtures (5-7), on the time required for the fresh concrete to reach the slump of 100 and 50 mm (initial slump 165 + 10 mm) [32].

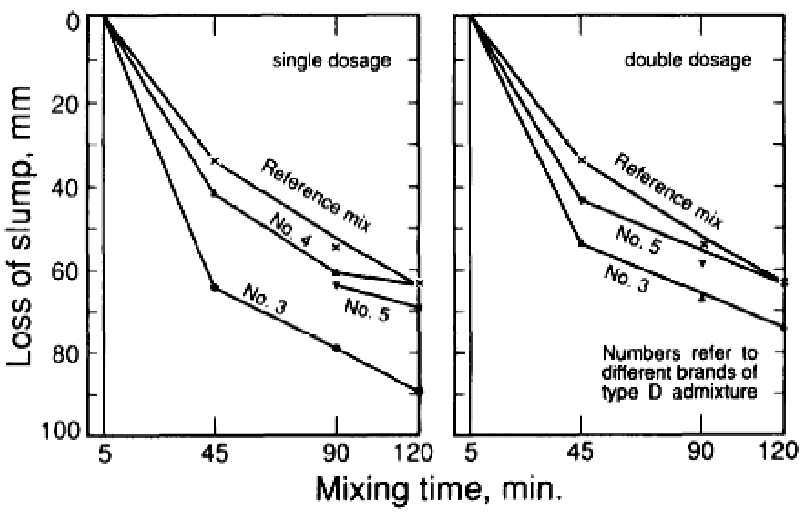

Figure 2.7 Effect of type D admixtures on slump loss. (Initial slump 95-115 mm, temperature 30°C) [87].

According to Ravina et al. continuous agitation of the fresh concrete results in a "grinding effect" with the "peeling off" of the adsorbed layer of the retarder or, alternatively, the precipitated layer of the calcium salts and this "peeling off" action makes the retarding mechanism fail to operate [9]. Ravina states that "Less water content with respect to "same slump, non-retarded mixture" concludes smaller spacing between the solid particles in the fresh mix resulting in the hydration products very close to each other at an earlier stage than "in a mix that contains a greater amount of water in which the spacing between the particles is greater" with the final effect of earlier stiffening" [9].

2.2.2 Effects of Prolonged Mixing on Compressive Strength of Concrete

Compressive strength is another important property of concrete. When prolonged mixing is taken into consideration, the reaction of compressive strength to the prolonged mixing is different from the reaction of slump, but it is also related with slump from placeability point of view.

The general truth about compressive strength of concrete is that, it is directly proportional to cement/water ratio of concrete. As a result of prolonged mixing, concrete is expected to loose water which will result in an increase in cement/water ratio. If the concrete can be compacted at a rate which is same with normally mixed concrete, strength of concrete has tendency to increase at about 5% per hour of mixing [14].

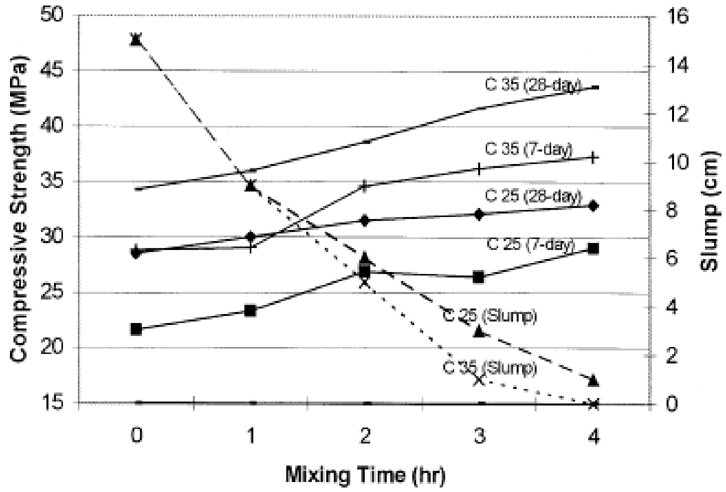

Figure 2.8 Compressive strengths and slumps of concretes C25 and C35, which were not subjected to retempering process [7] .

But this is not the case in practice. Since the inplace strength of concrete for structural purposes is as important as theoretical compressive strength and the inplace strength is directly correlated with placeability and compactability in other words workability of fresh concrete, there is a negative effect of prolonged mixing on inplace strength of concrete. The most important problems, depending on slump loss in concrete, include difficulty in handling, placement and compaction, with the results reduced ultimate strength, and worse durability [88]. Concrete with low strength and poor durability is undesirable, especially when it is exposed to aggressive environments with the result of ease permeation of destructive external effects through the concrete [85].

2.2.3 Effects of Prolonged Mixing on Setting Time, Unit Weight and Air Entrainment of Concrete

Baskoca et al. reported prolonged agitation caused decrease in both the initial and final setting times in addition to increase in slump loss, as a result of increased hydration based on increase in the temperature and reduction in the water/cement ratio that occured during the delayed agitation [13].

In the study proceeded by Erdoğdu [85] slight increase is observed in unit weight of concrete as a result of prolonged mixing as seen from Figure 2.9.

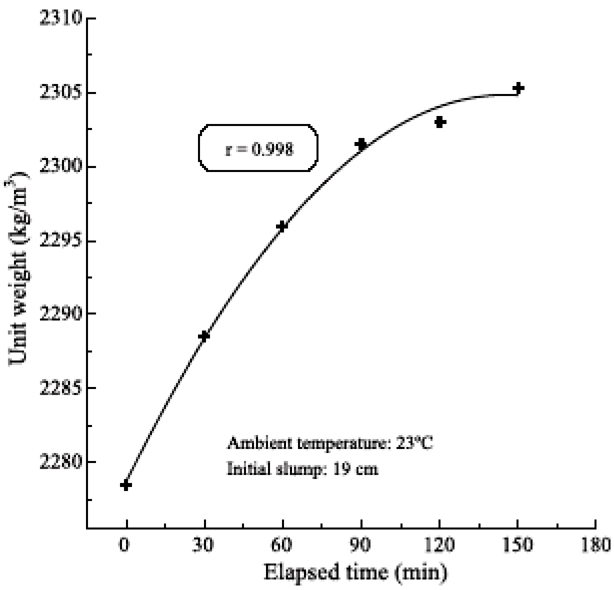

Figure 2.9 Effect of prolonged mixing on the unit weight of concrete [85].

In the case of air entrained concrete, prolonged mixing was stated to reduce the air content by about 1/6 per hour depending also the type of air entrained concrete [19].

2.3 Effects of Retempering on Prolonged Mixed Concrete

Retempering concrete with water or any admixture to bring it previously specified slump can be a solution to restore the workability of prolonged mixed concrete. The most of important reasons of need for retempering are insufficient water batched initially, higher rate of evaporation or absorption and higher rate of hydration (or grinding) than expected. If the retempering process with water is executed as a result of insufficient water in the batch or evaporation of water, there is not much problem, but if it is based on higher hydration rate, it may result in lower strength [12].

In the work proceeded by Erdoğdu prolonged mixed concrete is retempered by water and superplasticizer [85]. In Figure 2.10 the decrease, in strength of concrete parallel to amount of retempering water indicates that the greater amount of free water in concrete results in greater reduction in the strength of concrete. It can be also seen from Figure 2.10 retempering concrete with superplasticizer is much more advantageous than retempering process with water from concrete strength point of view. Erdoğdu has stated "The strength gain with respect to reference concrete can be due to ease of placement and compaction of concrete retempered with superplasticizer" and explained the reason for the slight drop in the strength of concrete retempered with superplasticizer beyond 90 min of mixing as the distorted rheological properties of fresh concrete depending on prolonged mixing [85].

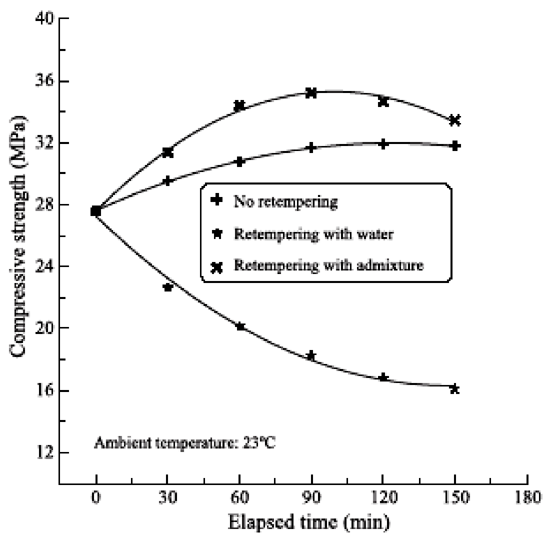

Figure 2.10 Effect of retempering on the compressive strength of concrete subjected to prolonged mixing [85].

In the study of Kırca et al. a chemical admixture (a melamine-based polymer dispersion conforming to ASTM C 494 Type F) is used with water as retempering agent . The aimed slump at each period of prolonged mixing action is 15cm in this study (See Figure 2.11, Figure 2.12, Table 2.1, Table 2.2) . The water–cement ratios of the concretes retempered with superplasticizer has been relatively lower as compared with no superplasticizer addition and the effect of retempering from strength point of view is more efficient, as the amount of chemical admixture increases in the total amount of retempering agent (mix of water and chemical admixture) . Lower decrease in compressive strength of the concretes retempered with superplasticizer and water mixture with respect to concretes retempered with plain water alone confirms this effect . Even slight increases are observed in compressive strengths of those concretes, which are retempered with superplasticizer and water mixture [7].

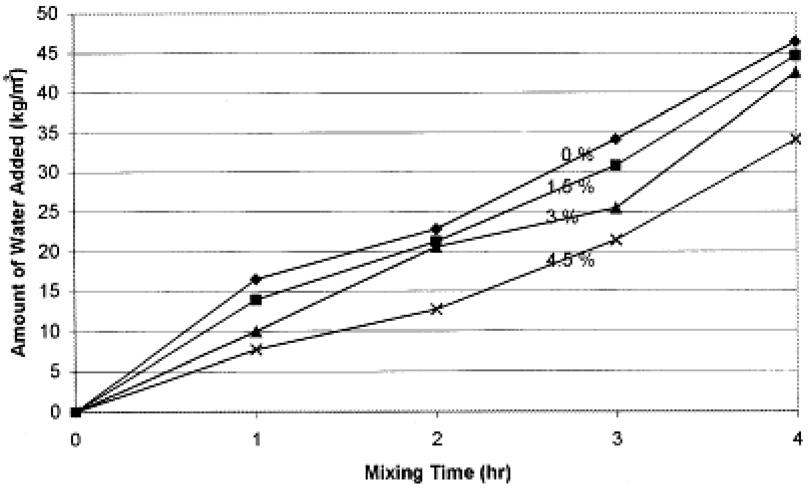

Figure 2.11 Amount of retempering water added to concrete for readjusting the slump to 15 cm, depending on the solution concentrations (from 0% to 4.5% solid superplasticizer by mass of retempering water) [7] .

Table 2.1 Twenty-eight-day compressive strengths of concrete whose slump was raised to 15 cm by different retempering applications throughout 4 h of mixing [7].

Type of retempering	Twenty-eight-day compressive strength of concrete C25, MPa				
	0 h	1 h	2 h	3 h	4 h
No retempering	28.5	30.0	31.5	32.1	32.9
Plain water	29.0	27.6	26.1	25.4	24.3
1.5%[a] Super-plasticizer	28.0	26.0	26.2	26.6	26.9
3.0%[a] Super-plasticizer	27.7	27.8	29.1	29.9	27.8
4.5%[a] Super-plasticizer	27.5	27.8	27.1	29.4	26.6

[a] Solution concentration (by mass of retempering water).

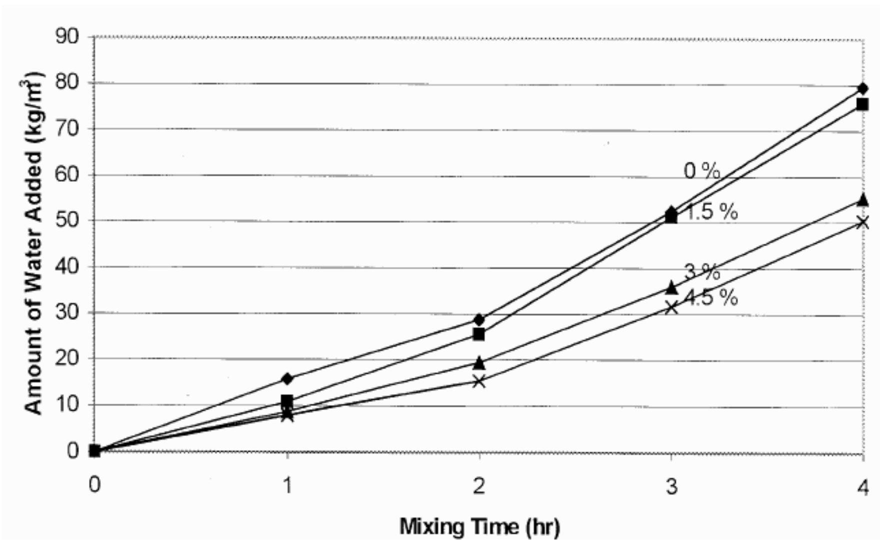

Figure 2.12 Amount of retempering water added to concrete for readjusting the slump to 15 cm, depending on the solution concentrations (from 0% to 4.5% solid superplasticizer by mass of retempering water) [7].

Table 2.2 Twenty-eight-day compressive strengths of concrete whose slump was raised to 15 cm by different retempering applications throughout 4 h of mixing [7].

Type of retempering	Twenty-eight-day compressive strength of concrete C35, MPa				
	0 h	1 h	2 h	3 h	4 h
No retempering	34.3	36.0	38.6	41.7	43.6
Plain water	34.6	32.4	32.1	30.5	28.1
1.5%[a] Super-plasticizer	35.5	34.3	32.9	31.1	29.2
3.0%[a] Super-plasticizer	35.1	34.6	34.5	32.3	31.9
4.5%[a] Super-plasticizer	36.6	35.4	36.2	36.7	34.2

[a] Solution concentration (by mass of retempering water).

2.4 Effects of Hot Weather Conditions on Concrete

Hot weather conditions for concrete are the situations, where one or more than one of conditions; high ambient temperature, low relative humidity, sun radiation, winds blowing fast, take place [1].

The most important factor determining the concrete characteristics at hot weather is increased water demand. Due to increased concrete and ambient temperature, the rate of setting increases. As a result of tests on cement –sand mortar mixture at ratio 1:2, it has been seen that the initial setting time decreased to half value of it with an increase in the temperature of the concrete from 28ºC to 46ºC [20].

The rate of hydration and the rate evaporation both increase with time at hot weather conditions resulting in a accelerated rate of decrease at the free water content of the mix. The rate of water content reduction in the mix, is thereby accelerated. The reduction in the free water content increases friction between the cement and aggregate particles and brings about corresponding stiffening of the fresh mix [32]. These problems bring greater difficulty in handling, compacting, and finishing of concrete resulting in a greater risk of cold joints and weaker areas on the overall structure.

A rise in the curing temperature speeds up the hydration reactions and results in a higher early strength of concrete. Higher temperature during and following the initial contact between cement and water reduces the length of dormant period so that overall structure of the of the hydrated cement paste becomes established very early [17,91].

In spite of the increase in early strength of concrete, the later strength from about 7 days is adversely affected. But this decrease in later strength is not so easily explained. It is believed that this is depending on hydration products with higher proportion of pores which will always remain unfilled as a result of fast hydration. On the other hand, the slowly hydrating cement at normal temperatures has been less porous resulting in a higher gel/space ratio and higher strength [17,91]. Verbeck and Helmuth suggested that the rapid initial rate of hydration at higher temperatures retards the subsequent hydration and produces a non-uniform distribution of the products within the paste depending on insufficient time available for the diffusion of hydration products away from the cement particle and for a uniform precipitation in the interstitial space [17, 19]. Verbeck and Helmuth believed that dense zones of hydration products would form around the hydrating grain at higher temperatures, and that these hydration shells would limit or even prevent diffusion of ions and water vapor, reducing the ultimate hydration [19]. The local weaker areas formed as a result of this situation also lower the strength of the hydrated cement paste as a whole [17].

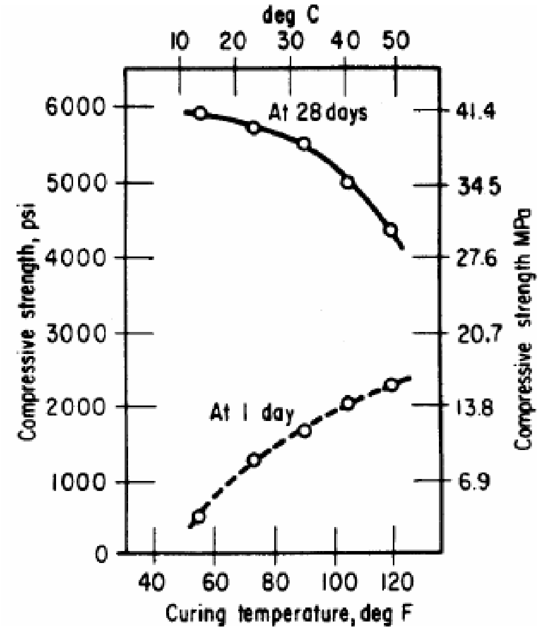

Figure 2.13 Effects of curing temperature on compressive strength of concrete [17, 19]

At concrete curing over 28 days, higher temperature (relative humidity is out of concern) may adversely affect the concrete strength, too. A possible explanation for this reduction may be presence of very fine cracks caused by the expansion of air bubbles in the cement paste, since the thermal expansion of air is higher than the solid concrete around it [19]. The temperature differences between the concrete and ambient conditions can cause greater expansion of air voids than concrete resulting in a decrease in strength. Also the temperature differential between external part of concrete and internal core part can cause unequal thermal expansion resulting in stresses, compressive in one part of the element and tensile in the other. If the tensile stress at the surface of the element depending on expansion and tensile stresses exceeds tensile strength of concrete, then surface cracking will occur [17].

Rapid evaporation of water can result in plastic shrinkage cracks when evaporation rate exceeds the bleeding rate of concrete at hot environments. Since there is water loss due to evaporation and hydration, the concrete tends to shrink.

There is no problem if there is enough water brought to the different areas of concrete with capillary action. But if hydration and especially evaporation rate of water is greater than capillary water at surface named bleeding water, cracks occur. It is considered that evaporation rate over 1kg/m^2/h is critical for shrinkage cracks [17].

In addition to these difficulties, air entrainment decreases at hot weather conditions for the same amount of air entraining agent. Also, it is a problem about air entrainment at hot weather conditions that the temperature differences between the concrete and ambient conditions can cause greater expansion of entrained air voids, than concrete resulting in a decrease in strength [17].

2.5 Effects of Mineral Admixtures on Concrete

Mineral admixtures are finely divided materials added to the concrete batch as separate ingredients either before or during mixing of concrete. Mineral admixtures are used in powder form, their fineness being at least at the value cement used together [20].

The most important mineral admixtures are named as pozzolans. According to ASTM C125 and ASTM C618 pozzolans are "siliceous or siliceous and aluminous materials which in themselves possess little or no cementitous value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitous properties." [22,23]. As known, hydration of C_3S and C_2S of Portland cement produces calcium hydroxide and C-S-H gel that provides the binding property to the Portland cements and calcium hydroxide. In addition to silica and alumina which are the main oxides, pozzolans usually include certain amounts of iron oxide, calcium oxide, alkalis and carbon, depending on the source that the material is obtained from [20].

2.5.1 Fly Ash

Fly ash is the finely divided residue or very fine ash which is by-product of burning pulverized coal to generate electric power. Rapid cooling of the ash from the molten state, after it leaves the flame, causes fly ash to be highly (60-90%) non-crystalline or glassy with minor amounts of crystalline constituents [24, 25].

Depending on nature of coal, the way of its pulverization, the operation of the furnace, the process of precipitation of ash from the combustion of gases and especially the extent of classification of the particles in the exhaust system, fly ash produced even in the same plant have different characteristics. It follows that behavior of concrete containing fly ash can not be presented depending on some basic properties of fly ash like particle size distribution of fly ash or its carbon content since fly ash is not a single material at nearly constant composition. So the users of fly ash have to be careful about the properties of the actual material used in concrete [26].

The main constituents of fly ash are silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3). In addition to these, certain amounts of minor constituents calcium oxide (CaO), magnesium oxide (MgO), sulfur trioxide(SO_3) and carbon (C) take place at certain amounts [21]. According to ASTM C 618 fly ashes are classified into two categories, Class F and Class C., depending on the chemical composition and the type of coal they are obtained from. Class F fly ash, which has been produced from anthracite or bituminous coal, has a total content of SiO_2, Al_2O_3, and Fe_2O_3 greater than 70%, whereas Class C fly ash, which has been produced from lignite or subbituminous coal may have a total content of SiO_2, Al_2O_3, and Fe_2O_3 greater than 50% . Also Class C fly ash has lime content greater than 10% showing pozzolanic and cementitous properties, while Class F fly ash has been showing only pozzolanic properties [22].

2.5.1.1 Effects of Fly Ash on Workability of Concrete

Fly ash consists of generally solid and some hallow particles of spherical shape. Generally the use of fly ash improves the workability and decreases the water content for the same slump value depending on the spherical particle shape of particles. This provides lower internal friction and lower need of water [21]. The spherical shape also minimizes the particle's surface to volume ratio, resulting in low fluid demands. Out of all 3-d shapes, a sphere gives the minimum surface area for a given volume [44]. This spherical shape gives fly ash its lubricant effect in the fresh concrete. This effect of fly ash is called “ball bearing effect”. The reduction in the water demand of concrete due to fly ash is usually between 5 and 15 percent by comparison with only Portland-cement mix having the same cementitous material content [34].

Fly ash also plays a role in increasing plasticity of mortar in concrete. Fly ash, cement and sand particles in a mixture fill the voids between aggregate particles and coat them, providing the fluid mass with cohesion and plasticity.

Smaller size of fly ash with respect to other pozzolans is also an additional factor for increase in workability [27]. According to Owens, the major influencing effect of ash on the workability of concrete is the proportion of coarse material (45 μm) in the ash. For example substitution of 50% by mass of the cement with fine particulate fly ash can reduce the water requirement by 25%. A similar substitution using ash with 50% of material > 45μm has no effect on the water requirement [27].

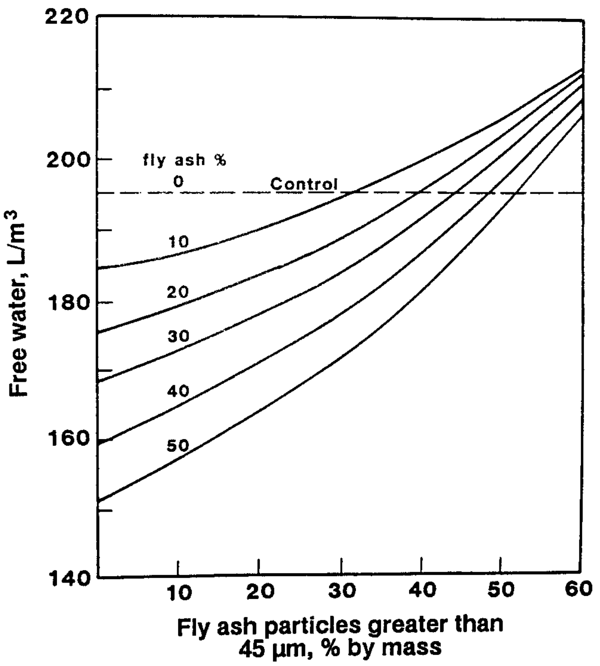

Figure 2.14 Influence of course-particulate content of fly ash on the water required for equal workability in concrete [27] .

Helmuth suggested an alternative hypothesis that decrease in the need for water, in mixtures containing fly ash, has been a result of the adherence of a thin layer of very fine fly ash particles on surfaces of the particles [28].

Ravina and Mehta reported that by replacing 35 -50% of cement by fly ash, there was 5-7 % reduction in the water requirement for obtaining the designated slump, and the rate and volume of bleeding water was either higher or about the same compared with the control mixture [31].

The mixture proportions of concrete has an important role on the water requirement. The mixtures where cement is replaced by the same amount of fly ash to take advantage of pozzolanic properties of fly ash, the required water content of fly ash concrete is less than that of non-fly ash concrete, at equal slump, whereas the water requirement may be higher when some part of fine aggregate is replaced by fly ash [21].

Brown reported that when ash was substituted by ~8% of sand or total aggregate, workability increased to a maximum value. Further substitution caused rapid decreases in workability [30].

Pasko and Larson examined the amount of water required to maintain 60mm slump in concrete mixtures with partial replacement of cement by fly ash. The result was decrease in water requirement by 7.2% in a mixture in which 20% cement had been replaced by 30 % fly ash [29].

Naik and Ramme searched for the relationship between the amount of water and the percentage of cement replacement by fly ash for the same amount of water and the percentage of cement replacement by the fly ash for the same workability with 21, 28 and 34 MPa nominal strength concrete mixtures, resulting with a conclusion that as the amount of fly ash increased in the mixtures, the water requirement decreased. Figure 2.15 shows the relationship between water requirement and 60% cement replacement by fly ash for 21 MPa compressive strength concrete at constant workability [89].

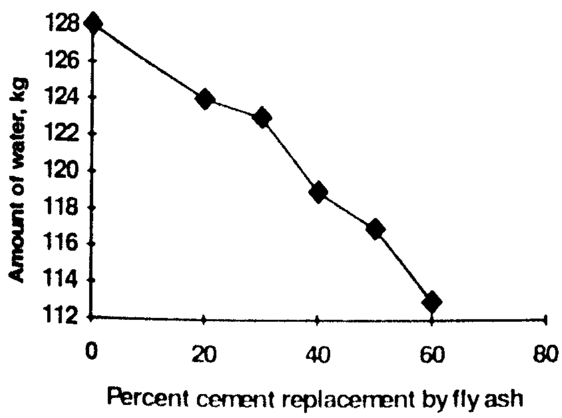

Figure 2.15 Effect of 60% cement replacement by fly ash on water requirement for 21 MPa compressive strength concrete at constant workability [89].

2.5.1.2 Effects of Fly Ash on The Rate of Slump Loss of Prolonged Mixed Concrete

The replacement of Portland cement by class F fly ash (ASTM C 618), has been found to reduce the rate of slump loss in a prolonged mixed concrete, and this reduction has increased with the increase in the amount of the cement replaced [9]. Figure 2.16 shows the relationship between the slump loss of concrete due to prolonged mixing and amount of fly ash in concrete

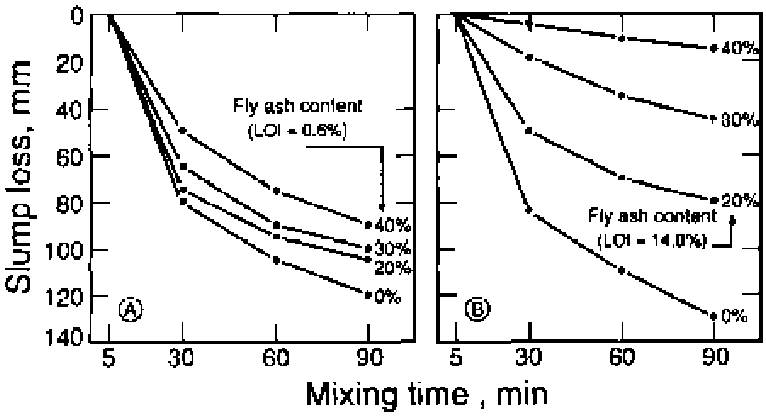

Figure 2.16 Effect of replacing the cement with class F fly ash (ASTM C 618) on the rate of slump loss at 30°C. Loss of ignition of fly ash A and B is 0.6% and 14.8%, respectively [9].

The effect of fly ash on reducing slump loss can be attributed to chemical and physical factors. It was found that the surface of fly ash particles may be partly covered with a vapor-deposited alkali sulfate that is readily soluble to form sulfate ions which have a retarding effect on the formation of the aluminates. Fly ash was found to be a more effective retarder than an equivalent quantity of gypsum since the solubility of gypsum in water is lower whereas the sulfate from the fly ash to be available for quite a long time to retard the hydration process of the C_3A [9].

Fly ash also was found to be beneficial in reducing slump loss in concretes with conventional water-reducing and retarding admixtures. The retarding admixtures accelerated, rather than slowed down, the rate of slump loss. This accelerating effect took place also in the concrete mixes in which fly ash was used but rate of slump loss remained much lower than the rate in mixes containing no fly ash [9].

Retarders, although accelerating the rate of slump loss, may be beneficial under hot weather conditions, because of their effect on water demand, possible formation of cold joints, etc. Noting that the presence of fly ash in the concrete mix may counteract the adverse effect on the rate of slump loss of both temperature and retarders, it may be concluded that, under hot weather conditions, the combined use of class F fly ash and retarders, is to be recommended. However, it must be realized that similarly to the effect of retarders, the use of fly ash involves greater plastic shrinkage and thereby increases the possibility of exposing of concrete to plastic shrinkage cracking [9].

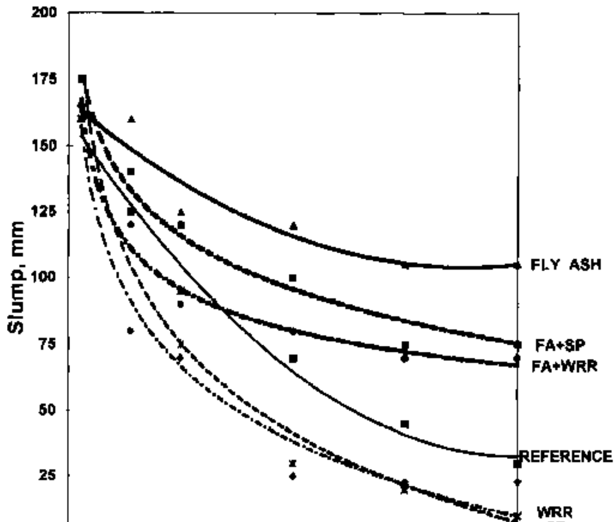

Figure 2.17. Slump loss of concretes with and without fly ash and with and without a water-reducing and retarding admixture or a superplasticizer after prolonged mixing at 32°C (90°F) [9].

2.5.1.3 Effects of Fly Ash on Setting Time, Bleeding, Air Entrainment and Concrete Temperature

Fly ash concrete has a longer setting time compared to mixtures without fly ash. The effect of fly ash on the setting time depends on the characteristics of the fly ash and the amount used. All class F fly ashes have tendency to increase setting time, whereas some class C fly ashes containing high amounts of calcium oxide may have no important effect to increase setting time of concrete [21]. Figure 2.18 shows a graphic from Ramakrishnan which compares the setting times of fly ash and control concretes made from ASTM Type 1 and ASTM Type 3 (with rapid hardening and rapid development of alkalinity of pore water properties) cements. The presence of fly ash has retarded the setting time of both types of cement [33]. On the other hand, retardation may be advantageous when concreting in hot weather, depending on slower hydration and less heat of hydration [19].

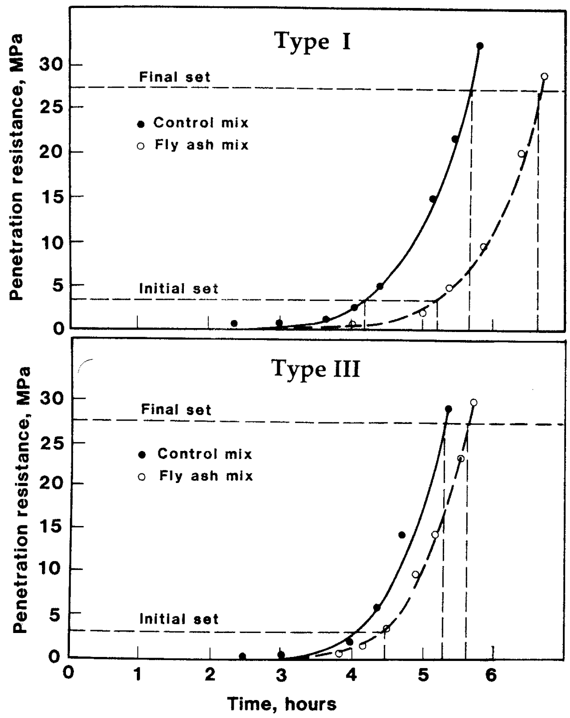

Figure 2.18 Comparison of setting times of fly ash and control concretes made from ASTM Type 1 and ASTM Type 3 [33].

Fly ash concretes generally have lower rates of bleeding than non-fly ash concretes for the same workability, based on increase in the surface area of total area of solids. An example of data due to bleeding is given in the Figure 2.19. But this is not the case for fly ash concrete which has same water content with the control concrete. If the water/cementitous material ratio is kept constant for fly ash concrete, bleeding may also increase with increase in workability [36].

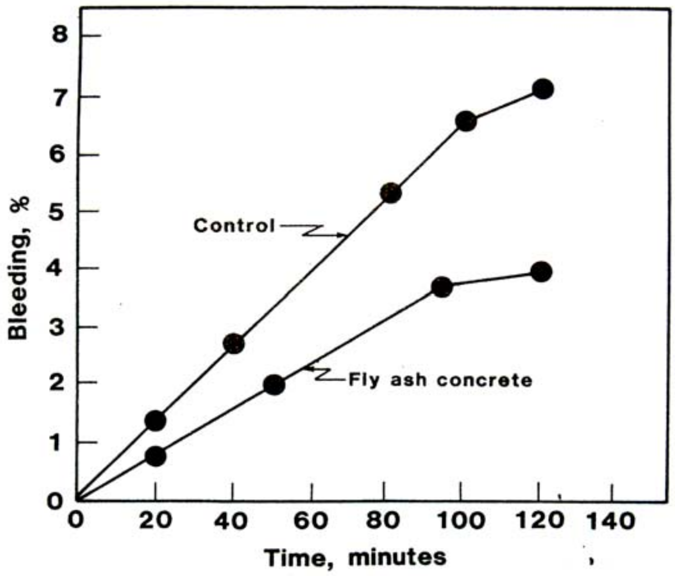

Figure 2.19 Relative bleeding of control and fly ash concretes [90].

When compared with control concrete, the amount of air entraining admixture for the same air entrainment increases in the case of fly ash concrete. It is mainly depending on presence of carbon particles in the ash, since air entraining admixture tends to get adsorbed on the surface of the carbon particles [35].

The hydration of concrete results in heat evolution causing a temperature rise in concrete. Fly ash decreases the amount of heat generation depending on slower setting. It has been estimated that the contribution of fly ash to early- age heat generation is 15-30% of that of the equivalent mass of Portland cement [37]. The reduction in peak temperature and rate of heat gain is seen in Fig. 5.6, where inplace measurements were reported by Bamforth (1980) comparing concrete with 100% Portland cement to concrete with 30% fly ash and concrete with 75% blast furnace slag [38].

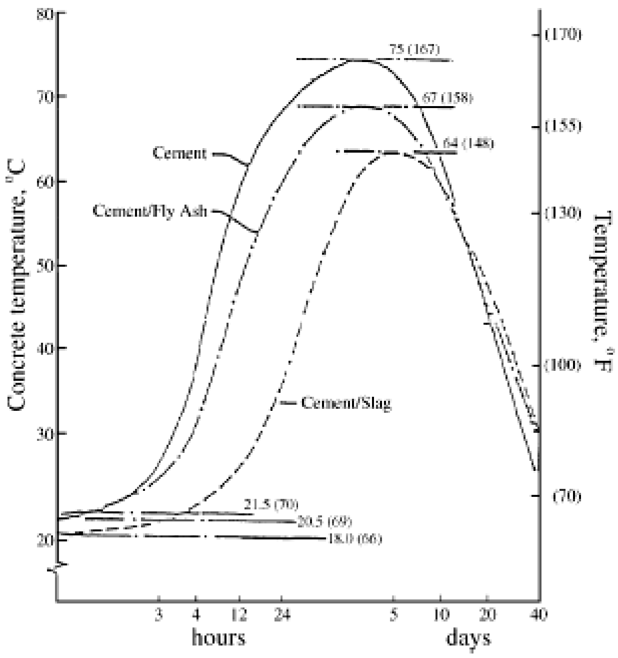

Figure 2.20 Variation of temperature recorded at mid-height in fly ash, slag and plain concrete foundation units [38].

2.5.1.4. Effects of Fly Ash on Concrete Strength

In general, the rate of strength development of fly ash concrete is mainly affected by the calcium (CaO) content of fly ash. Many authors stated that concrete containing high calcium fly ashes can be made on an equal weight or equal volume replacement basis without any significant effect on strength at early ages [39,40]. In addition to this, pozzolanic reactivity of fly ash also affects the strength of fly ash concrete [39].

Particle size of fly ash is another aspect that affect strength of fly ash concrete. Since the particles greater than 45μm has tendency to keep workability constant or to decrease it, they act counter to the needs of the proportioning methods used to compensate for the slow rate of reaction of fly ash at early ages. Also surface area which is directly related to particle size of fly ash plays an important role in determining the kinetics of cementing activity since the cementing activity occurs on the surface of solid phases [35]. Mehta stated that the compressive strength of mortars containing fly ash has been directly proportional to the percentage of <10μm particles in the fly ash [10].

As stated before the Portland cement concrete have higher strength values at early ages at high temperature, but the strength of mature concrete comes to values lower than the normal values as a result of long term curing at high temperature. The temperature effect on fly ash concrete is different from Portland cement concrete. The low calcium Class F fly ashes show higher strength values at earlier and lateral stages with respect to fly ash concrete, cured at normal temperature conditions [35]. Figure 2.21 shows the general way in which the temperature, reached during early ages of curing influences the 28 day strength of concrete [35].

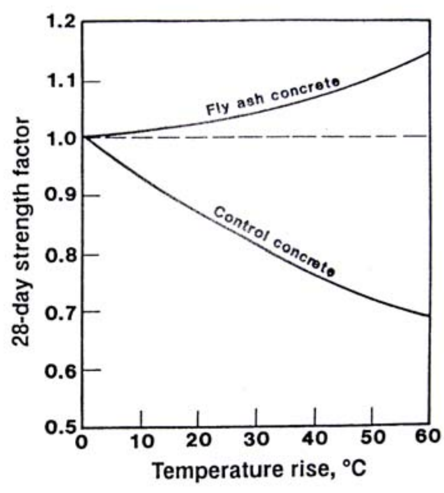

Figure 2.21 Effect of temperature rise during curing on the compressive strength development of concretes [35]

Ravina concluded that the mechanical properties of hydration products of fly ash concrete do not show poor mechanical properties like Portland cement concrete, as a result of his research. The temperature make the strength of fly ash concrete increase so significantly that, the effect of particle size on pozzolanic behavior are largely overcome [42].

The relationship between the strength of fly ash concrete and Portland cement concrete at high temperature is figured by Bamforth. Fig 2.22 shows the development of strength for normal concrete and fly ash concrete at different curing temperatures [43].

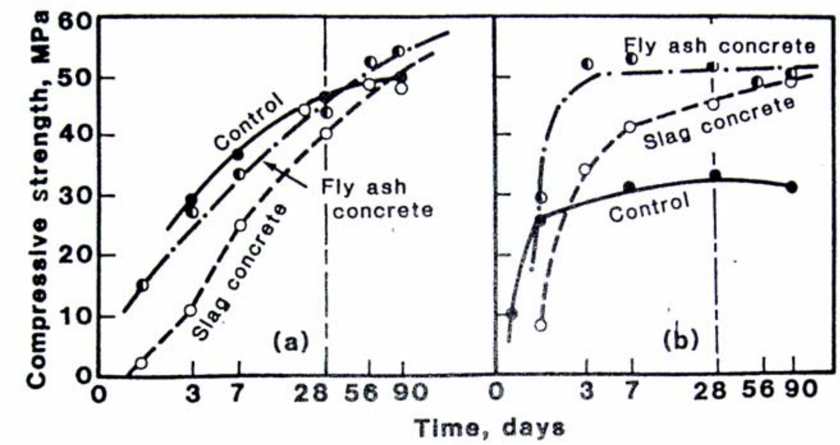

Figure 2.22 Compressive strength development of concretes: (a) cured under normal conditions; (b) cured by temperature matching [43]

2.5.2 Ground Granulated Blast Furnace Slag

Iron ores contains compounds of iron, usually iron oxides with some clay, silica, etc. called gangue. In order to extract the iron from ore, in other words to remove the oxygen and the gangue from the ore, it is heated in a blast furnace generally using coke, in the presence of a flux, usually limestone. As a result of this process molten iron is left with elements such as carbon, silicon, alumina, manganese, phosphorus and sulfur. Then the flux combines with the gangue of the ore and ash of the fuel, producing a nonmetallic melt called "slag". Molten iron is collected in the bottom of the furnace leaving the liquid iron blast-furnace slag floating on the pool of iron [21].

Blast furnace slags compose of silica (SiO_2), alumina (Al_2O_3) and lime (CaO) with small amounts of iron (Fe_2O_3), magnesia (MgO), manganese oxide (MnO) and sulfur(S). Depending on the type of cooling, three type of slags at solid form is handled: Air cooled blast furnace slags, expanded blast-furnace slags and granulated blast furnace slags [21].

Among different type of blast furnace slag, granulated blast furnace slag is the only product suitable for use as a cementitous ingridient depending on high contents of silica and alumina in non-crystalline state. Ground granulated blast furnace slags show pozzolonic reactions, depending on high silica (30%-40%) and alumina (7%-20%) content with some self-cementitous properties, due to relatively high content of calcium oxide (30%- 40%) with respect to other pozzolanic materials [21].

2.5.2.1 Effects of Ground Granulated Blast Furnace Slag on Workability of Concrete

The glassy surface texture of blast furnace slag and the increase of fines per unit volume of concrete generally increase the workability and finishing characteristics of concrete. Also it is claimed that the static electric charges of slag which is lower than those of cement, resulting easier dispersion in the mixture is another important reason of increase in workability [43].

Lange et al. [45] measured the water demand of mortars with increasing additions of a very fine blast furnace slag. He found that, for a specific flow an optimum amount of blast furnace slag reduced the water demand of the mortar.

Collins et al. [46] reported that in concrete containing alkali-activated ground granulated slag as the binder, the workability was improved by replacing some part of the binder with ultra-fine materials. This material had 90 % by mass of the particles smaller than 13.7 µm. It is also reported that, workability of concrete containing ground granulated blast furnace slag is more sensitive to water/cement content than the one, prepared with only Portland cement [17].

Wood stated that the workability and placeability of concrete containing slag cement was improved due to the surface characteristics of the slag cement, which created smooth slip planes in the paste and depending on this smooth, dense surfaces of the slag cement particles, the slag cement absorbed little water during initial mixing, unlike Portland cement [49].

Wu and Roy found that pastes containing slag cements showed different rheological properties, a better particle dispersion and higher fluidity, both with and without water-reducing admixtures, compared with pastes of Portland cements, alone [54].

Fulton designed a test using Vebe apparatus in which unconsolidated concrete was molded by vibration, and differences in molding time of mixtures with and without slag were compared. In all cases, the consolidation of the concrete containing 50% slag cement was superior to that of mixtures without slag cement. As a result, concrete containing slag cement is consolidated under mechanical vibration more easily than concrete, that does not contain slag cement (Figure 2.23) [48].

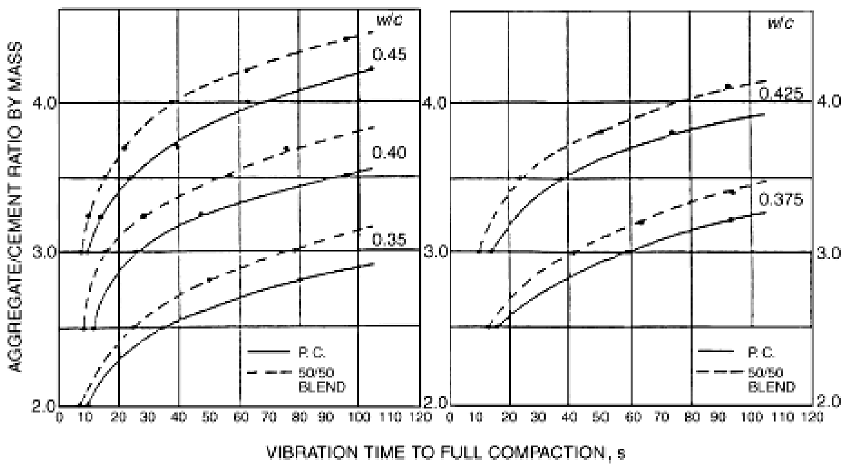

Figure 2.23 Relationship between response to vibration of concrete mixtures made with Portland cement with mixtures containing 50% slag cement [48].

Meusel and Rose found that increased slump has been obtained with all slag cement blends tested when compared with concrete without slag cement at the same water content (Figure 2.24). They have reported that with an increasing proportion of slag as a cementitous material in concrete, there is an increase in slump, thereby indicating lower water demand for slag concrete [47].

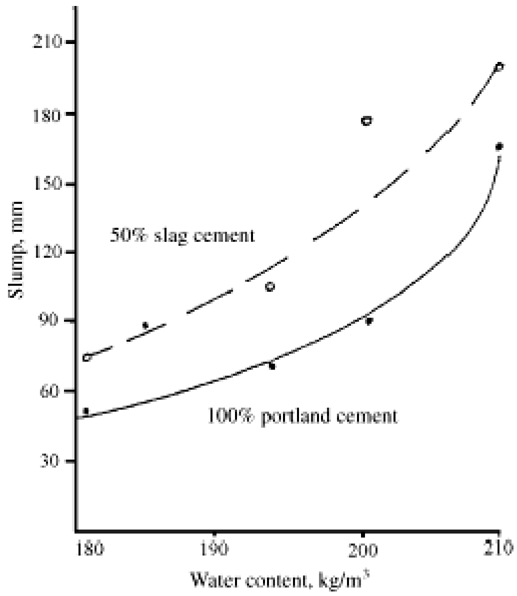

Figure 2.24 Effect of water content on slump of concrete mixtures with and without slag cement [47]

Osborne presented results of slump, Vebe, and compacting factor tests for concrete containing 0, 40, and 70% slag cement. The tests showed that as the percentage of slag cement increased, the w/c had to be reduced to maintain workability properties, more or less similar to the concrete with no slag cement. [55].

Clear reported that fresh concrete containing GGBFS has improved plastic properties and, for the same slump, GGBFS concrete can exhibit a greater flow value than Portland cement concrete. Thus, GGBFS concrete will require less effort to place and achieve full compaction [53].

2.5.2.2 Effects of Ground Granulated Blast Furnace Slag on the Rate of Slump Loss of Prolonged Mixed Concrete

Meusel and Rose stated that concrete containing 50% slag, yielded slump loss equal to that of concrete without slag cement [47].

Experiences in the United Kingdom indicated reduced slump loss, particularly when the Portland cement used in the blend exhibited rapid slump loss, such as that caused by false-set characteristics of the cement [52].

Clear stated that the workability, whether measured by slump or flow, will be retained longer in GGBFS concrete. Retention of workability is also dependent on the concrete mix proportions and temperature [53].

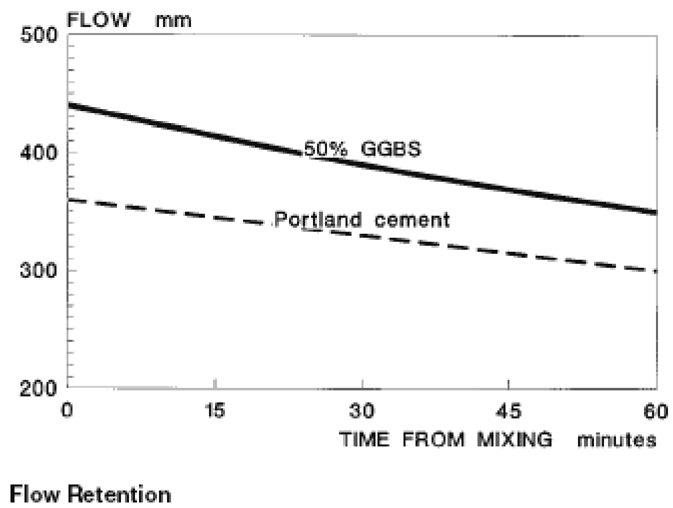

Figure 2.25 Effect of GGBFS on flow retention of prolonged mixed concrete [56].

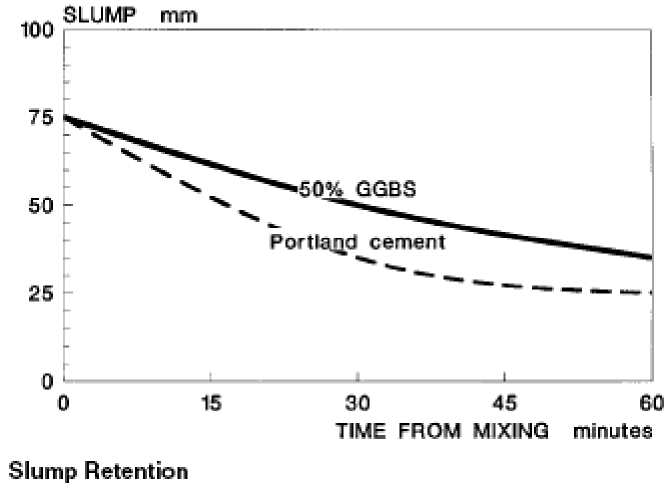

Figure 2.26 Effect of GGBFS on flow retention of prolonged mixed concrete [56].

Near the stated works, some exceptions have also been reported about the slump loss of concrete prepared with ground granulated blast furnace slag [35]. At the study proceeded by Nishibayashi et. al, the result of addition of superplasticizer to the mixture of concrete prepared with air entrainer and replacement of 85% of cement by ground granulated blast furnace slag, after 60 minutes of mixing is a very rapid slump loss [16].

2.5.2.3 Effects of Ground Granulated Blast Furnace Slag on Setting Time, Bleeding, Air Entrainment and Concrete Temperature

The use of slag generally increases the setting time of concrete, particularly at high water cement ratios and low temperatures [21]. Final setting time can be delayed up to several hours depending on ambient temperature (lower than 23ºC) and concrete temperature and it can result in serious problems in winter concreting. It is reported that at temperatures higher than 27ºC; the time of setting is not affected, but at temperatures lower than 15 ºC, the time of setting has extended by 2 to 4 hours [50]. The presence of slag in the mix causes a retardation of 30 to 60 minute at normal temperatures [51].

The degree to which the setting time is affected depends also on the amount of slag cement used, the w/c ratio, and the characteristics of the Portland cement [48]. Delays in setting time can be expected, when more than 25% of Portland cement has been replaced by slag cement in concrete mixtures. The amount of Portland cement is also important. Hogan and Meusel (1981) found that for 50% slag cement, the initial setting time is increased 1/2 to 1 h at 23 °C (73 °F); little if any change was found above 29 °C (85 °F) [58]. Also Malhotra reported that 25% cement replacement caused no significant increase in the initial setting time of concrete with respect to control concrete and the increases in the final setting time can reach the range from 16 to 101 minutes for different type of slags. Whereas for 50% cement replacement, the increases in the initial setting time can be ranged from 17 to 80 minutes and the increases in the final setting time can be ranged from 93 to 192 minutes [57].

Bleeding capacity and bleeding rate of concrete are influenced by a number of factors including the ratio of the surface area of solids to the unit volume of water, air content, subgrade conditions, and concrete thickness, but when slag is taken into consideration, bleeding characteristics can be estimated due to fineness of the slag cement compared with that of the Portland cement and the combined effect of the two cementitious materials. As a result, when finer slag with respect to Portland cement, is substituted on an equal-mass basis, bleeding may be reduced; whereas when coarser slag with respect to Portland cement is used, the rate and amount of bleeding increases [59].

When some cement is replaced by same amount of slag in concrete, a greater amount of air-entrainment admixture may be needed depending on the fineness of the slag, which is typically greater than that of the Portland cement replaced [21]. Malhotra stated that the admixture dosage needed to entrain about 5% air is 563ml/m^3 for the concrete produced using 65% slag and 177ml/m^3 for the control concrete. He also observed at higher water/(cement+slag) ratios, the increase was not as marked as the lower ratios [57].

The addition of slag cement causes reduction in the early rate of heat generation and the peak temperature of the concrete [59]. This is beneficial in large mass pours where excessive heat of hydration can lead to cracking based on thermal differences within the concrete. The heat of hydration of slag concrete depends on the Portland cement used and the activity of the slag [38]. The reduction in generated heat is more evident with greater substitution rates of GGBFS for cement. Figure 2.20 shows a study on temperature variation of mass concrete prepared with slag and fly ash reported by Bamforth [38] . The mixtures with slag cement produced the greater cumulative heat [38,58], but it does not indicate the rate of heat rise.

2.5.2.4 Effects of Ground Granulated Blast Furnace Slag on Concrete Strength

The compressive strength development of slag concrete depends primarily on the type, fineness, activity index, and the proportions of slag used in concrete mixtures [60]. In addition to these, w/c ratio, physical and chemical characteristics of the Portland cement, and curing conditions can affect the performance of slag in concrete [59].

The strength development of concrete incorporating slags is slow at 1-5 days compared with that of the control concrete. Between 7 and 28 days, the strength approaches that of the control concrete; beyond this period, the strength of the slag concrete exceeds the strength of control concrete [61]. When highly active slag cements have been used, the greatest 28-day strengths are found with blends as high as 65% slag cement [47, 48, 58]. Figure 2.27 compares compressive strength development of various blends of slag cement and Portland cement with a Portland-cement mixture only.

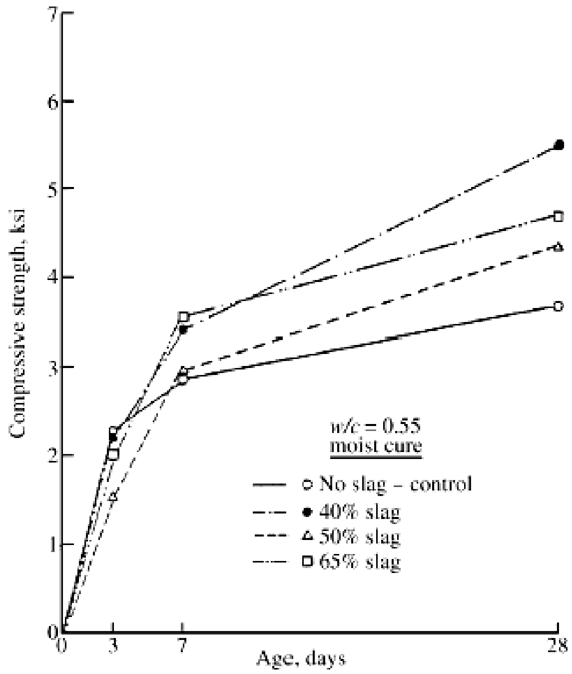

Figure 2.27 Compressive strength of concrete containing various blends of slag cement compared with concrete using only Portland cement as cementitious material [58].

Since a blend of Portland cement and GGBFS contains more silica and less lime than Portland cement alone, more C-S-H gels and less lime is produced as a result of hydration of the blended cement. This results in a cement paste which has denser microstructure. However, earlier hydration of GGBFS is very slow, since it depends upon the breakdown of the glass by the hydroxyl ions released during the hydration of Portland cement. Then the reaction of GGBFS with calcium hydroxide takes place [17]. The release of alkalis by the GGBFS, together with the formation calcium hydroxide by Portland cement, results in continuing reaction of slag over a long period and a long term gain in strength [58].

Concentration of alkalis in the total cementitous material is an important factor in hydration process of slag and cement mechanism. Also, the properties of Portland cement used in mixture are important, too. Generally finer Portland cements with high C_3A and alkali contents results in a better development in strength [59].

In general, where early-age strengths are concerned, the rate of strength gain is inversely proportional to the fraction of slag used in the blend. The effect of proportion of the slag cement used, on the strength and rate of strength gain is figured in Figure 2.28. According to Duboyov for the highest medium term strength cement to slag ratio should be 1:1 [63] .

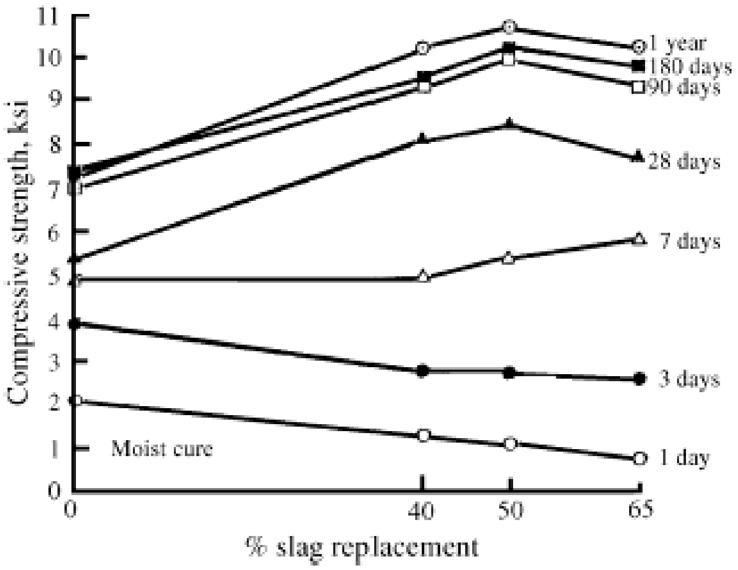

Figure 2.28 Influence of slag cement on mortar cube compressive strength (1 ksi = 6.89 MPa) [58]

As seen in Figure 2.29, the percentage of strength gain, relative to Portland-cement concrete, with slag cement is greater in mixtures with a high w/c ratio than in mixtures with a low w/c ratio [47, 48].

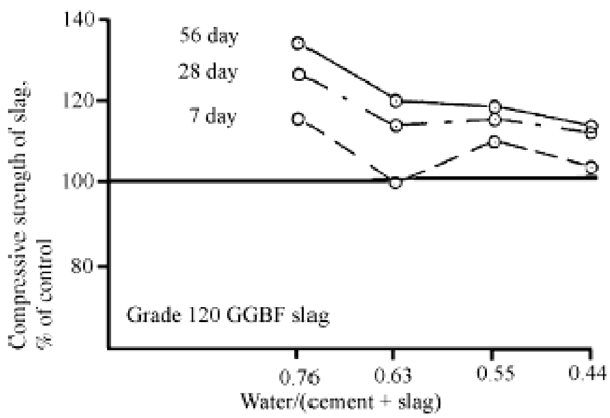

Figure 2.29 Effect of w/c ratio on compressive strength of mixtures containing 50% slag cement, expressed as a percentage of mixtures made with only Portland cement [47].

The temperature at which concrete is cured will have a great effect on strength, particularly at early ages. Roy and Idorn have reported, concrete containing slag cement responds well to elevated temperature curing conditions [62]. In fact, strength exceeding that of Portland-cement concrete at 1 day and beyond has been reported for accelerated curing conditions [48, 52, 58]. Conversely, lower early-age strength is expected for concrete containing slag cement when cured at normal or low temperatures. Generally 40% to 50% replacement results in an optimum blend at normal temperatures, whereas at low temperatures, the strengths are substantially reduced up to 14 days, and the percentage of slag is usually reduced to 25-30% of replacement levels [61]. This is due to higher activation energy of slag with respect to Portland cement [21]. The solubility of alkali hydroxides increases with an increase in temperature and the reactivity of slag at higher temperatures is considerably increased. Therefore GGBF slag is useful for steam curing [63]. Prolonged moist curing is essential for slag concrete, since the lower initial rate of hydration results in a system of capillary pores, which allows the loss of water resulting in no continuing hydration [17].

Greater fineness of GGBF slag leads to a better strength development only at later ages since the fineness can have a role at hydration, only after activation. Also a greater fineness of Portland cement speeds up the activation [17].

Other factors influencing the reactivity of GGBF slag are the chemical composition of the slag and the glass content. Although higher glass content is essential, a few percent crystal material may be beneficial due to reactivity of GGBFS since these crystals act as a nuclei for hydration [64].

2.5.3 Natural Pozzolans

Pozzolan is defined in ACI 116R as: "...a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties." [66]. They are naturally occurring pozzolanic materials other than industrial by-products [21].

Volcanic glasses, volcanic tuffs, trasses, diatomaceous earths and some clays, opaline chert and shale, burnt clay which can be classified as natural pozzolans show pozzolanic property when they are ground to a certain fineness. While some materials of volcanic origin show pozzolanic properties in their natural state, some clays and shales need to be processed by heat treatment to show pozzolonic properties. It is essential that pozzolan be in a finely divided state, since only then silica can combine with calcium hydroxide in the presence of water to form stable calcium silicates which have cementitous properties. Also silica in the pozzolona has to be amorphous and glassy since crystalline silica has very low reactivity [17] .

Some natural pozzolans like diatomaceous earths may create problems when used as a mineral admixture in concrete, based on their high water absorption capacity because of their physical properties like porosity and angularity. Some natural pozzolans improve their activity by calcination at temperatures 550 °C to 1100°C [17] .

The properties of natural pozzolans vary depending on their origin, depending on different proportions of the constituents and the variable mineralogical and physical characteristics of the active materials. Most pozzolans contain alumina and iron oxide which give reaction with calcium hydroxide and alkalies (sodium and potassium) to form complex compounds in addition to silica. Since amorphous silica reacts with calcium hydroxide and alkalis more rapidly than does silica in the crystalline form (quartz), the amount of amorphous material usually determines the reactivity of a natural pozzolan, rather than the chemical composition of pozzolan and the amounts of the constituents, silica, alumina, and iron. Also, as is the case with all chemical reactions, the larger the particles (the lower the surface area per unit volume) the less rapid the rate of reaction [66].

The natural pozzolans have no classification in the natural specifications, but Mielenz, Masazza and Mehta give some proposals for specification on them. For example Mielenz classified them due to activity of them as volcanic glasses, opal, clays (with subclassification of kaolonite, montmorillonite, illite, attapulgite and mixed clay with vermiculite), zeolites, hydrated oxides of aluminum and non-pozzolans [67]. Also it can be appropriate to consider natural pozzolans under two main groups: “Natural pozzolans of volcanic origin (volcanic glasses, volcanic tuffs, trasses and volcanic ashes)” and “thermally treated clays, shales diatomaceous earths” [21].

2.5.3.1 Effects of Ground Natural Pozzolans on Workability of Concrete

Generally natural pozzolans have tendency to increase water requirement of concrete mixture based on their microporous structure and higher surface area [35]. A favorable particle shape, which is not flat or elongated, and a satisfactory fineness of the mineral admixture, are necessary qualities, if low water content is aimed to be achieved. For example, coarse pozzolan of poor particle shape, such as finely divided pumicites, may require an increase in water content of the concrete for a given slump [66]. The increase in water requirement of concrete, caused by these types of pozzolans can be overcome by using water-reducing admixtures [21]. But, natural pozzolans' "water absorption capacity from the mixture" hold this excess water in the system allowing for improved finishing so they produce a cohesive mixture that maintains a plastic consistency for finishing [66]. Also the higher water demand of a concrete mixture containing a natural pozzolan may not have a negative effect on strength, since the excess water is absorbed by pozzolan and will not cause an extra porosity [35]. Nicolaidis stated that this absorbed water would later be available for the pozzolanic reaction [68].

When the available concrete aggregates are deficient in finer particle sizes (No: 200 sieve), an appropriate quantity of pozzolan can be used to correct such grading deficiencies by supplying those fines missing from the aggregate, with no increase in total water content of the concrete to achieve a given consistency or slump [66].

2.5.3.2 Effects of Ground Natural Pozzolans on Setting Time, Bleeding, Air Entrainment and Concrete Temperature

It is stated in report ACI 232.1R-00 that "The setting-time characteristics of concrete are influenced by ambient and concrete temperature; cement type, source, content, and fineness; water content of the paste; water soluble alkalis; use and dosages of other admixtures; the amount of pozzolan; and the fineness and chemical composition of the pozzolan". The combination of these conditions concludes setting time of concrete containing natural pozzolans. But in general, the use of natural pozzolans may extend the time of setting of the concrete if some part of Portland cement content is replaced by pozzolan [66]. Mehta stated that "This can be due to dilution effect of most active ingredient, Portland cement and partly because of the increased water requirement for making the cement paste of normal consistency" [35]. According to Nicolaidis, initial and final setting times of blended Portland cement containing 20% Santorin earth were increased by 20 minutes with respect to normal Portland cement concrete which had water requirements 24,5 and 26,5% for the Portland cement and the blended Portland-pozzolan cement, respectively [68]. On the other hand, in the study proceeded by Turanli et al.[69], initial and final setting time of natural pozzolan blended Portland cement (55% Pozzolan) concrete decreased with respect to normal Portland cement concrete. In this study major crystalline structure in all natural pozzolans used, had been albite. This result has been interrelated with to the expression of Targan [70] that says “The increasing natural pozzolan content of the paste, that results in greater interparticle contact, based on its high surface area, can cause retarding effect in setting time”.

When the ratio of surface area of solids to volume of water is low, the rate of bleeding increases. Moreover, most of the bleeding does not appear at the surface, since the water containing paste continues to bleed within the pockets defined by aggregate particles, leaving water-filled spaces at the undersides of the particles, after the aggregate particles settle for a short period. Therefore, with such mixtures, bleeding reduces homogeneity of the concrete. These undesirable effects can be reduced by increasing the ratio of surface area of solids to volume of water in the paste, resulting in increased stiffness of the paste and, at a given slump and a wider separation of the aggregate particles in the concrete, which can be provided by increasing the amount of a suitable pozzolan [66]. The interference provided by the finely pulverized particles of the pozzolan to the water flow channels and partly absorption of the microporous pozzolan decrease the bleeding of concrete [71].

Like the general tendency of all mineral admixtures, the natural pozzolans have tendency to cause an increase in the amount of air entraining admixture, to obtain a given amount of entrained air for concrete [35].

The addition of natural pozzolans causes reduction in the early rate of heat generation and the peak temperature of the concrete since the pozzolanic reaction is much slower with respect to chemical reaction of Portland cement with water

[21]. Depending on this property, pozzolans have been widely used in mass concrete as a partial replacement of Portland cement to reduce the temperature rise [66]. Townsend stated that "the heat of hydration that a pozzolan will contribute is approximately 50% of what would have been developed by an equal amount of Portland cement" [72].

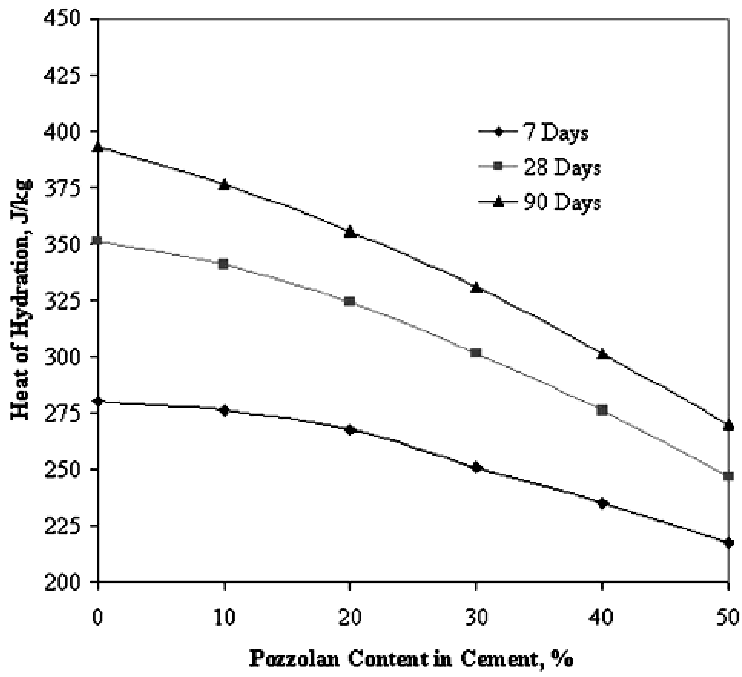

Figure 2.30 Effect of substituting Italian natural pozzolan for Portland cement on heat of hydration [73]

Massazza and Costa show that the replacement of Portland cement by the Italian pozzolan cause a decrease in the heat of hydration which is nearly proportional to the amount of Portland cement replaced (Figure 2.30). It is not directly proportional because the pozzolanic material evolve some heat during pozzolanic reaction [73] .

With Figure 2.31, it is shown by Elfert that, using calcined diatomaceous shale has reduced temperature rise in mass concrete with reduction in the rate of strength development [74].

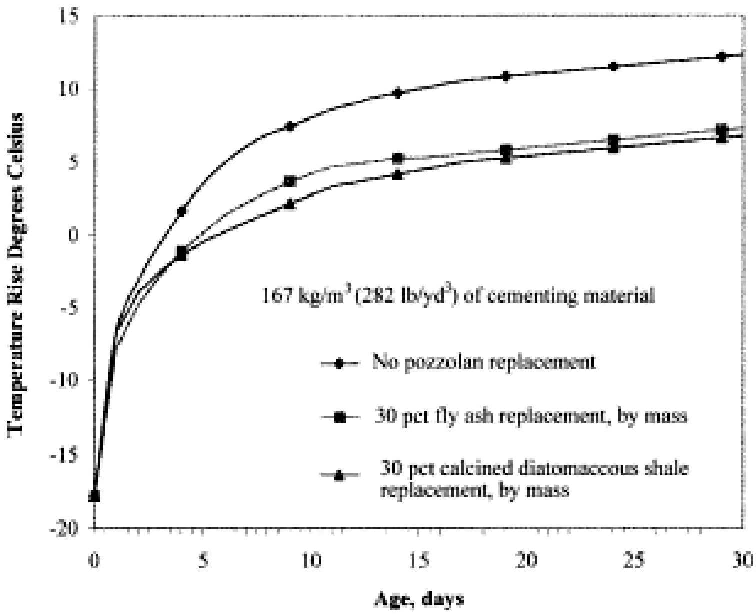

Figure 2.31 Effect of pozzolan on temperature rise of concrete [74]

Figure 2.32 shows the adiabatic temperature rise of concretes containing 30% and 50% calcined-clay pozzolan as replacements by volume (Saad, Andrade, and Paulon 1982) [75] whereas Figure 2.33 shows the autogenous temperature rise of concrete mixtures containing metakaolin and silica fume as partial replacements [76].

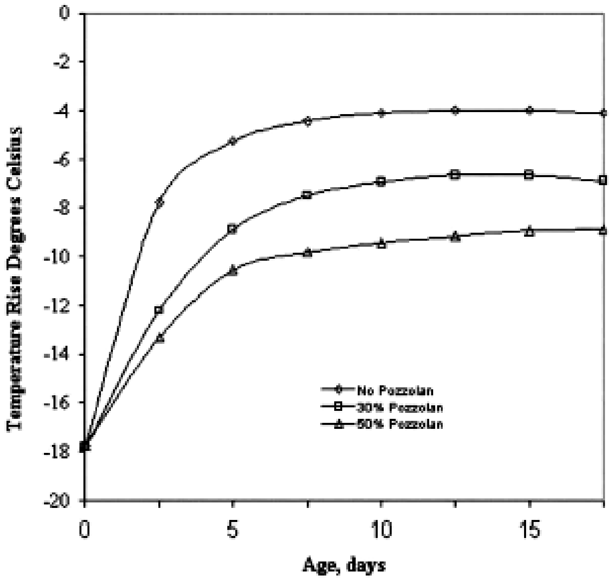

Figure 2.32 Adiabatic temperature rise [75]

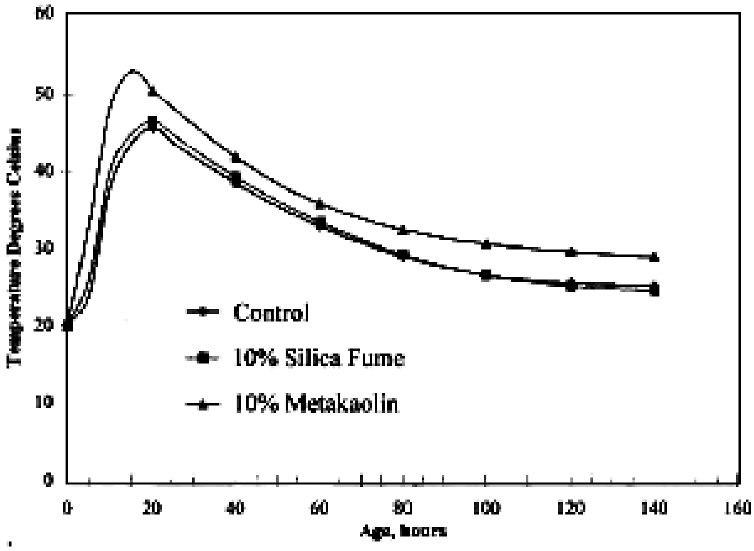

Figure 2.33 Autogenous temperature rise in 152 x 305 mm concrete cylinders [76]

2.5.3.3 Effects of Ground Natural Pozzolans on Concrete Strength

The effect of a natural pozzolan on the compressive strength of concrete can vary depending on chemical interaction between the natural pozzolan and the Portland cement during hydration [66]. On the other hand, pozzolans affect strength because of their physical character in terms of particle packing, pore refinement and improvement in the structure of transition zone, too [77,78].

The effect of curing time on the compressive strength of ASTM C 109 mortar cubes, made with Portland pozzolan cements containing 10, 20, and 30% Santorin earth, are shown in Fig. 2.33 and 2.34. It is clear from these results that the pozzolanic reaction had not progressed enough for development of compressive strength in the first seven days of hydration, since the lime that is necessary for the pozzolonic reaction comes after the hydration of calcium silicate compounds of the Portland cement[79].

In Figure 2.36, Massazza and Costa (1979) stated the effect of using different proportions of an Italian natural pozzolan on compressive strength [73] .

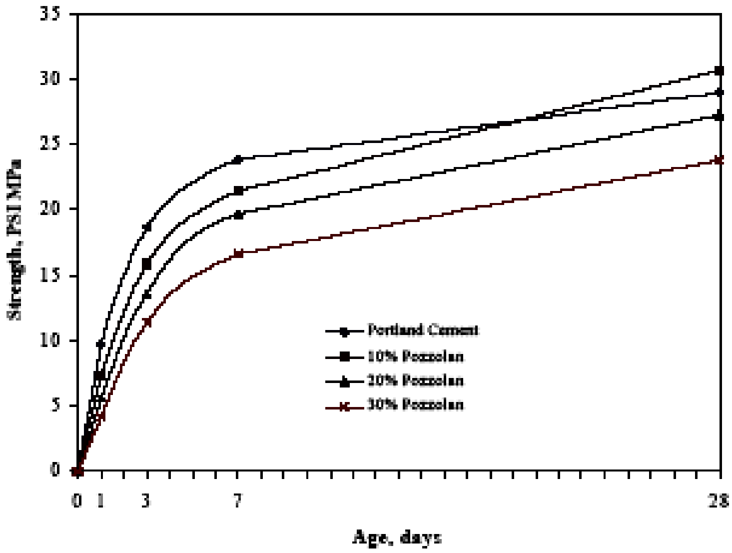

Figure 2.34 Effect of curing time on compressive strength of mortar cubes up to 28 days made with Portland pozzolan cements containing Santorin earth [79]

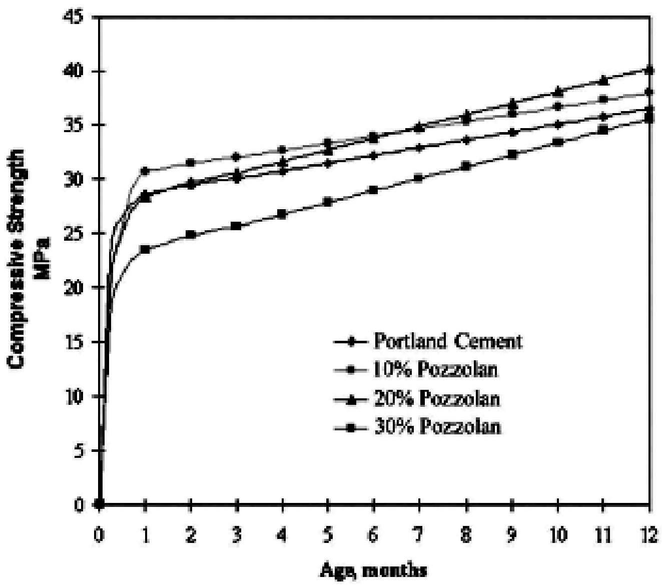

Figure 2.35 Effect of curing time on compressive strength of mortar cubes up to 12 months made with Portland pozzolan cements containing Santorin earth [79]

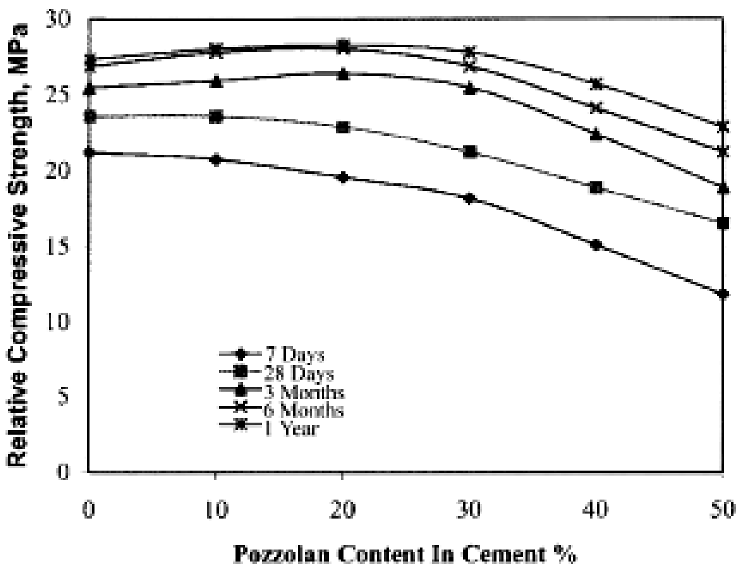

Figure 2.36 Effect of substituting Italian natural pozzolan for Portland cement on compressive strength of ISO mortar [73]

2.5.4 Ground Clay Brick

Ground clay bricks (GCB), which is constituted mainly of silica quartz, aluminosilicate, anhydrite, and hematite is a solid waste material (broken and crushed bricks) produced from the manufacture of clay bricks [80].

For the environmental benefits and sustainable development, it is important to use waste clay brick as a mineral admixture in concrete [81,82]. CB fines can be obtained at little economical cost, which will result in an overall reduction in the cost of the concrete [83]. Also, GCB shows high pozzolanic activity when in a finely ground state under ambient conditions. As a result the development of new technologies for the utilization of GCB is an ongoing study and research topic worldwide [81,82].

2.5.4.1 Effects of Ground Clay Brick on Concrete Properties

Since the ground clay brick can be classified as thermally treated clay it can be said that the water requirement for the same workability increases with the use of ground clay brick as partial replacement of cement. In addition to this concept, heat of hydration decreases depending on long term pozzolonic reactions which take place instead of the initial cementitous reactions [21].

In the study of Heikal, "The Effect of Calcium Formate as an Accelerator on the Physicochemical and Mechanical Properties of Pozzolanic Cement Pastes", he observed that the addition of ground clay brick with 20% replacement of Portland cement increased initial and final setting times of cement paste [85].

In the work proceeded by Gutovic et al., different types of CB wastes from major CB manufacturers in Sydney, Australia, passing 2.38 mm, were used to make mortar specimens with cement replacements beginning from 10% to 80% which have been cured under 180 ºC saturated steam for 7.5 h, 6 h (autoclaving). As a result of this work, Gutovic stated that "CB series show a steady increase in strength up to 40–50 mass% CB additions, followed by a decrease at greater additions" [83]. In figure 2.36 the strength development of cement-different clay brick mixtures has been shown.

The lower strengths at 0–20 mass% CB additions, can be explained by the presence of CH and C_2SH low-strength giving phases, whereas lower strength at additions of clay brick greater than 50 mass%, can be explained by the decrease in the availability of CaO from cement also resulting in the formation of fewer hydration products [83]. Gutovic et al stated that "For all CB types, maximum strengths also coincided with the disappearance of CH, the dominant phases being tobermorite, C–S–H, and to a lesser extent also hydrogarnet."

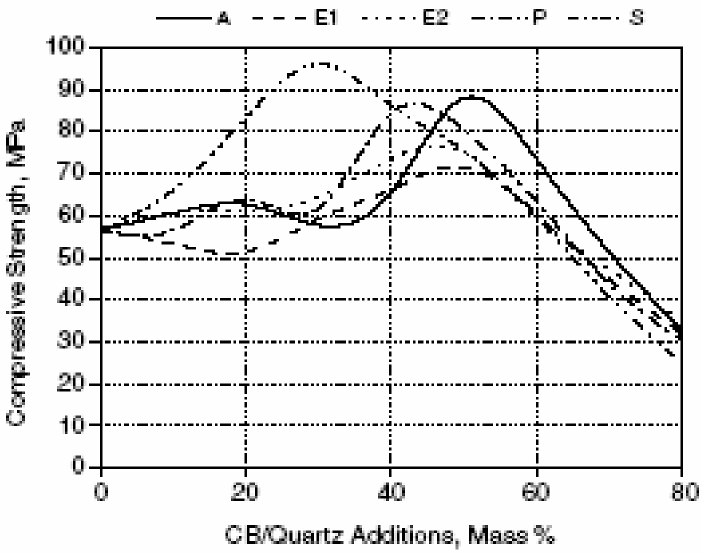

Figure 2.37 Average compressive strength of autoclaved OPC:CB(A, E1, E2, P) and OPC:quartz (S) blends [83].

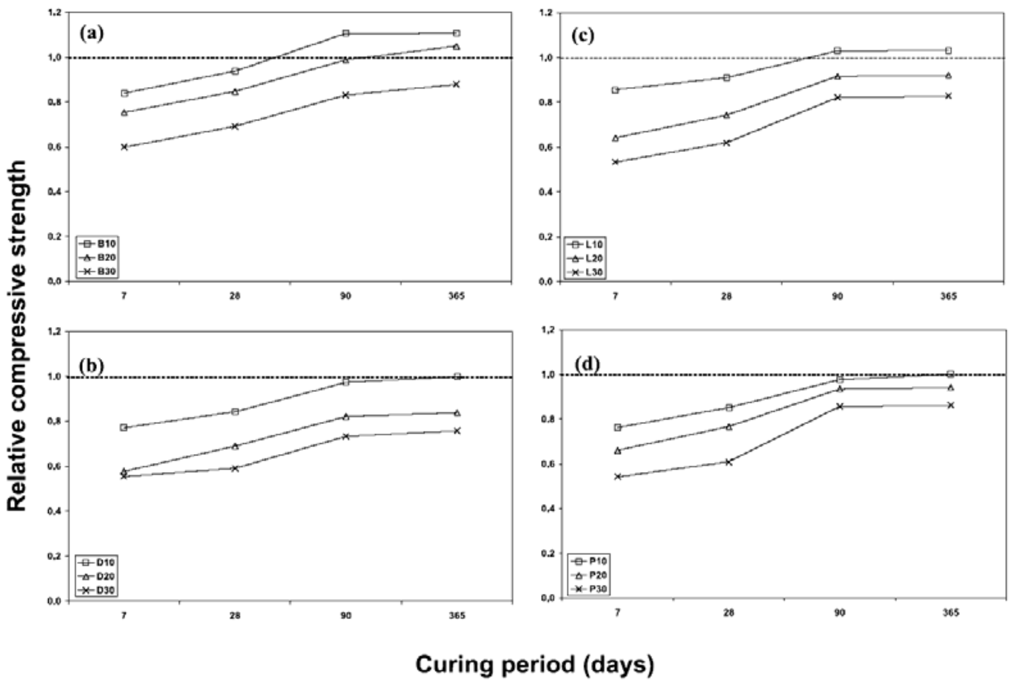

Figure 2.38 Relative compressive strength of GCB type a)B, b)D, c)L, d)P mortars [84]

As a result of the study proceeded by Farrell, Wild and Sabir, the results of the strength distribution of mortar that contains varying amounts of ground brick from different European brick types have been obtained . Cement was replaced by clay brick deriving from different countries of Europe in quantities of 0%, 10%, 20%, and 30% in standard mortars for this study. At early ages up to 28 days partial replacement of PC by GCB, irrespective of source, results in a significant decrease in compressive strength. But over 90 days especially strength of mortars prepared with 10% cement replacement by ground clay brick had passed strength of reference mortar made of pure Portland cement. 20% and 30% replacements have given different results due to ground clay brick type [84].

CHAPTER 3

EXPERIMENTAL STUDY

3.1 Experimental Program

In the scope of this study nine concrete mixtures have been prepared in a stationary mixer located at METU Materials of Construction Laboratory. Control concrete, one of these nine mixtures, has been designed to be C30 without any mineral admixture and any prolonged mixing operation. The other eight mixtures have been containing mineral admixtures: fly ash, ground granulated blast furnace slag, natural pozzolan and ground clay brick at amounts 25% and 50% of cement (by weight). The initial mixture has been calculated to be 450 kg. Here the calculations are made on weight basis rather than volume, since the procedure contains weighing fresh concrete. Water content of different concrete mixtures prepared with different mineral admixtures at different amounts could have changed in tolerable limits, since mineral admixtures can have different water absorption capacities.

One of the important aspects in this study has been the air entraining admixture and water reducer-superplasticizer added to concrete mixtures. By this study, the effect of prolonged mixing on air entrained and superplasticized concrete is also observed.

The mixing operation has taken place in an isolated room at temperature of 40±5ºC. A concrete mixer of 330 liters has been used for prolonged mixing operation. After finishing of normal mixing operation at a normal mixing speed (about 20 revolutions per minute - for five minutes), 20% of concrete by weight

(90±10kg) has been taken out of mixer. The slump of concrete has been controlled if it is 15cm and standard testing procedure has been applied on this sample.

The remaining concrete is continued to be mixed at a much slower speed, 4 revolutions per minute. After one hour of agitation, the mixer is stopped and second 20% of concrete has been taken out of mixer. The slump is controlled to find the value 15±2 cm. If the value is under 13 cm the retempering operation with superplasticizer is proceeded to find the slump value 15±2 cm, if not, standard test procedure has been applied. For the retempering operation, the 20% portion is taken and put into the second mixer. The superplasticizer has been directly added to the second mixer during mixing operation at 20 revolutions per minute. The amount of retempering agent is determined based on slump value of concrete in the mixer. After retempering operation, standard testing procedure has been applied on the retempered concrete. This operation is repeated four times to finish all concrete mixture.

Shortly, the mixer is stopped at the end of the first five minutes, and at the end of the following first, second, third and fourth hours. At the end of first, second, third and fourth hours, the 20% portion of concrete is taken to the second mixer to be mixed at the speed of 20 revolutions per minute for five minutes and if needed to be retempered with superplasticizer to take the slump value 15±2cm. Superplasticizer is directly added to the second mixer for retempering action during mixing operation.

All the operation take place at hot environment and low humidity. The temperature was aimed to be 40±5C^o and the humidity was aimed to be 20±10% during concreting operation. For simulation of hot weather conditions a small isolated room has been constructed (Figure 3.1, Figure 3.2). All tests on fresh concrete have been done and all specimens have been taken at these intervals of temperature and humidity.

Figure 3.1 Isolated room (Outside view)

Figure 3.2 Mixer used for prolonged mixing of concrete and containers for curing of concrete at 50ºC

The slump, temperature, air content values have been inspected for fresh concrete samples. The compressive strength and splitting tensile strength of specimens taken from all mixtures have been determined.

Since the volume of laboratory mixer has a limited capacity, the dimensions of specimens used for hardened concrete tests have been decreased. The specimens used for determination of compressive strength and splitting tensile strength of concrete are d:67mm*h:134mm cylinders. PVC molds have been used to produce these specimens. The specimens are compacted with 15 rodding of Φ10mm rod, at each half of two layers of cylinder. Since the results in this study are relative to each other and during all study the same procedures are applied, there has not been much problem about standard deviation through out the study.

The specimens have been cured in two different surrounding. One of them is water at 50ºC to simulate the hot weather conditions which has been maintained in the constructed isolated room. The small specimens have been put into containers full of water at 50ºC heated by electrical heaters in the isolated room. The other environment used to cure specimens has been normal conditioned curing room at 23ºC.

The specimens are subjected to compressive strength test at 7 and 28 days, whereas splitting tensile test has been conducted on 28th day of concreting.

The tests proceeded on concrete making materials are made complying with ASTM standard specifications. The tests performed on aggregates, cement, cement paste, cement mortar, mineral admixtures are given in Table 3.1 and Table 3.2. Tests performed on fresh and hardened concrete are summarized at Table 3.3.

Table 3.1 Tests performed on aggregates

Tests Performed	**Relevant Standards**
Specific Gravity and Absorption	ASTM C 127, C 128
Sieve Analysis	ASTM C 136

Table 3.2 Tests performed on cements and mineral admixtures

Tests Performed	**Relevant Standards**
Chemical Analysis	ASTM C 114
Density	ASTM C 188
Fineness	ASTM C 204
Setting Time	ASTM C 191
Normal Consistency	ASTM C 187
Heat of Hydration	ASTM C 186
45 µm Sieve Residue	ASTM C 430
Compressive Strength	ASTM C 109
Strength Activity	ASTM C 618
Slag Activity	ASTM C 989

Table 3.3 Tests performed on fresh and hardened concrete.

Tests Performed	**Relevant Standards**
Slump	ASTM C 143
Air Content	ASTM C 231
Compressive strength	ASTM C 39
Splitting tensile strength	ASTM C 496

3.2 Materials

3.2.1. Cement

One type of Portland cement which is procured by Baştaş Cement Factory is used during all experimental study. Chemical composition and physical properties of cement have been shown in Table 3.4 and Table 3.5, respectively.

Table 3.4 Chemical analysis of the Portland cement used

Oxides and Other Determinations	% by weight	ASTM Limits
CaO	62.56	-
SiO_2	20.47	-
Al_2O_3	5.68	-
Fe_2O_3	3.08	-
MgO	1.80	max. 6.0%
SO_3	3.22	max. 3.0%
K_2O	0.95	-
Na_2O	0.30	-
Free CaO	0.98	max. 3.0%
Cl^-	0.014	max. 0.1%
LOI	2.49	max. 3.0%
IR	0.47	max. 0.75%

Table 3.5 Physical properties of the Portland cement used

Property		**Value**	**ASTM Limits**
Specific Gravity		3.12	-
Blaine Fineness (cm^2/g)		3915	min. 2800
W/C for NC		0.26	-
Setting Time (min)	Initial	108	min. 45
	Final	162	max. 375
Compressive Strength (MPa)	3 days	27.6	min. 12.4
	7 days	39.0	min. 19.3
	28 days	47.7	-
Heat of Hydration (cal/gr)	3 days	67.5	-
	7 days	74.9	-
	28 days	92.1	-

3.2.2 Aggregates

A suitable aggregate mixture is obtained by mixing fine and coarse crushed limestone using 50% percentage for each in the mixture. The mixture proportions of aggregate have been same for all mixtures.

Aggregate proportions and physical properties of aggregates have been tabulated at Table 3.6 and sieve analyses have been tabulated at Table 3.7.

Table 3.6 Physical properties of fine and coarse aggregate

Property	**Crushed Stone Fine aggregate (0-4)**	**Crushed Stone Fine aggregate (4-10)**
Weight Percentage in total aggregate in the mixture	50	50
Specific Gravity (SSD)	2,67	2,70
Water Absorption	0,78	0,54

Table 3.7 Sieve analysis of fine and coarse aggregate

Sieve No.	**%Cumulative PASSING**	
	(0-4)	**(4-10)**
3/4” (19,1mm)	100	100
1/2” (12,7mm)	100	98.52
3/8” (9,5mm)	100	64,56
#4 (4,76mm)	99,95	6,51
#8 (2,38mm)	83,75	2,23
#16 (1,19mm)	57,58	2,00
#30 (0,59mm)	38,62	1,84
#50 (0,297mm)	25,45	1,70
#100 (0,149mm)	14,75	1,35

3.2.3 Mixing Water

Drinkable tap water used in METU Campus which does not contain excessive amounts of harmful material for concrete has been used in the preparation of the mixture.

3.2.4 Chemical Admixtures

An air entraining admixture of Sika (AER) and ASTM C 494 Type G superplasticizer of Sika (Sikament 520 T) has been used in all concrete mixtures. The ratios to the cement (total binder weight) have been 0,1% for the air entrainer and 1,25% for the superplasticizer.

For retempering process, ASTM C 494 Type F superplasticizer of Turkish firm KONSAN (HS 100) has been used at different amounts to have a concrete mixture at 15±2cm slump.

3.2.5 Mineral Admixtures

3.2.5.1 Fly Ash

A class F fly ash obtained from Tunçbilek Power Plant has been used in the concrete mixtures. 25% and 50% portions of cement by weight have been replaced with fly ash.

Table 3.8 Chemical analysis of the fly ash

Oxides and Other Determinations	% by weight	ASTM Limits
CaO	3.34	-
SiO_2	58.44	-
Al_2O_3	18.79	-
Fe_2O_3	10.60	-
MgO	4.52	-
SO_3	1.75	max. 5.0%
K_2O	1.86	-
Na_2O	0.22	max. 1.5%
Cl^-	-	-
P_2O_5	0.25	-
TiO_2	-	-
Mn_2O_3	0.22	-
LOI	0.77	max. 6.0%
IR	86.72	-

Table 3.9 Physical properties of the fly ash

Property		Value	ASTM Limits
Specific Gravity		2.10	-
Blaine Fineness (cm^2/g)		2890	-
W/C for NC		0.53	-
45 µm sieve residue (%)		27.3	max. 34%
Strength Activity Index (%)	7 days	89.1	min. 75%
	28days	82.0	min. 75%

3.2.5.2 Ground Granulated Blast Furnace Slag (GGBFS)

GGBFS which is obtained from Iskenderun Iron Factory has been used in this research. Chemical analysis and some physical properties of this GGBFS are given at Table 3.10 and Table 3.11 respectively.

Table 3.10 Chemical analysis of the GGBFS

Oxides and Other Determinations	% by weight	ASTM Limits
CaO	35.48	-
SiO_2	36.88	-
Al_2O_3	15.20	-
Fe_2O_3	0.70	-
MgO	9.95	-
SO_3	0.23	max. 4.0%
LOI	0.49	-
IR	0.69	-

Table 3.11 Physical properties of the GGBFS

Property		Value	ASTM Limits
Specific Gravity		2.83	-
Blaine Fineness (cm^2/g)		4685	-
45 μm sieve residue (%)		0	max. 20%
Slag Activity Index (%)	7 days	64	min. 75%
	28 days	103	min. 75%

3.2.5.3 Natural Pozzolan

Natural pozzolan which has been provided from Bursa Cement Factory has been used in the study. Chemical analysis and some physical properties of this pozzolan are given at Table 3.12 and 3.13, respectively.

Table 3.12 Chemical analysis of the natural pozzolan

Oxides and Other Determinations	% by weight	ASTM Limits
CaO	4,93	-
SiO_2	62,23	-
Al_2O_3	15,16	-
Fe_2O_3	3,27	-
MgO	1,51	-
SO_3	0,50	max. 4.0%
LOI	6,12	max. 10.0%
IR	86,18	-

Table 3.13 Physical properties of the natural pozzolan

Property	Value	ASTM Limits
Blaine Fineness (cm^2/g)	4430	-

3.2.5.4 Ground Clay Brick

The ground clay brick is obtained from a factory in Manisa, which produces race courses from broken bricks, commercially. Chemical analysis and physical properties of the brick powder used are given at Table 3.14 and Table 3.15 respectively.

Table 3.14 Chemical analysis of the ground clay brick

Oxides and Other Determinations	% by weight	ASTM Limits
CaO	3.94	-
SiO_2	62.7	-
Al_2O_3	17.1	-
Fe_2O_3	6.84	-
MgO	2.25	-
SO_3	0.84	max. 4.0%
LOI	2.67	max. 10.0%
IR	84.45	-

Table 3.15 Physical properties of the ground clay brick

Property		Value	ASTM Limits
Specific Gravity		2.64	-
Blaine Fineness (cm^2/g)		4000	-
45 µm Sieve Residue (%)		37	max. 34%
Strength Activity Index (%)	7 days	66.2	min. 75%
	28 days	80.3	min. 75%

3.3 Concrete Mixes

Concrete mix proportions used in experimental study are given in Table 3.16.

Table 3.16 Mixture proportions of concrete in experimental program

Material Used		**Amount (kg/m^3)**
Portland Cement		400
Water		152
Superplasticizer (Sika)		5
Air-entraining admixture		0.4
Aggregate	0-4 mm	950
	4-10 mm	960
Expected unit weight		**2462 kg/m^3**

The values showing the aggregate contents have been determined accepting aggregates at saturated surface dry condition.

The concrete is designed to be at the slump value of 15cm. But since the control concrete's slump value has been measured 12cm at the start of experimential study, an extra 5 liters water has been added to starting control concrete mixture and other mixtures. So the water/cement ratio of control mixture has come to the value 0.48 with a slump measurement of 15cm.

The concrete batch is planned to be 450 kg for each mixture. With the addition of extra 5 kg water, this value has become 455 kg and 20% of concrete mixture, value which will be taken at the end of each prolonged mixing hour has become 91±10 kg. The values considered to be batched for each mixture are tabulated at Table 3.17.

Also extra water is needed for some mixtures, since the water absorption capacities of different mineral admixtures are different. These values are also noted at Table 3.18.

Table 3.17 Mixture proportions of concrete in a mix-batch (450kg +5kg extra water, aggregates are at oven-dry position)

Material Used		**Amount (kg)**
Portland Cement		73
Water		30 (+ extra 5kg)
Superplasticizer (Sika)		0,91
Air-entraining admixture		0,073
Aggregate	0-4 mm	172
	4-10 mm	175

Table 3.18 The amount extra water (the value over 5kg) to set the slump value of initial mixture to 15cm

The admixture used / ratio%	**Water added (gr)**
No admixture	0
Fly ash / 25%	0
Fly ash / 50%	700
GGBFS / 25%	500
GGBFS / 50%	1800
Clay brick/ 25%	1100
Clay brick / 50%	3500
Natural pozzolan / 25%	2500
Natural pozzolan / 50%	8600

CHAPTER 4

TEST RESULTS AND DISCUSSION

4.1 Tests on Fresh Concrete

4.1.1 Temperature Measurements

The temperature of concrete and ambient temperature in the isolated room has been measured periodically at the stages of concreting. The ambient temperature has been recorded 40±5ºC during concreting operation.

The concrete temperature is measured between 30ºC and 31ºC at the starting time of mixing operation. With an increase, temperature has been recorded 36ºC and 37ºC at fourth hour of mixing of concrete mixtures containing mineral admixtures. The temperature of fresh concrete containing pure cement as binder material has been measured 39ºC. This result can be attributed to the rapid hydration reaction of Portland cement which does not need any preliminary reaction to give hydration reactions with water. Whereas mineral admixtures need hydration and hydration products of Portland cement to give reaction with water. Also the amount of admixture is an important factor determining the concrete temperature.

The temperature measurements in the 2^{nd}, 3^{rd}, 4^{th} hours of mixing do not show any significant effect on the results of test. The increase in temperature is slow and proportional to time. Increase in temperature of concrete does not give much information about hydration rate of fresh concrete, because of the high ambient temperature making the concrete temperature rise without the need of hydration.

4.1.2 Slump Values of Concrete and Amount of Superplasticizer Used in Retempering Process for Slump Retention

The slump values of concrete, which are noted as a result of tests conducted on the concrete samples taken out right after 5 minutes of mixing and after an agitation period of 1hr, 2hr, 3hr and 4hr, are tabulated in Table 4.1. In addition to slump values, the amount of retempering agent, superplasticizer, used to retain the slump value of 15±2cm is also noted on the Table 4.1, too.

Table 4.1 The effect of prolonged mixing on slump of concrete (the values in parenthesis show the slump values, as a result of retempering)

	THE CONCRETING STAGE				
	1	**2**	**3**	**4**	**5**
CONTROL CONCRETE					
SLUMP (cm)	15	16	13	1 (14)	0 (15)
Amount of superplasticizer added to 90 kg mix to retemper (g) (for 14.6kg binder) (%)	0	0	0	222 (1.5%)	446 (3.0%)
FLY ASH CONCRETE (25%)					
SLUMP (cm)	15	15	13	5 (17)	2 (16)
Amount of superplasticizer added to 90 kg mix to retemper (g) (for 14.6kg binder) (%)	0	0	0	215 (1.5%)	397 (2.7%)
FLY ASH CONCRETE (50%)					
SLUMP (cm)	15	15	15	6 (17)	1 (16)
Amount of superplasticizer added to 90 kg mix to retemper (g) (for 14.6kg binder) (%)	0	0	0	296 (2.0%)	331 (2.2%)
BLAST FURNACE SLAG C.(25%)					
SLUMP (cm)	15	15	10 (17)	0 (15)	0 (15)
Amount of superplasticizer added to 90 kg mix to retemper (g) (for 14.6kg binder) (%)	0	0	223(1.5%)	205 (1.4%)	359 (2.5%)
BLAST FURNACE SLAG C.(50%)					
SLUMP (cm)	15	15	3 (14)	0 (15)	0 (15)
Amount of superplasticizer added to 90 kg mix to retemper (g) (for 14.6kg binder) (%)	0	0	147(1.0%)	291 (2.0%)	446 (3.1%)
CLAY BRICK CONCRETE(25%)					
SLUMP (cm)	15	17	15	7 (15)	0 (16)
Amount of superplasticizer added to 90 kg mix to retemper (g) (for 14.6kg binder) (%)	0	0	0	154 (1.0%)	273 (1.9%)
CLAY BRICK CONCRETE(50%)					
SLUMP (cm)	15	14	8 (14)	3 (17)	0 (17)
Amount of superplasticizer added to 90 kg mix to retemper (g) (for 14.6kg binder) (%)	0	0	143(1.0%)	238 (1.6%)	437 (3.0%)
NATURAL POZZOLAN C.(25%)					
SLUMP (cm)	15	16	15	0 (13)	0 (17)
Amount of superplasticizer added to 90 kg mix to retemper (g) (for 14.6kg binder) (%)	0	0	0	324 (2.2%)	602 (4.1%)
NATURAL POZZOLAN C. (50%)					
SLUMP (cm)	15	0 (17)	0 (16)	0 (17)	0 (15)
Amount of superplasticizer added to 90 kg mix to retemper (g) (for 14.6kg binder) (%)	0	177(1.2%)	213(1.5%)	416	622

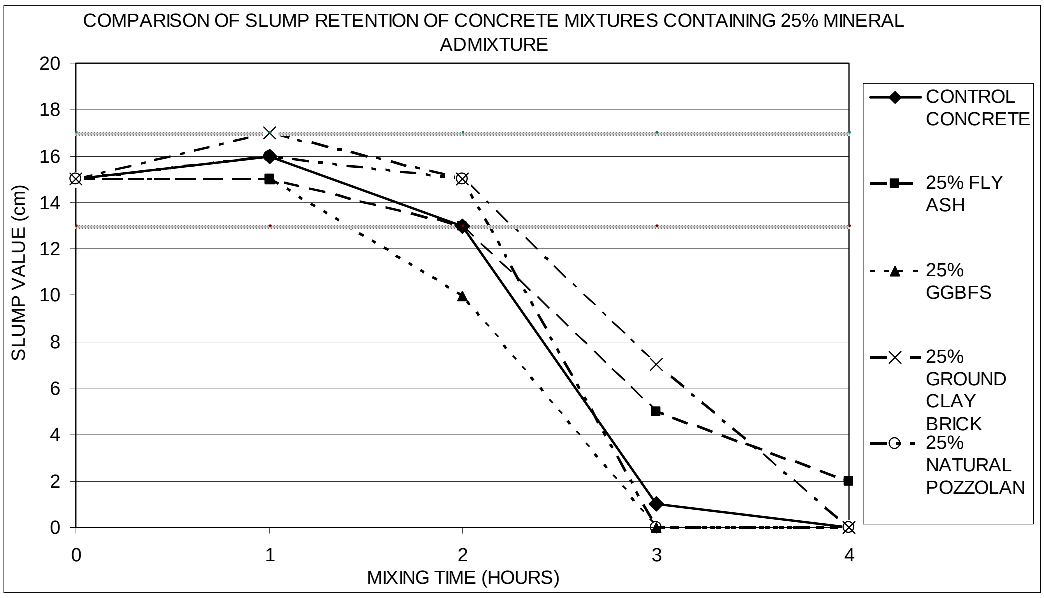

Figure 4.1 Effect of prolonged mixing on slump of concrete mixtures containing different mineral admixtures at ratio 25%.

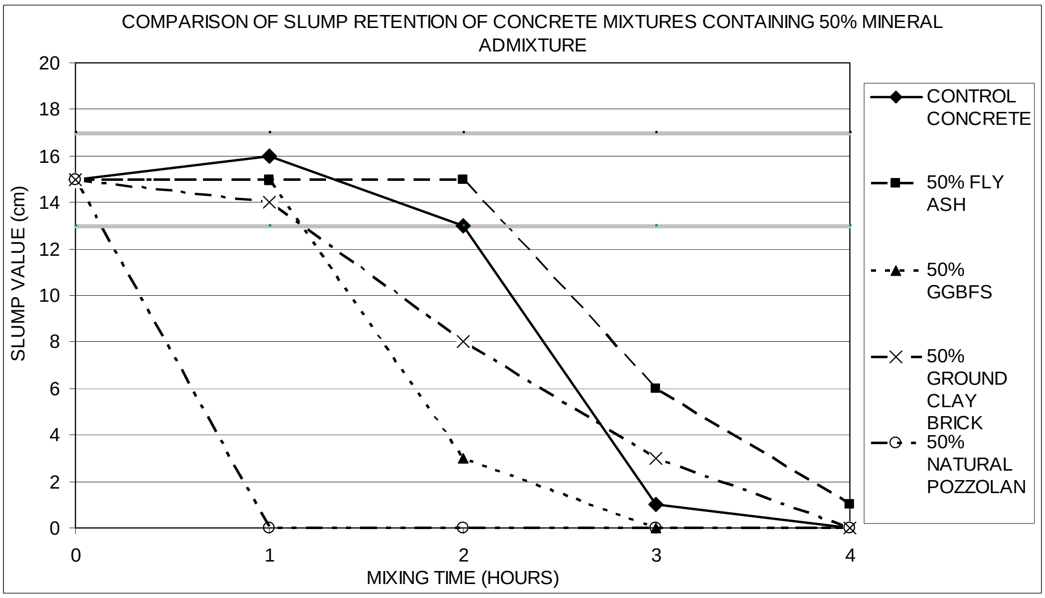

Figure 4.2 Effect of prolonged mixing on slump of concrete mixtures containing different mineral admixtures at ratio 50%.

When replacements of 25% of cement by mineral admixtures are taken into consideration (Figure 4.1), it has been seen that “the slump retention is provided better with the use of fly ash and ground clay brick”. The performance of fly ash and ground clay brick is better than the control concrete, whereas natural pozzolan and GGBFS comes after control concrete respectively.

There is nearly no slump loss at the end of second hour of mixing when fly ash and ground clay brick are used at amount, 25% of Portland cement. At the end of fourth hour of mixing, the slump loss of 25% fly ash and ground clay brick containing concretes has been also less with respect to other mineral admixtures and there is no need to add superplasticizer for retempering, until fourth hour of mixing at these concrete mixtures (Figure 4.1).

The spherical shape of fly ash particles may provide this behavior, from fly ash point of view. As known the spherical shape of fly ash particles make the particles have lubricant effect in the concrete mixture. This may decrease the grinding effect of particles, which can increase the slump loss.

Also, the blaine fineness of ground clay brick and fly ash used in this experimental program is lower with respect to other mineral admixtures used. This may result in a decrease at hydration speed and slump loss, too. On the other hand very high fineness value of GGBFS is a positive effect on slump loss of concrete.

Also it is a reason for retarding effect of fly ash that the surface of fly ash particles are partially covered by alkali-sulfates that can be solved to form sulfate ions [9].

When experimental stage, in which 50% of cement has been replaced by mineral admixtures, has been considered, it is seen that slump loss values have been generally greater than the values of pure Portland cement mixture. This may depend on the cement replacement process which has been proceeded on weight basis increasing the total surface area of materials in the mixture. On the other hand, decreased slump loss with respect to control concrete, at the mixture prepared with replacement of 50 % cement with fly ash, may be provided by spherical shape and lower fineness of fly ash. The decrease in slump loss brought by these properties of fly ash may pass over the negative effect of increased surface area of materials in the mixture (Figure 4.2).

The slump retention nearly at all of the mixtures, at the end of first hour of mixing may be caused by increased amount of air which is tabulated in Table 4.2. As known the entrained air has lubricant effect on concrete, like the effect provided by the fly ash.

The amount of superplasticizer added to retemper the mixture, have changed depending on mixing time, the type and amount of mineral admixture. As seen from Table 4.1 as the amount of mineral admixture has increased from 25% to 50%, the amount of superplasticizer added to retemper the mixture also have increased except for fly ash.

The highest slump loss bringing the result of highest amount of retempering superplasticizer has been seen when 50% of cement has been replaced by natural pozzolan. The higher grinding ratio of natural pozzolan may result in this effect. Also irregular surface texture of natural pozzolan can be another reason for this situation.

Figure 4.3, 4.4, 4.5 and 4.6 compare slump loss of concrete containing different mineral admixtures with slump loss of pure Portland cement concrete.

As seen pure Portland cement concrete has higher slump loss with respect to fly ash concretes and the amount of slump loss decreases as the amount of fly ash in the mixture increases (Figure 4.3). On the other hand, as the amount of ground granulated blast furnace slag has increased in the concrete mixture, the slump loss of fresh concrete has increased at mixtures prepared with GGBFS. Both mixtures, which are containing 25% and 50% GGBFS have slump loss values higher than the concrete containing pure Portland cement (Figure 4.4).

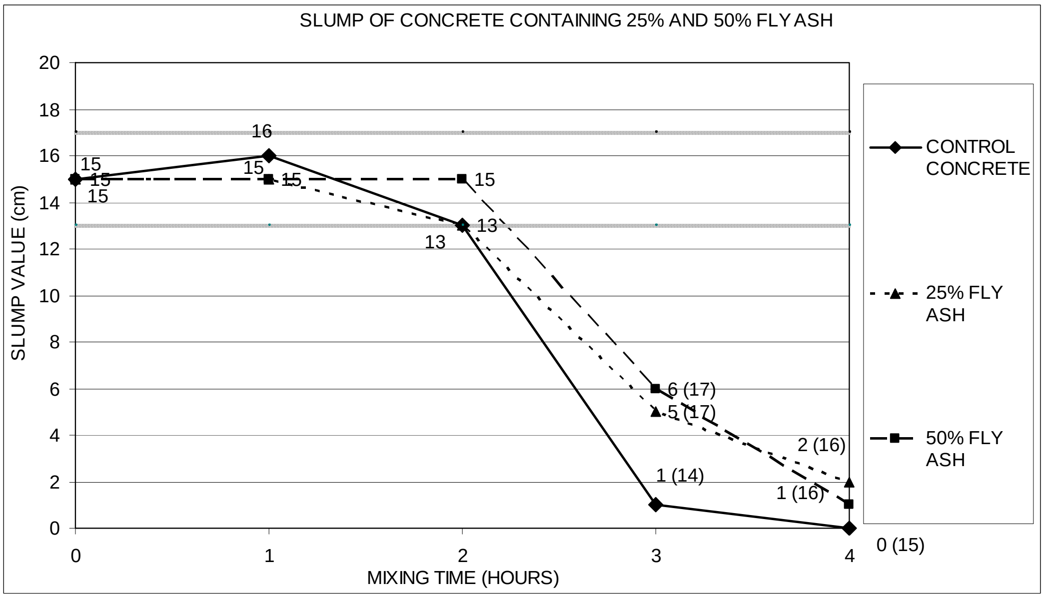

Figure 4.3 Effect of prolonged mixing on slump of concrete mixtures containing fly ash at amounts 25% and 50%

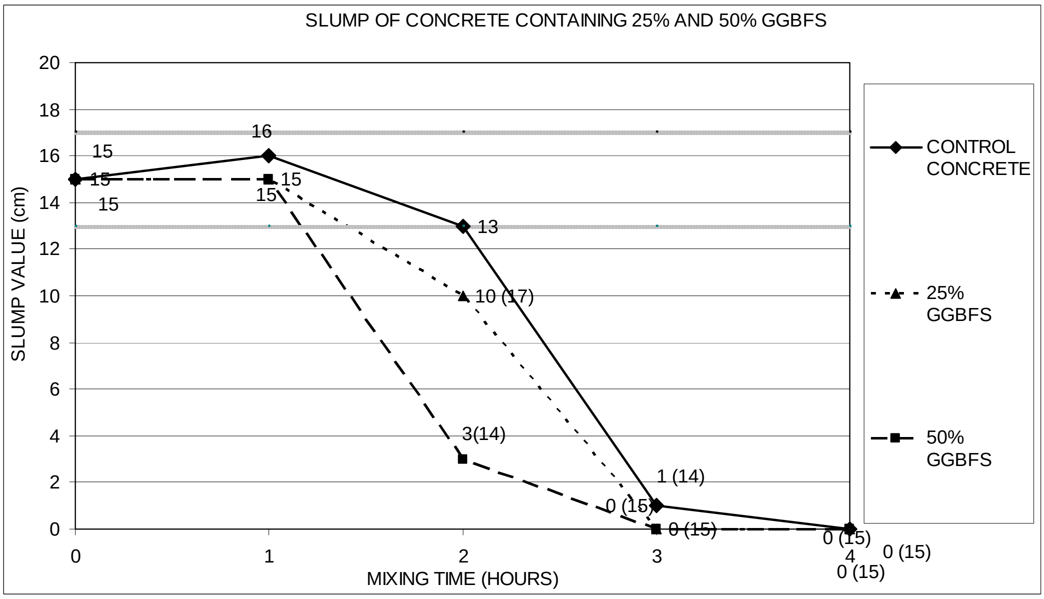

Figure 4.4 Effect of prolonged mixing on slump of concrete mixtures containing GGBFS at amounts 25% and 50%

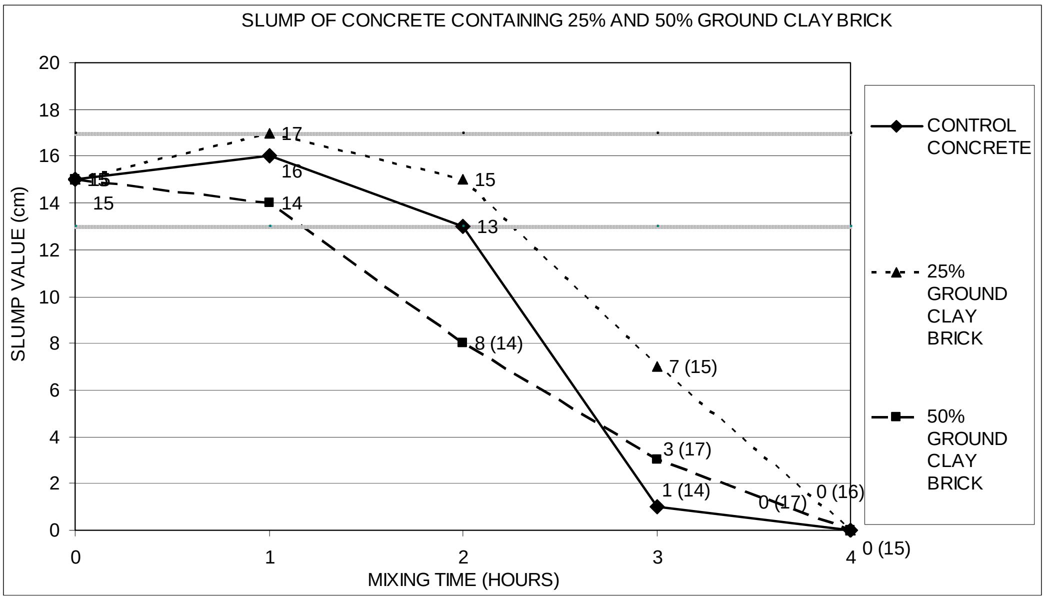

Figure 4.5 Effect of prolonged mixing on slump of concrete mixtures containing ground clay brick at amounts 25% and 50%

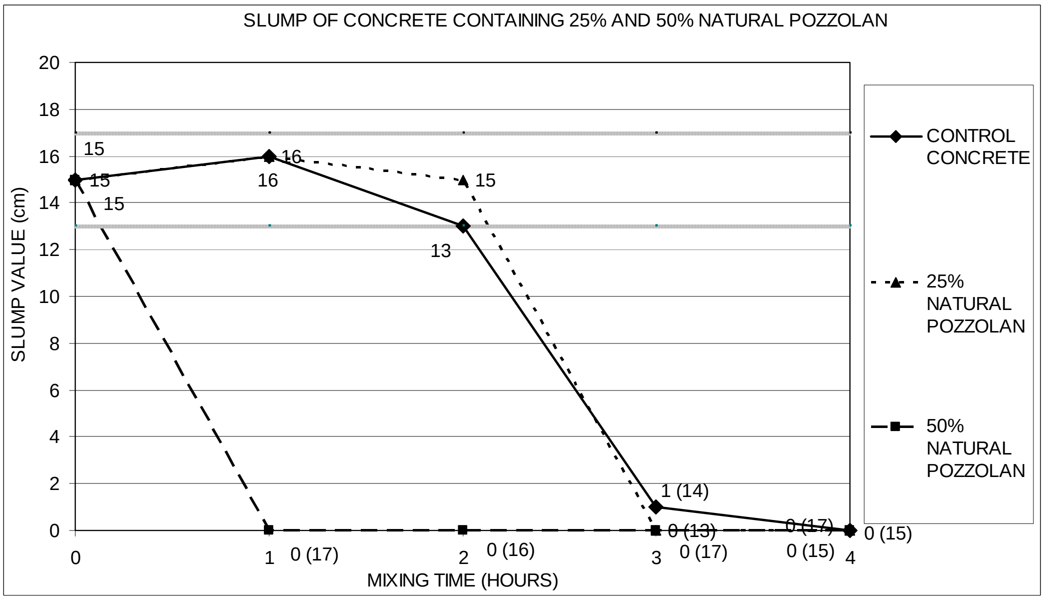

Figure 4.6 Effect of prolonged mixing on slump of concrete mixtures containing natural pozzolan at amounts 25% and 50%

The behaviors of ground clay brick and natural pozzolan have been alike to a point, from slump loss behavior point of view. The slump loss at 25% replacement with both admixtures is less with respect to control concrete. Whereas the slump loss is higher, when replacement of 50% cement is taken into consideration with respect to control concrete for both mineral admixtures. But at cement replacement by natural pozzolan, the slump loss is much faster with respect to ground clay brick containing mixture. Even at second hour of mixing with 50% natural pozzolan, the slump has come to 0 cm value.

The general order of response to the prolonged mixing, from slump loss point of mineral admixture containing concrete mixtures, has been said to be fly ash, ground clay brick, control, GGBFS and natural pozzolan concretes for this study.

4.1.3 Air Content of Concrete Subjected Prolonged Mixing

In the references, prolonged mixing has been stated to reduce the air content by about 1/6 of it, per hour, depending also the type of air entrained concrete [19]. However the air entrainment in the experimental part of this thesis study has shown an unexpected result. The air in the concrete has increased as a result of prolonged mixing operation and after reaching the top value, it has begun to decrease forming a curve (Figure 4.7, Figure 4.8). This behavior is not only observed in mixture that is containing Portland cement as binder material. All mixtures containing different mineral admixtures at different amounts show this property. Normally the air is expected to decrease proportionally.

The second important matter in this study about air in concrete is the sudden decrease in the amount of air, when the superplasticizer has been added to the fresh concrete to retemper it for slump retention.

The main question about the increasing amount of air in concrete has been about the type of air, if it is entrapped or entrained. Normally as it is stated above, entrained air is expected to decrease as the mixing time of concrete increases. In this experimental study, the basic differentiating factor may be high ambient temperature.

The estimation about the high amount of air in fresh concrete may be the transformation of entrained air into the entrapped air with an increasing volume. Prolonged mixing operation with high ambient temperature, resulting in higher amount of hydration reactions of cement, can deform the order of entrained air in concrete with the result, transformation of regularly precipitated entrained air into the entrapped air. The decrease in air content of agitated concrete with the usage of superplasticizer as a retempering agent, may be a proof for this estimation (Table 4.2, Figure 4.7, Figure 4.8, Figure 4.9, Figure 4.10, Figure 4.11, Figure 4.12)

Table 4.2 Air Content of Prolonged Mixed Air Entrained Concrete

	THE CONCRETING STAGE				
	1	**2**	**3**	**4**	**5**
CONTROL CONCRETE					
AIR CONTENT (%)	8	13	12	8	2.5
FLY ASH CONCRETE (25%)					
AIR CONTENT (%)	8.5	13	12	3.6	2.7
FLY ASH CONCRETE (50%)					
AIR CONTENT (%)	7.2	11	11.5	3.2	2.7
BLAST FURNACE SLAG C.(25%)					
AIR CONTENT (%)	10.5	13	3.6	3.4	2.8
BLAST FURNACE SLAG C.(50%)					
AIR CONTENT (%)	6	9	3.3	2.6	2.4
CLAY BRICK CONCRETE(25%)					
AIR CONTENT (%)	10	11.5	13	4.2	2.6
CLAY BRICK CONCRETE(50%)					
AIR CONTENT (%)	8.5	9	3.6	1.8	1.6
NATURAL POZZOLAN C.(25%)					
AIR CONTENT (%)	6	8	7	2.7	1.4
NATURAL POZZOLAN C. (50%)					
AIR CONTENT (%)	7.5	1	1.8	1.6	1.4

The increase in air content of concrete due to prolonged mixing can also be attributed to the low slump values of concrete, making compaction harder and causing more entrapped air for the same amount of compaction.

The entrained air content of concrete at first (starting) stage of concreting (after 5 minute of mixing) is lowest at concrete mixture which has been containing blast furnace slag of 50%, bringing the result of highest strengths (Table 4.2, Figure 4.8) .

When 25% cement replacement with mineral admixtures has been considered (Figure 4.7), generally mixture prepared with natural pozzolan is said to be less air capturing with respect to other concrete mixtures. The retempering action with superplasticizer results in a sharp decrease at the air content of all concrete mixtures. Also the reaction of air content of natural pozzolan mixture to the retempering action using superplasticizer is less with respect to other mixtures. This can be attributed to the lower pozzolanic reactivity of the natural pozzolan. The mixture prepared with 25% ground clay brick seems to have an increase in the amount of air until second hour of mixing unlikely to the other mixtures which seem to have increases in the amount of air for only one hour of mixing.

The response of air content at 50% mineral admixture containing mixtures to the prolonged mixing is nearly same with response at 25% mineral admixture containing concretes. Concrete containing natural pozzolan at ratio 50% have stable amount of air in mixture in spite of prolonged mixing and retempering. Rapid decrease in the amount of air, as a result of retempering action needed at first hour of mixing of 50% natural pozzolan containing concrete, may show that high amount of air captured due to prolonged mixing is not entrained air.

The general tendency at amount of air in concrete mixtures is a soft increase for one or two hours than again a soft decrease until retempering action. The retempering operation with superplasticizer brings a sharp decrease in the amount of air.

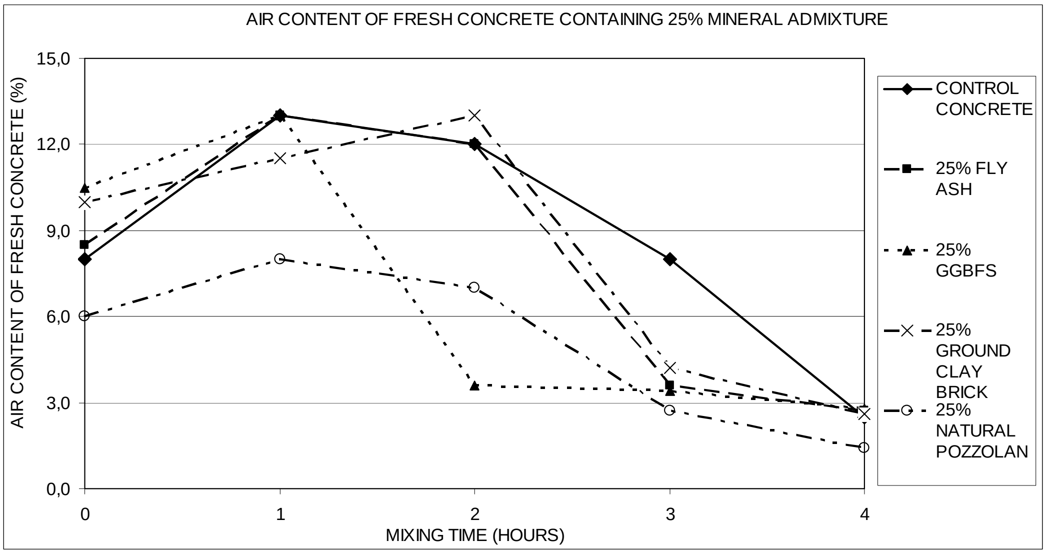

Figure 4.7 Effect of prolonged mixing on air content of concrete mixtures containing different mineral admixtures at ratio 25%.

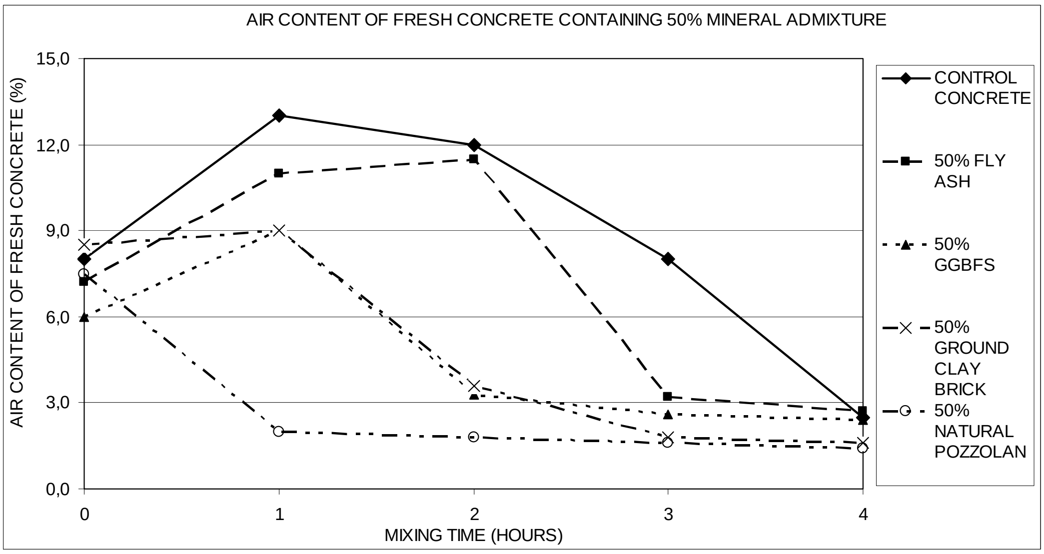

Figure 4.8 Effect of prolonged mixing on air content of concrete mixtures containing different mineral admixtures at ratio 50%.

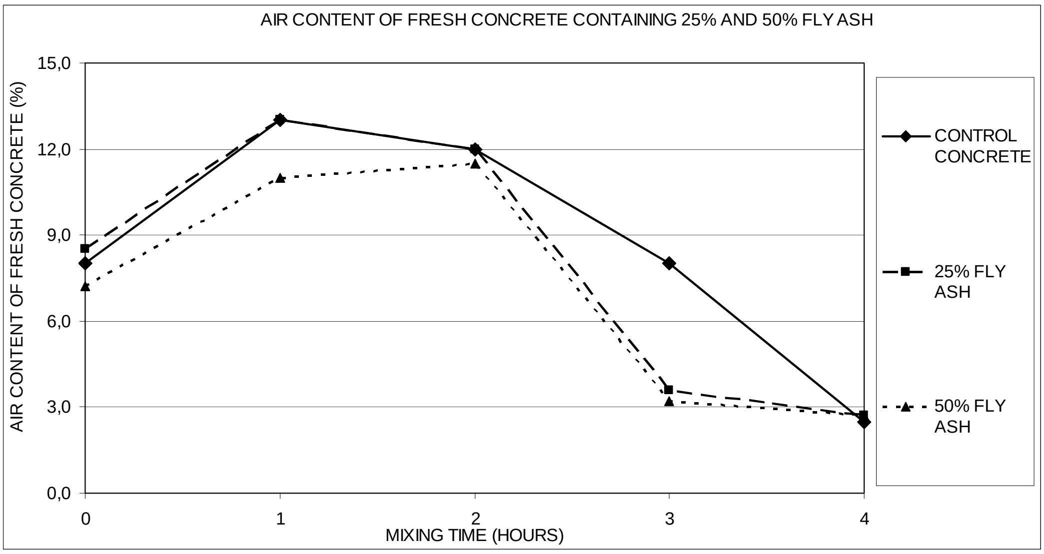

Figure 4.9 Effect of prolonged mixing on air content of concrete mixtures containing fly ash at ratios 25%, 50%.

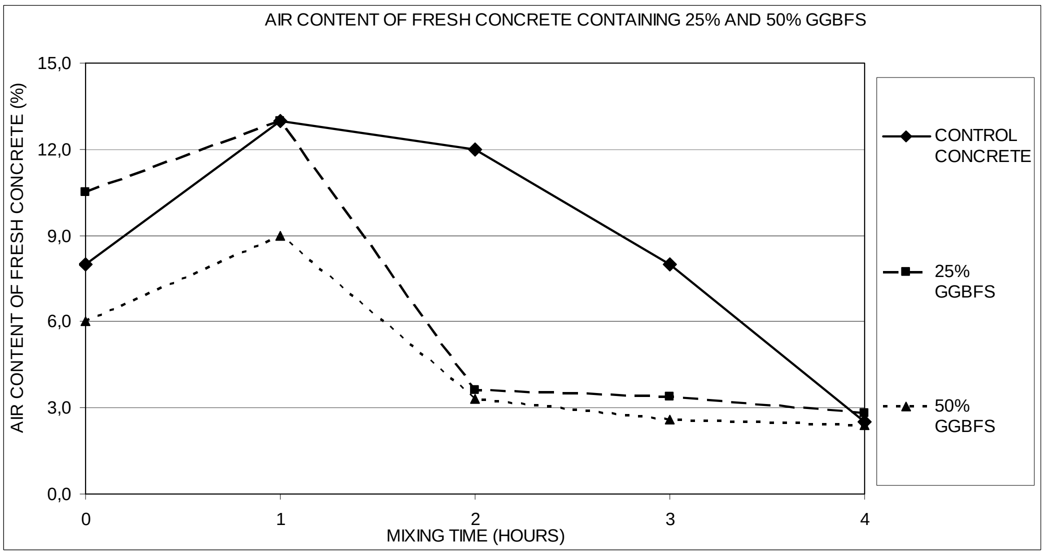

Figure 4.10 Effect of prolonged mixing on air content of concrete mixtures containing GGBFS at ratios 25%, 50%.

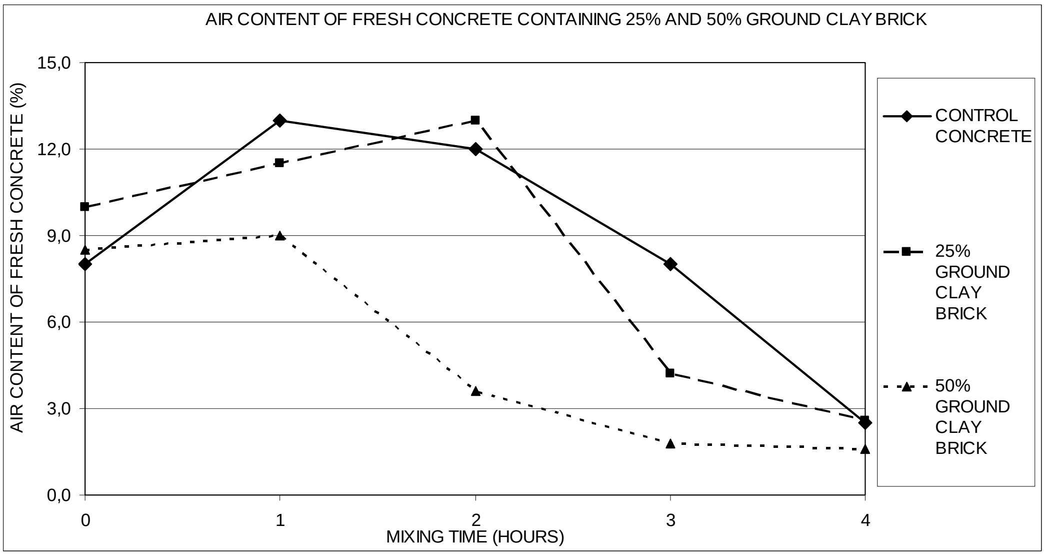

Figure 4.11 Effect of prolonged mixing on air content of concrete mixtures containing ground clay brick at ratios 25%, 50%.

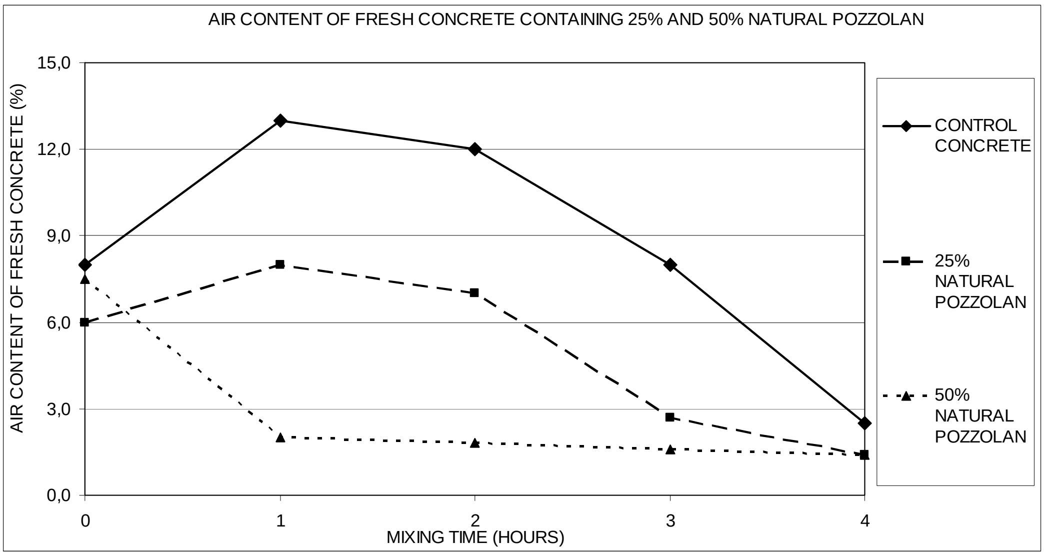

Figure 4.12 Effect of prolonged mixing on air content of concrete mixtures containing natural pozzolan at ratios 25%, 50%.

4.2 Tests on Hardened Concrete

4.2.1 Compressive Strength and Splitting Tensile Strength Tests

All the cylinder specimens used in the experimental program have been in dimensions 67 mm diameter and 134 mm height. Since the capacity of mixer is not sufficient to give one batch from which, enough number of standard cylinder specimens are able to be taken, and processing different batches may cause higher standard deviations of test results, the dimensions of specimens are decreased.

The specimens have been taken from the primary mixtures or retempered mixtures hourly . They have been cured at two different temperatures. One group at 23ºC and the others at 50ºC to simulate the hot weather conditions, both in water. Compressive strength tests were conducted at ages of 7 and 28 days. All specimens were capped before application of compression.

The results of 7- day compressive strength and 28-day compressive strength tests are tabulated at Table 4.3 and Table 4.4. Tabulated values are than graphed for each mixture (for example 25% fly ash) showing also the effect of curing temperature on compressive strength.

The compressive strengths are expected to increase as the mixing duration gets longer due to the fact that the increase in mixing time causes a decrease in water cement ratio, as a result of loss of water by evaporation. Also the hydration reactions which take place during prolonged mixing may result in a loss in compressive strength. In addition to these, grinding of aggregates may cause a decrease in aggregate size with the final result of decrease in strength. But these two effects are generally minor.

Table 4.3 7 Day Compressive Strengths of Prolonged Mixed Concrete

	THE CONCRETING STAGE				
	1	**2**	**3**	**4**	**5**
CONTROL CONCRETE					
Compressive Strength (7 days 50C°) (MPa)	28.1	14.3	18.8	37.3	37.6
Compressive Strength (7 days 23C°) (MPa)	28.8	16.0	13.6	34.5	32.9
FLY ASH CONCRETE (25%)					
Compressive Strength (7 days 50C°) (MPa)	26.8	23.6	21.2	32.3	38.4
Compressive Strength (7 days 23C°) (MPa)	20.0	15.4	13.4	24.4	31.0
FLY ASH CONCRETE (50%)					
Compressive Strength (7 days 50C°) (MPa)	14.5	12.1	16.0	20.8	27.9
Compressive Strength (7 days 23C°) (MPa)	12.7	9.0	8.0	15.4	18.6
BLAST FURNACE SLAG C.(25%)					
Compressive Strength (7 days 50C°) (MPa)	30.9	27.6	31.1	36.9	40.3
Compressive Strength (7 days 23C°) (MPa)	26.4	23.3	25.1	26.7	28.6
BLAST FURNACE SLAG C.(50%)					
Compressive Strength (7 days 50C°) (MPa)	31.4	29.4	33.4	35.3	35.9
Compressive Strength (7 days 23C°) (MPa)	23.9	26.2	31.6	29.1	38.2
CLAY BRICK CONCRETE(25%)					
Compressive Strength (7 days 50C°) (MPa)	19.5	14.2	15.0	27.0	27.8
Compressive Strength (7 days 23C°) (MPa)	14.9	11.9	11.5	22.0	26.4
CLAY BRICK CONCRETE(50%)					
Compressive Strength (7 days 50C°) (MPa)	17.9	14.3	13.1	17.5	17.8
Compressive Strength (7 days 23C°) (MPa)	11.7	11.1	15.1	19.8	18.1
NATURAL POZZOLAN C.(25%)					
Compressive Strength (7 days 50C°) (MPa)	19.0	12.0	12.9	15.2	18.3
Compressive Strength (7 days 23C°) (MPa)	20.5	13.1	14.2	19.4	25.3
NATURAL POZZOLAN C. (50%)					
Compressive Strength (7 days 50C°) (MPa)	9.8	13.6	13.6	12.7	16.0
Compressive Strength (7 days 23C°) (MPa)	8.4	9.0	8.8	9.4	10.6

Table 4.4 28 Day Compressive Strengths of Prolonged Mixed Concrete

	THE CONCRETING STAGE				
	1	**2**	**3**	**4**	**5**
CONTROL CONCRETE					
Compressive Strength (28 days 50C°) (MPa)	34.8	17.3	25.6	31.6	39.8
Compressive Strength (28 days 23C°) (MPa)	28.0	16.8	23.9	29.9	34.1
FLY ASH CONCRETE (25%)					
Compressive Strength (28 days 50C°) (MPa)	30.2	27.0	23.9	39.3	48.4
Compressive Strength (28 days 23C°) (MPa)	20.8	25.2	19.9	37.4	45.7
FLY ASH CONCRETE (50%)					
Compressive Strength (28 days 50C°) (MPa)	30.7	23.7	21.9	32.8	37.6
Compressive Strength (28 days 23C°) (MPa)	22.4	19.5	18.7	30.9	36.3
BLAST FURNACE SLAG C.(25%)					
Compressive Strength (28 days 50C°) (MPa)	34.2	27.6	42.3	42.7	43.5
Compressive Strength (28 days 23C°) (MPa)	39.9	32.6	33.1	35.7	42.9
BLAST FURNACE SLAG C.(50%)					
Compressive Strength (28 days 50C°) (MPa)	43.4	39.2	42.9	42.1	47.1
Compressive Strength (28 days 23C°) (MPa)	40.5	34.3	36.3	36.4	46.0
CLAY BRICK CONCRETE(25%)					
Compressive Strength (28 days 50C°) (MPa)	24.1	20.1	14.9	35.9	37.8
Compressive Strength (28 days 23C°) (MPa)	18.9	18.7	11.5	21.2	29.1
CLAY BRICK CONCRETE(50%)					
Compressive Strength (28 days 50C°) (MPa)	21.9	24.3	25.9	34.2	36.4
Compressive Strength (28 days 23C°) (MPa)	19.9	23.2	27.1	29.9	33.5
NATURAL POZZOLAN C.(25%)					
Compressive Strength (28 days 50C°) (MPa)	26.4	25.4	21.0	26.0	35.4
Compressive Strength (28 days 23C°) (MPa)	23.9	21.2	19.9	22.0	29.5
NATURAL POZZOLAN C. (50%)					
Compressive Strength (28 days 50C°) (MPa)	20.2	22.0	21.0	27.8	22.9
Compressive Strength (28 days 23C°) (MPa)	15.3	15.9	17.1	22.4	21.6

General tendency in our experimental study is a decrease in compressive strength depending on the mixing time. This decrease may be attributed to the amount of air in concrete mixtures. As seen in Table 4.2, the amount of air in fresh concrete has increased as a result of prolonged mixing. Then drawing a curve it has decreased.

Normally, an increase in entrained air is not expected as a result of agitation of concrete at normal conditions. However, higher hydration rate of concrete at high temperature may result in early hydration around entrained air and mixing operation may destroy the order of hydrated air entrained concrete with the final effect of increasing air content and the transformation of entrained air into entrapped air.

The retempering action has positively affected the compressive strength. Since no water is used for retempering, water content of mixture is not increased. Also some water is lost depending on the evaporation at 40°C. These factors may positively affect the compressive strength of concrete. In addition to these, the retempering action has corrected the slump losses causing a well compacted, less air containing concrete at higher strengths.

When compressive strengths at 7^{th} day of curing at 23°C are considered, it has been observed that 25% mineral admixture containing concretes are stronger than 50% admixture containing concretes except for GGBFS as expected (Figure 4.23, Figure 4.27, Figure 4.31, Figure 4.35). The retempering operation, it does not matter that at which stage it occurs, has caused sharp increases at strength of concrete. The differences between strength of different pozzolans can not be observed clearly at this stage. But it has been detected that compressive strength of both mixtures containing GGBFS at ratios 25% and 50% have been more stable to the actions, prolonged mixing and retempering at these conditions (Figure 4.17, Figure 4.19).

When 28 day compressive strengths at curing temperature, 23°C are considered, it has been observed that again GGBFS containing concretes have given more stable strength results, depending on different mixing durations and different amount of retempering admixture added at different stages of mixing operation, as they were at 7th day of curing at 23°C (Figure 4.18, Figure 4.20).

The response of compressive strength of 50% ground clay brick containing concrete to the prolonged mixing action is better among the mixtures that are 50% mineral admixture containing. It does not have the highest strength but continuously increasing one. The continuous increase in the strength of concrete containing ground clay brick at ratio %50 can be caused by the retempering action (Figure 4.20).

On the other hand 25% fly ash containing concrete responds in a better way to the retempering action from compressive strength (for specimens cured at 23°C for 28 days) point of view. This can be attributed to the better workability and compaction with the usage of superplasticizer and fly ash together.

When 25% mineral admixture containing concretes are considered, it has been observed that the reaction of compressive strength to the prolonged mixing for 25% fly ash and 25% ground clay brick are very alike (Figure 4.14, Figure 4.18).

50°C curing is used at this experimental study to continue to simulate hot weather conditions. As a result of curing at 50°C, it has been observed that concretes prepared using ground clay brick show greater performance among mixtures that have 50% admixture. Fly ash mixture specimens cured at high temperature have shown also very good performance with respect to low temperature specimens as expected. Especially 25% fly ash containing mixture give the highest compressive strength as a result of retempering process applied on fresh concrete at 28 days.

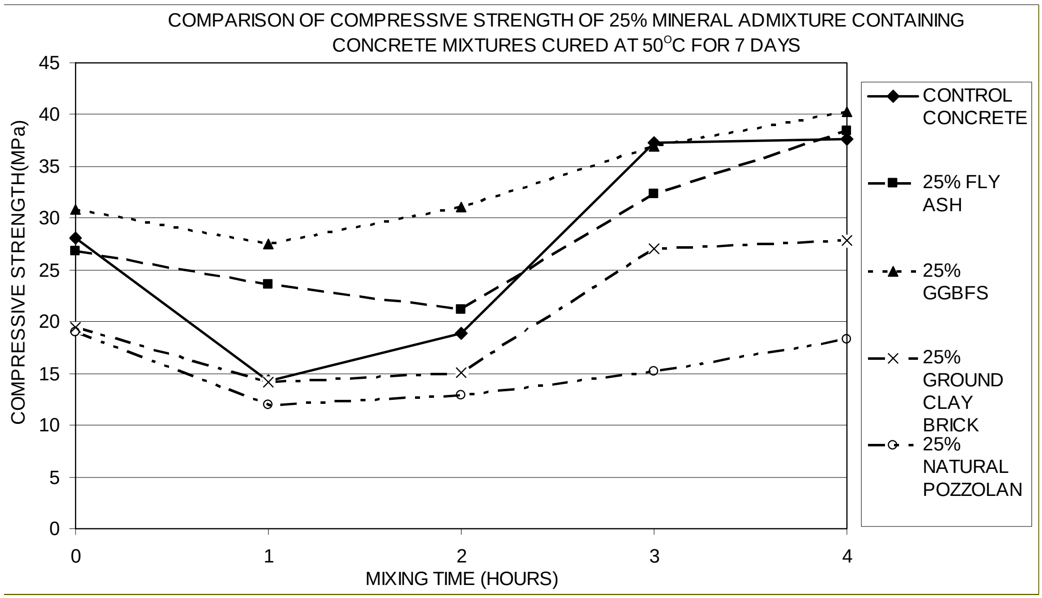

Figure 4.13 Effect of prolonged mixing on 7 day compressive strength of concrete mixtures (cured at 50°C) containing different mineral admixtures at ratio 25%.

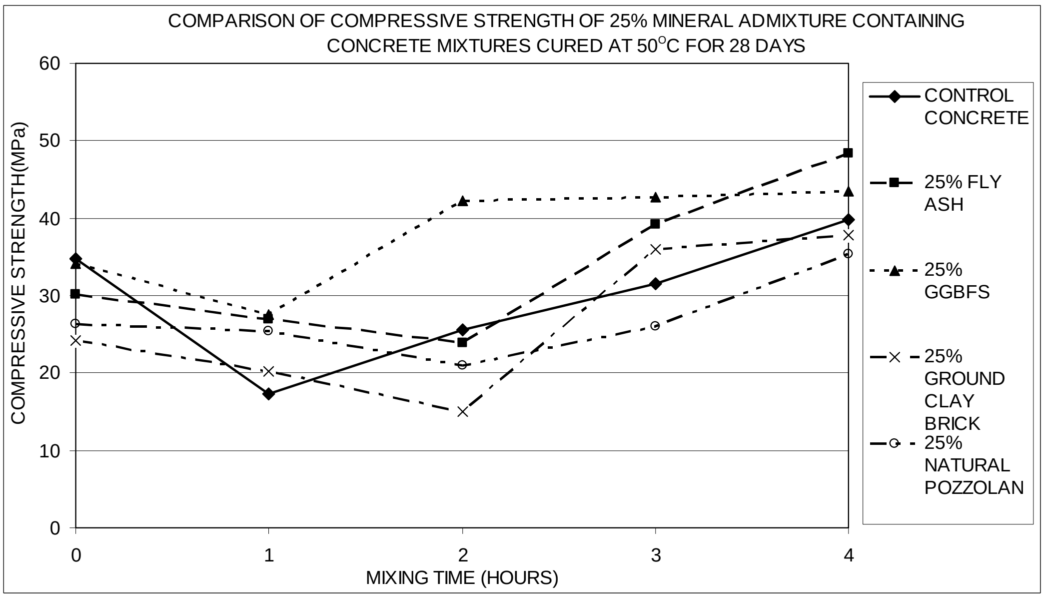

Figure 4.14 Effect of prolonged mixing on 28 day compressive strength of concrete mixtures (cured at 50°C) containing different mineral admixtures at ratio 25%.

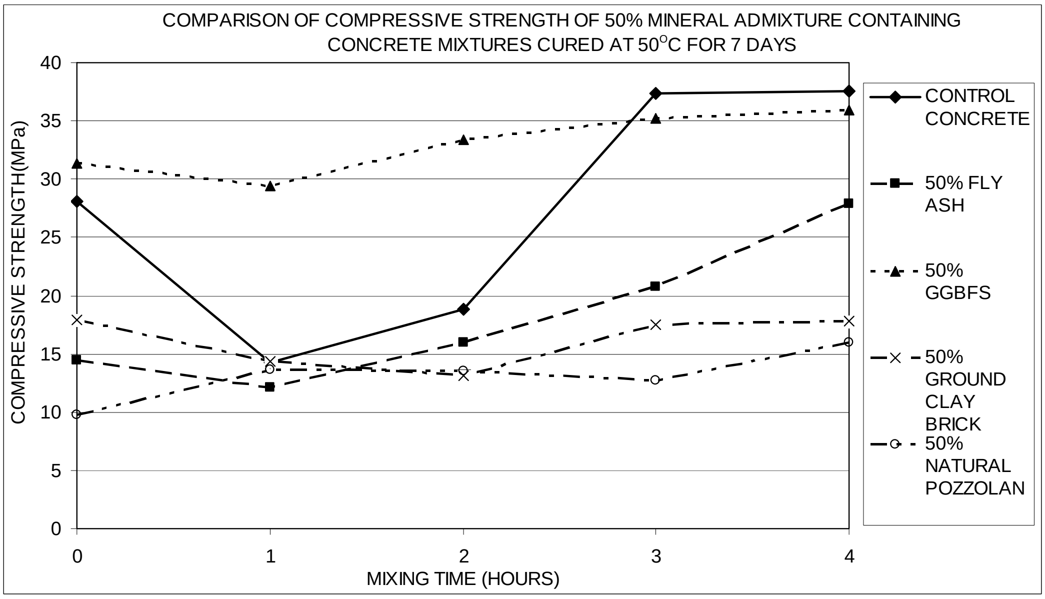

Figure 4.15 Effect of prolonged mixing on 7 day compressive strength of concrete mixtures (cured at 50°C) containing different mineral admixtures at ratio 50%.

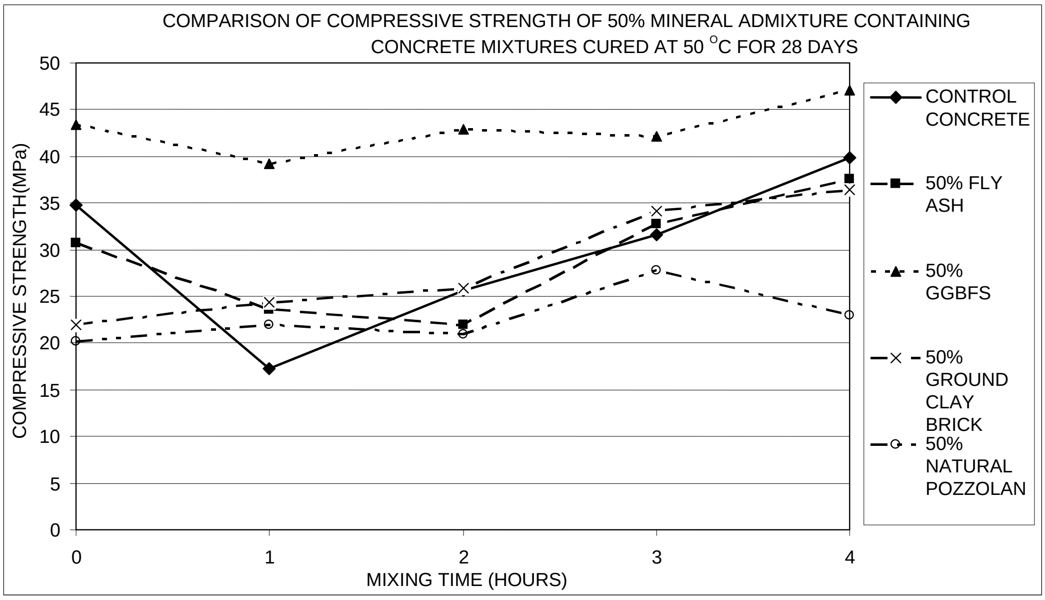

Figure 4.16 Effect of prolonged mixing on 28 day compressive strength of concrete mixtures (cured at 50°C) containing different mineral admixtures at ratio 50%.

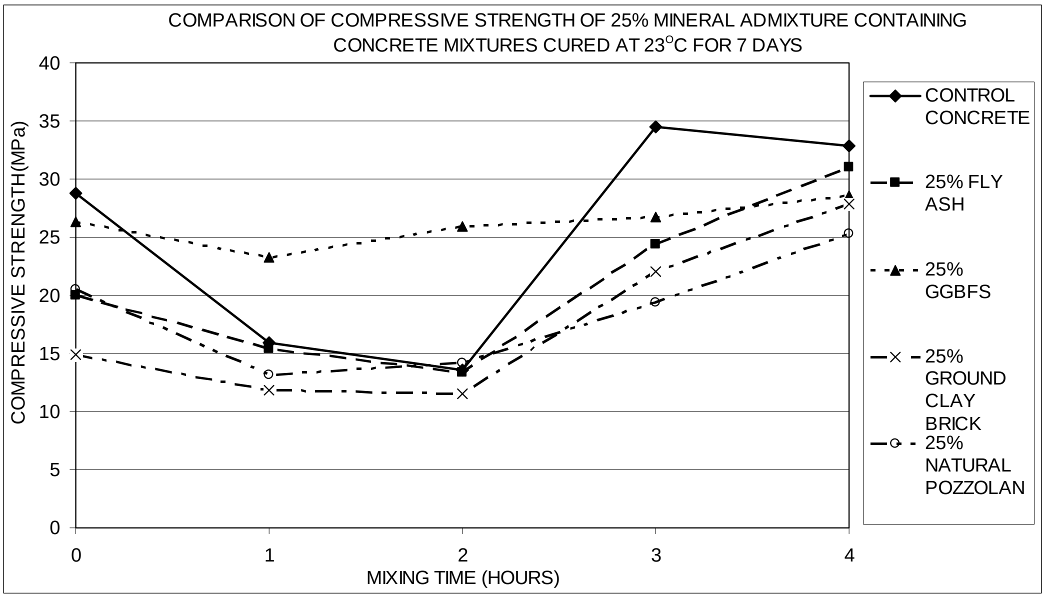

Figure 4.17 Effect of prolonged mixing on 7 day compressive strength of concrete mixtures (cured at 23°C) containing different mineral admixtures at ratio 25%.

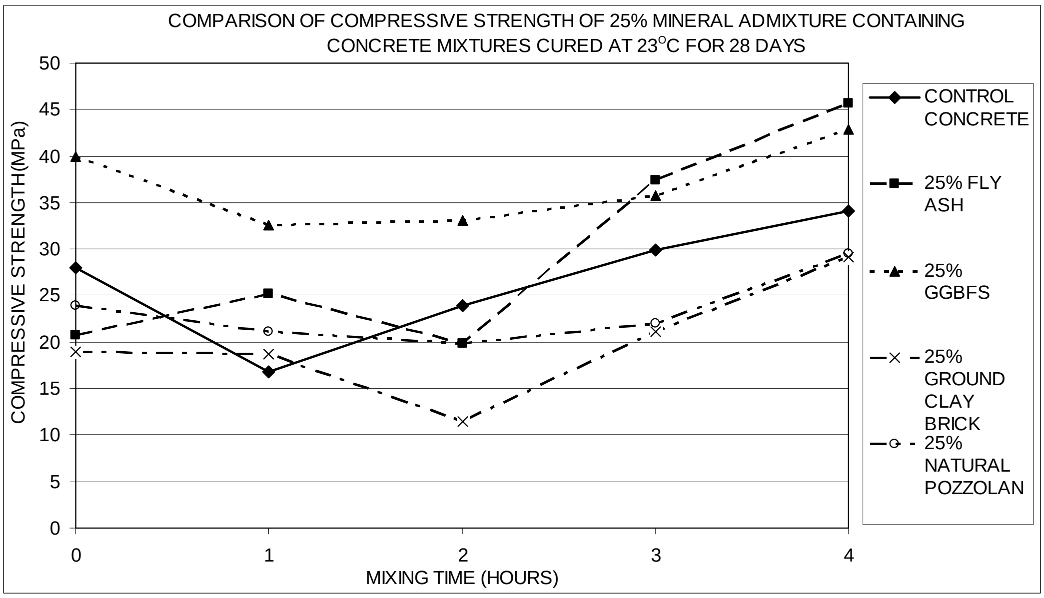

Figure 4.18 Effect of prolonged mixing on 28 day compressive strength of concrete mixtures (cured at 23°C) containing different mineral admixtures at ratio 25%.

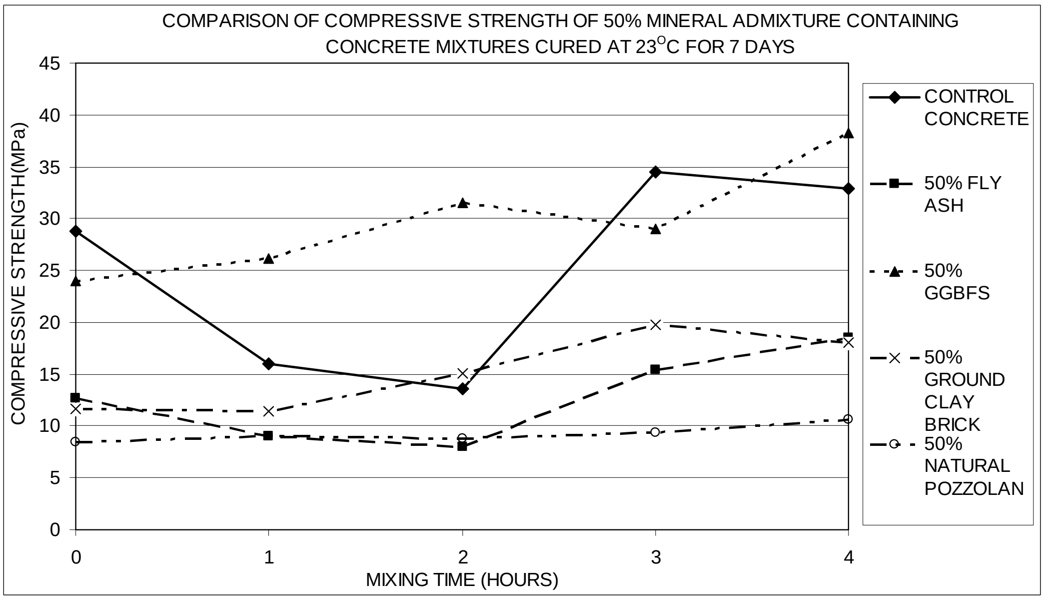

Figure 4.19 Effect of prolonged mixing on 7 day compressive strength of concrete mixtures (cured at 23°C) containing different mineral admixtures at ratio 50%.

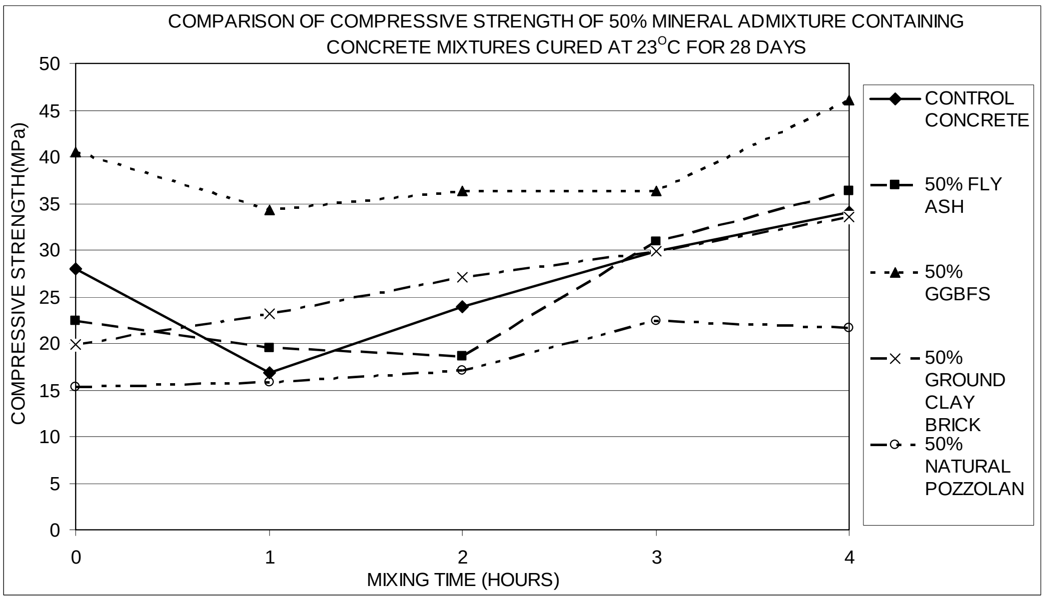

Figure 4.20 Effect of prolonged mixing on 28 day compressive strength of concrete mixtures (cured at 23°C) containing different mineral admixtures at ratio 50%.

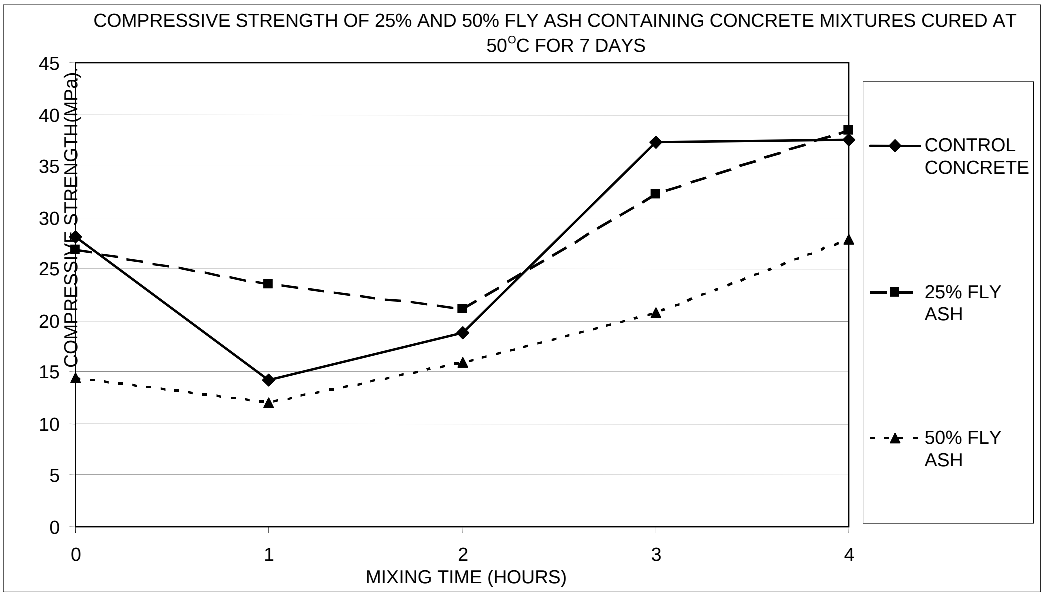

Figure 4.21 Effect of prolonged mixing on 7 day compressive strength of concrete mixtures containing fly ash at amounts, 25% and 50% (cured at 50°C).

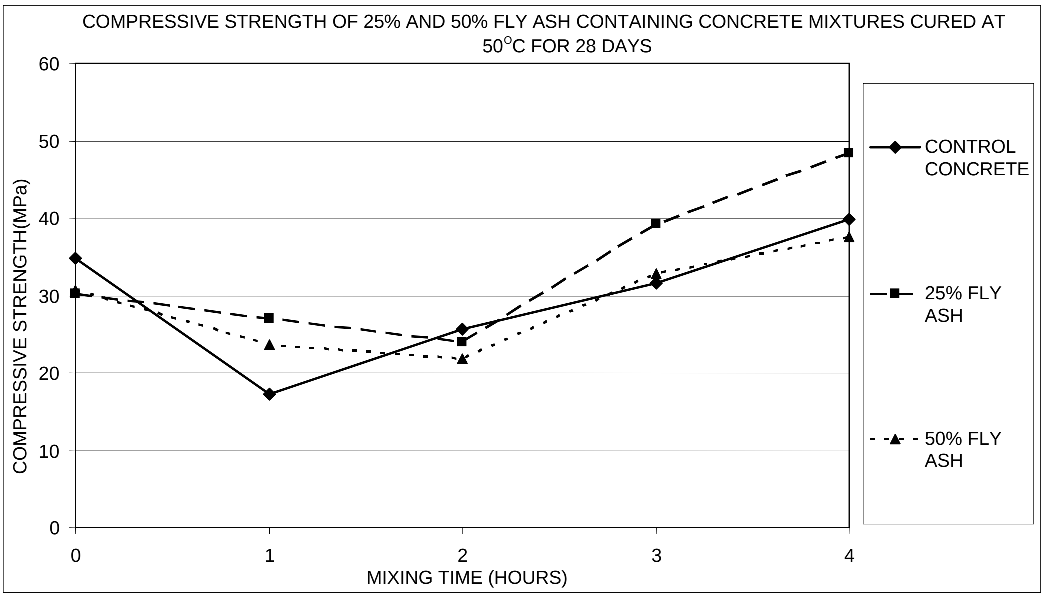

Figure 4.22 Effect of prolonged mixing on 28 day compressive strength of concrete mixtures containing fly ash at amounts, 25% and 50% (cured at 50°C).

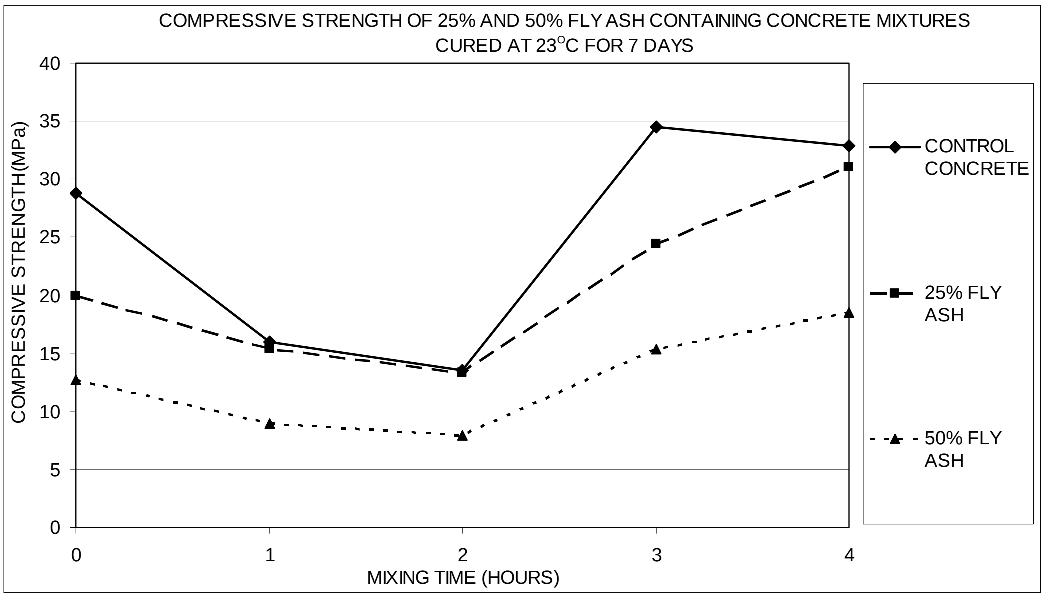

Figure 4.23 Effect of prolonged mixing on 7 day compressive strength of concrete mixtures containing fly ash at amounts, 25% and 50% (cured at 23°C).

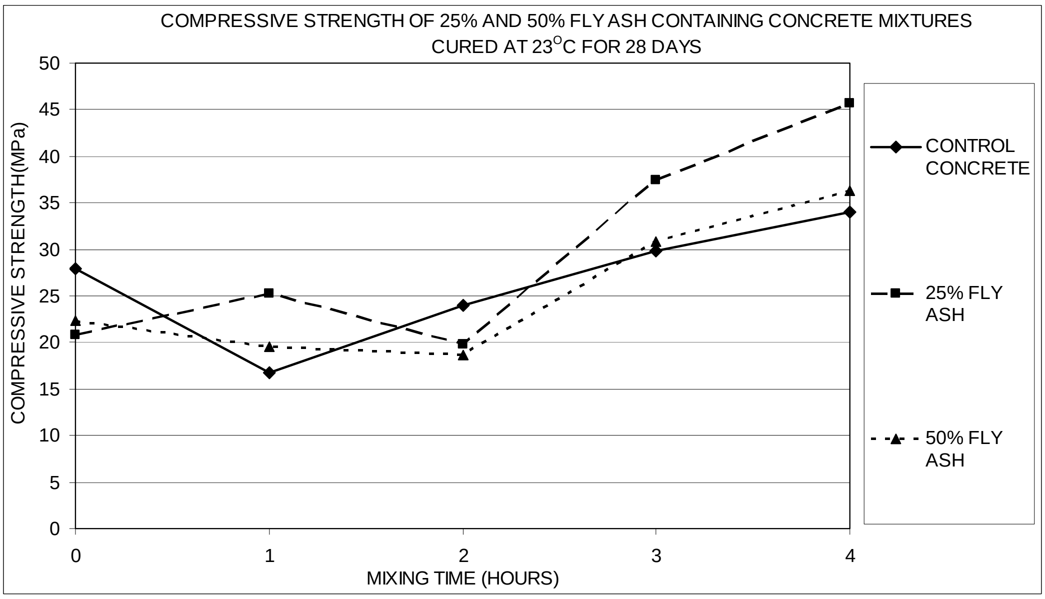

Figure 4.24 Effect of prolonged mixing on 28 day compressive strength of concrete mixtures containing fly ash at amounts, 25% and 50% (cured at 23°C).

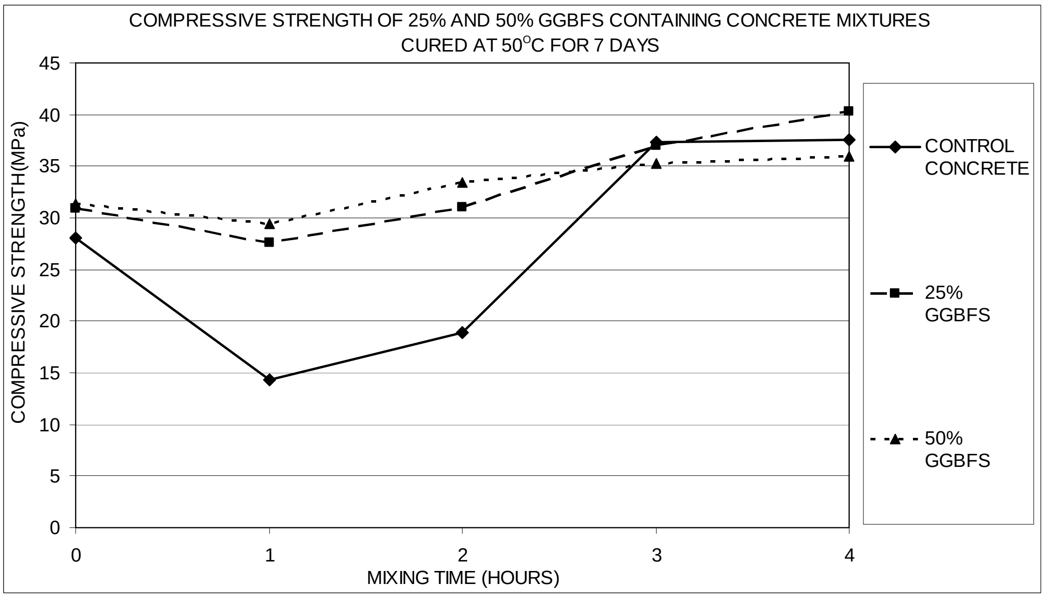

Figure 4.25 Effect of prolonged mixing on 7 day compressive strength of concrete mixtures containing GGBFS at amounts, 25% and 50% (cured at 50°C).

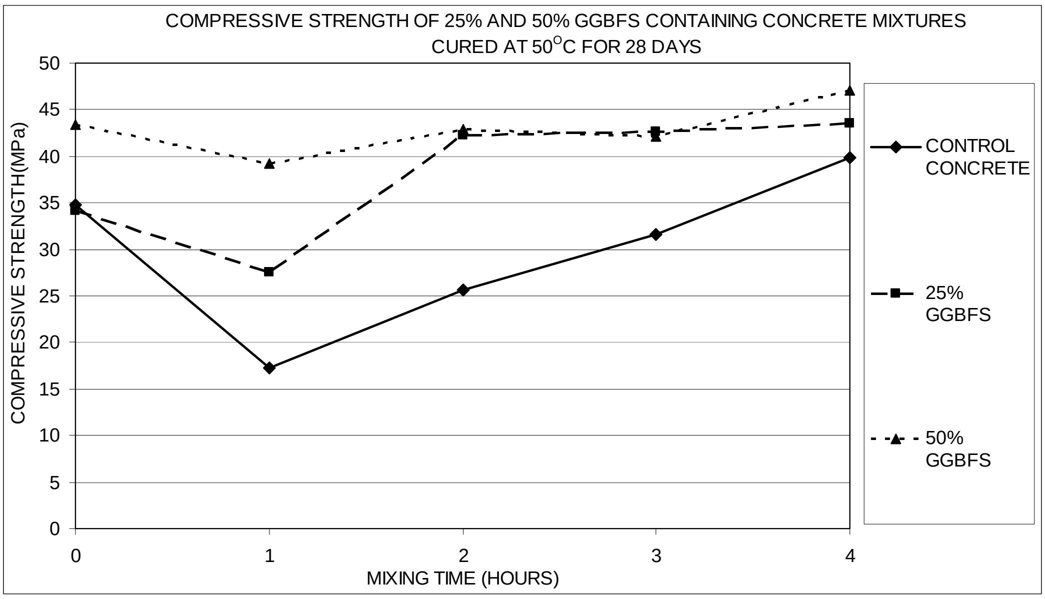

Figure 4.26 Effect of prolonged mixing on 28 day compressive strength of concrete mixtures containing GGBFS at amounts, 25% and 50% (cured at 50°C).

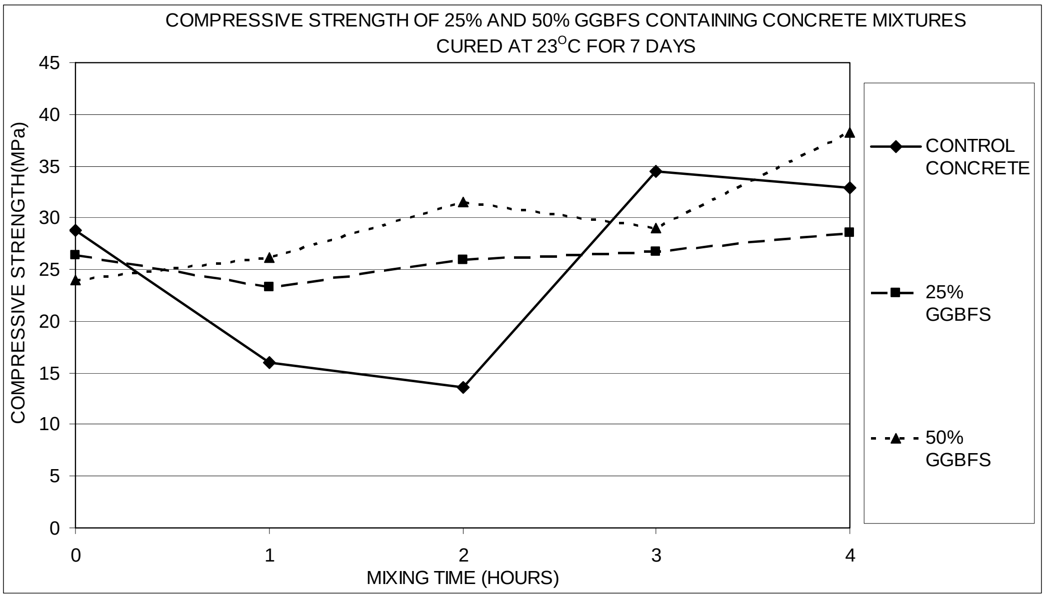

Figure 4.27 Effect of prolonged mixing on 7 day compressive strength of concrete mixtures containing GGBFS at amounts, 25% and 50% (cured at 23°C).

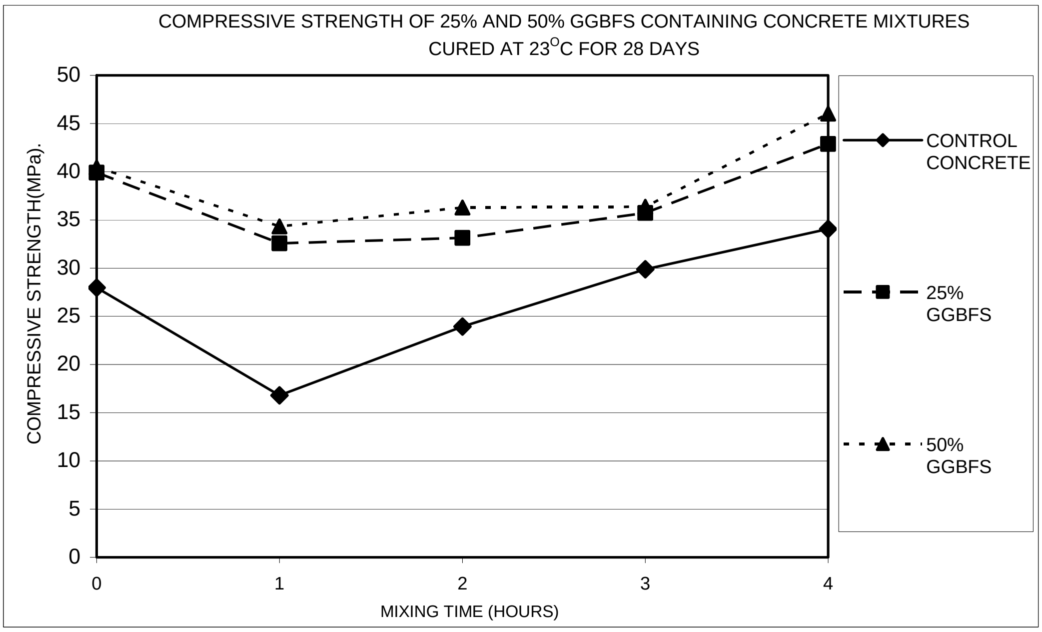

Figure 4.28 Effect of prolonged mixing on 28 day compressive strength of concrete mixtures containing GGBFS at amounts, 25% and 50% (cured at 23°C).

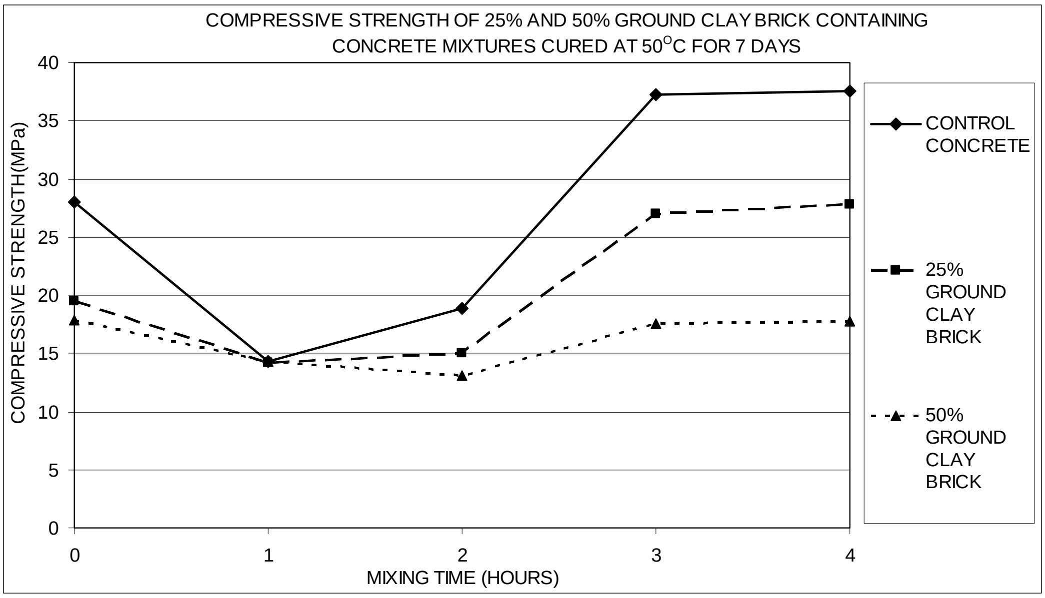

Figure 4.29 Effect of prolonged mixing on 7 day compressive strength of concrete mixtures containing ground clay brick at amounts, 25% and 50% (cured at 50°C).

Figure 4.30 Effect of prolonged mixing on 28 day compressive strength of concrete mixtures containing ground clay brick at amounts, 25% and 50% (cured at 50°C).

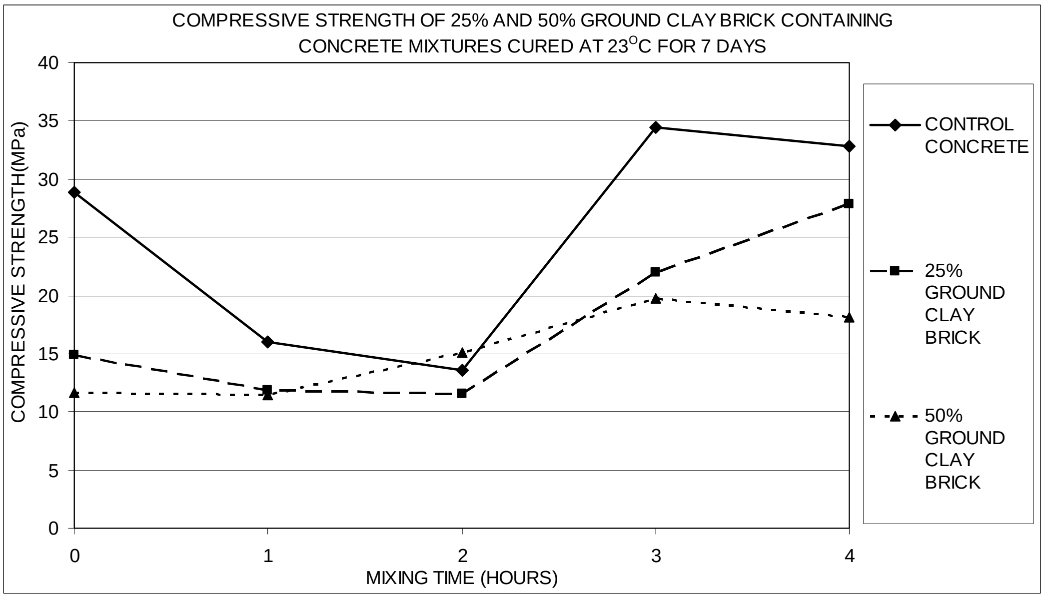

Figure 4.31 Effect of prolonged mixing on 7 day compressive strength of concrete mixtures containing ground clay brick at amounts, 25% and 50% (cured at 23°C).

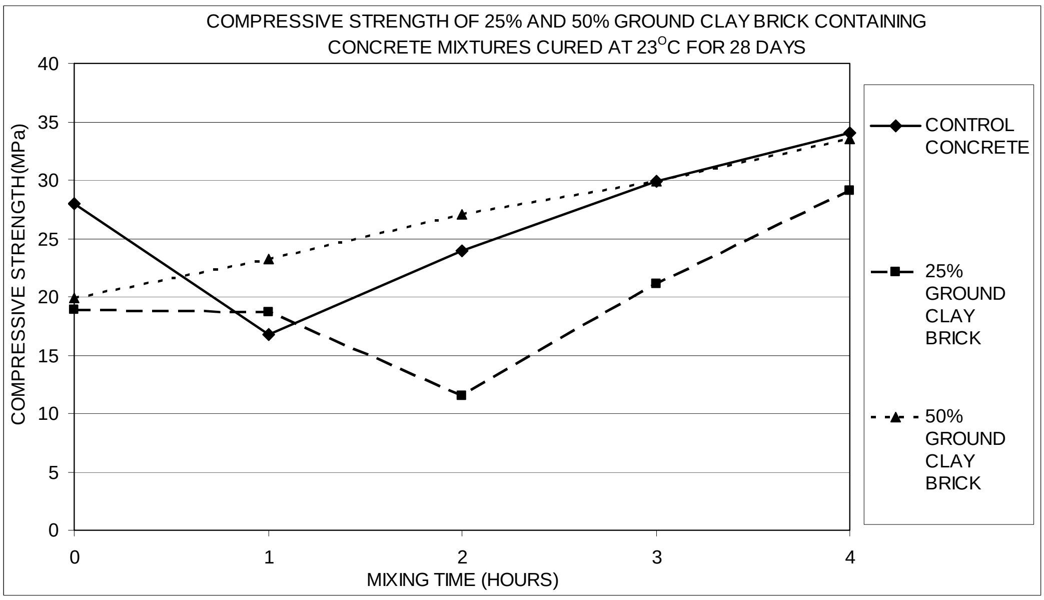

Figure 4.32 Effect of prolonged mixing on 28 day compressive strength of concrete mixtures containing ground clay brick at amounts, 25% and 50% (cured at 23°C).

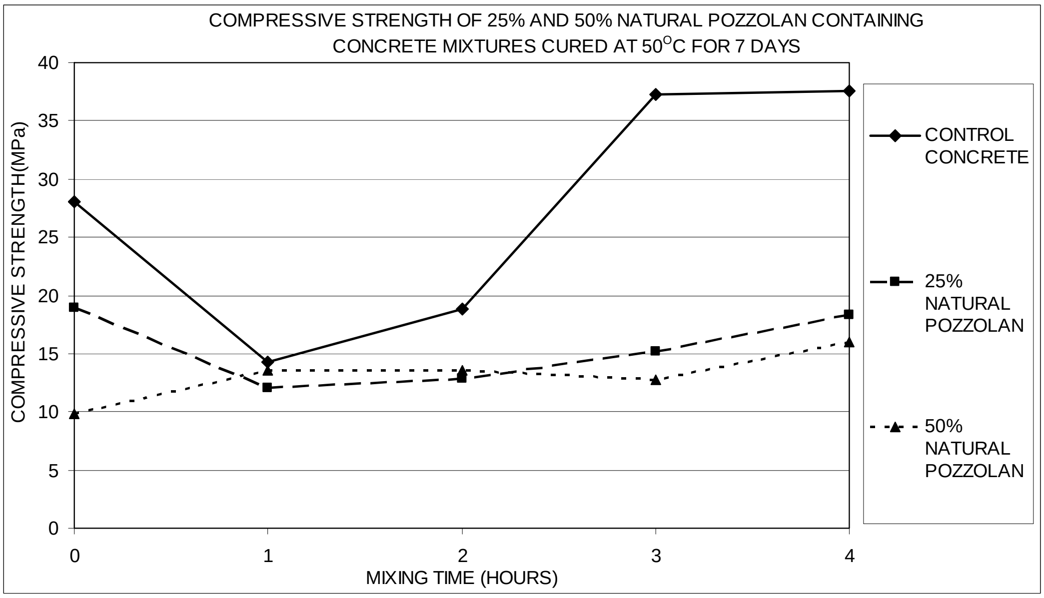

Figure 4.33 Effect of prolonged mixing on 7 day compressive strength of concrete mixtures containing natural pozzolan at amounts, 25% and 50% (cured at 50°C).

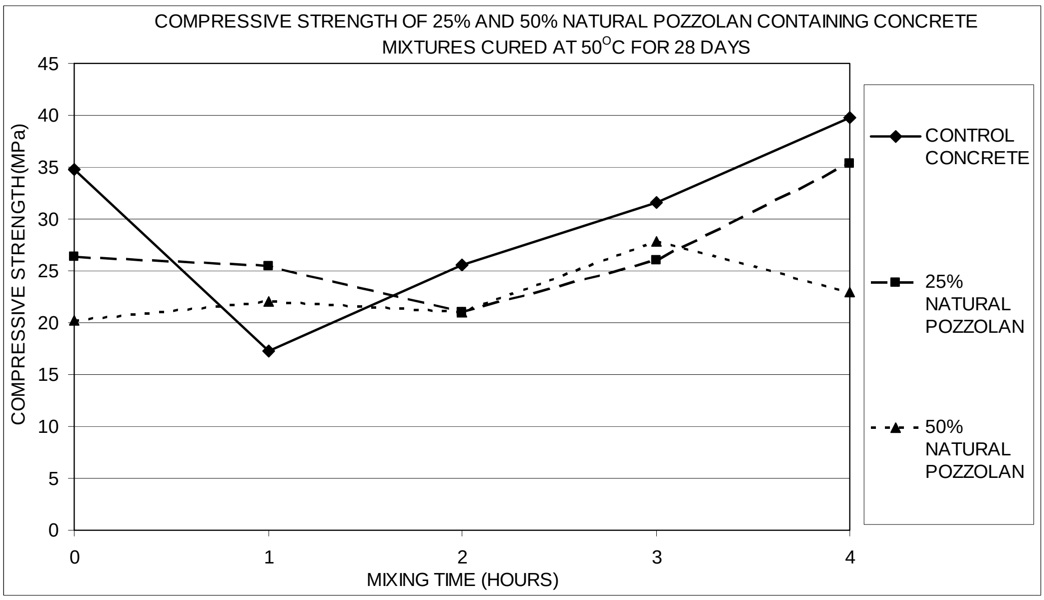

Figure 4.34 Effect of prolonged mixing on 28 day compressive strength of concrete mixtures containing natural pozzolan at amounts, 25% and 50% (cured at 50°C).

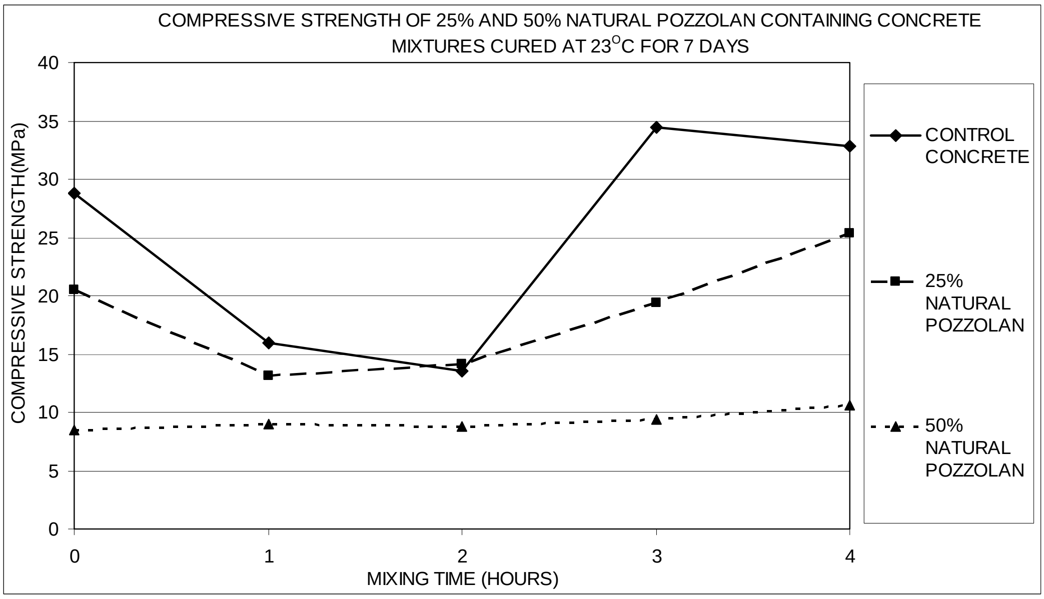

Figure 4.35 Effect of prolonged mixing on 7 day compressive strength of concrete mixtures containing natural pozzolan at amounts, 25% and 50% (cured at 23°C).

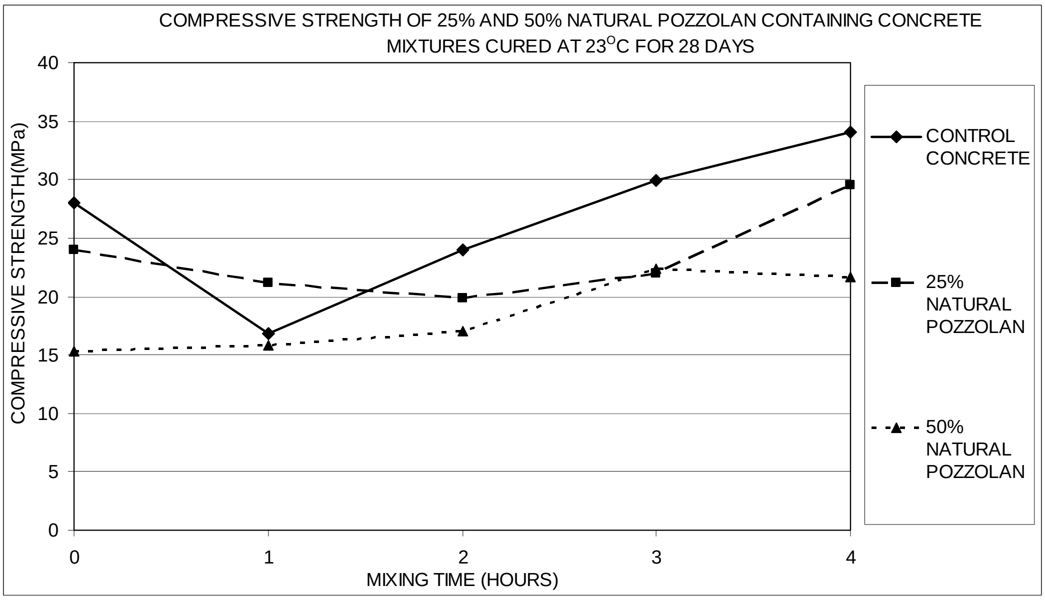

Figure 4.36 Effect of prolonged mixing on 28 day compressive strength of concrete mixtures containing natural pozzolan at amounts, 25% and 50% (cured at 23°C).

Splitting tensile test is applied to the cylinder specimens at the dimensions 67 mm* 134 mm, too. The width of splitting apparatus is determined according to these dimensions.

The test is applied to the specimens at 28th days of curing . 50ºC curing is applied to the specimens. The results can be seen at Table 4.5 and Figure 4.37 to 4.42.

Table 4.5 Effect of prolonged mixing on 28 day split tensile strength of concrete containing different mineral admixtures

	THE CONCRETING STAGE				
	1	**2**	**3**	**4**	**5**
CONTROL CONCRETE					
Split Tensile Strength (28 days 50Cº) (MPa)	2.4	1.7	2.2	2.9	4.2
FLY ASH CONCRETE (25%)					
Split Tensile Strength (28 days 50Cº) (MPa)	3.5	2.5	3.0	5.1	4.0
FLY ASH CONCRETE (50%)					
Split Tensile Strength (28 days 50Cº) (MPa)	3.4	1.5	2.6	4.7	3.3
BLAST FURNACE SLAG C.(25%)					
Split Tensile Strength (28 days 50Cº) (MPa)	3.3	3.1	3.1	3.2	5.1
BLAST FURNACE SLAG C.(50%)					
Split Tensile Strength (28 days 50Cº) (MPa)	5.3	3.6	5.4	5.5	6.0
CLAY BRICK CONCRETE(25%)					
Split Tensile Strength (28 days 50Cº) (MPa)	2.3	1.8	1.7	3.1	3.2
CLAY BRICK CONCRETE(50%)					
Split Tensile Strength (28 days 50Cº) (MPa)	3.1	3.1	3.0	3.1	3.2
NATURAL POZZOLAN C.(25%)					
Split Tensile Strength (28 days 50Cº) (MPa)	2.9	2.5	2.5	3.1	3.1
NATURAL POZZOLAN C. (50%)					
Split Tensile Strength (28 days 50Cº) (MPa)	2.4	2.8	2.6	2.9	2.8

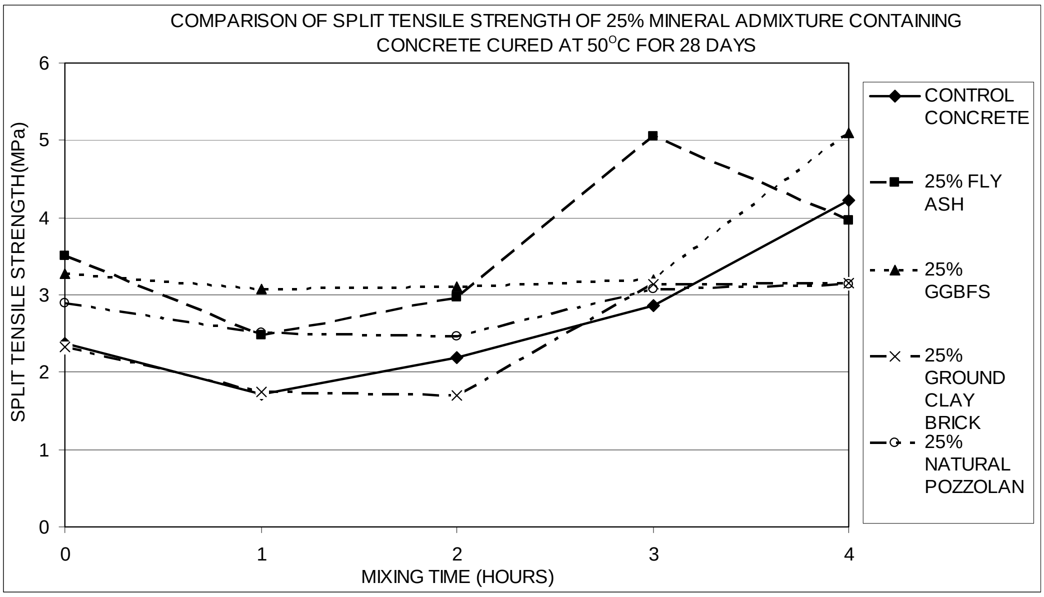

Figure 4.37 Effect of prolonged mixing on 28 day split tensile strength of concrete mixtures containing different mineral admixtures at ratio 25 %.

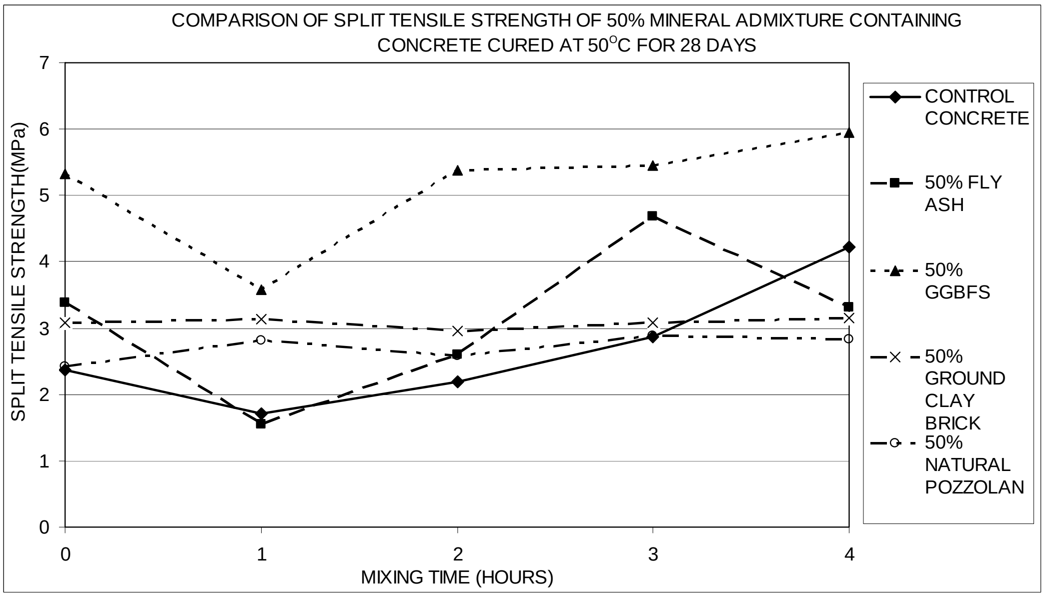

Figure 4.38 Effect of prolonged mixing on 28 day split tensile strength of concrete mixtures containing different mineral admixtures at ratio 50 %.

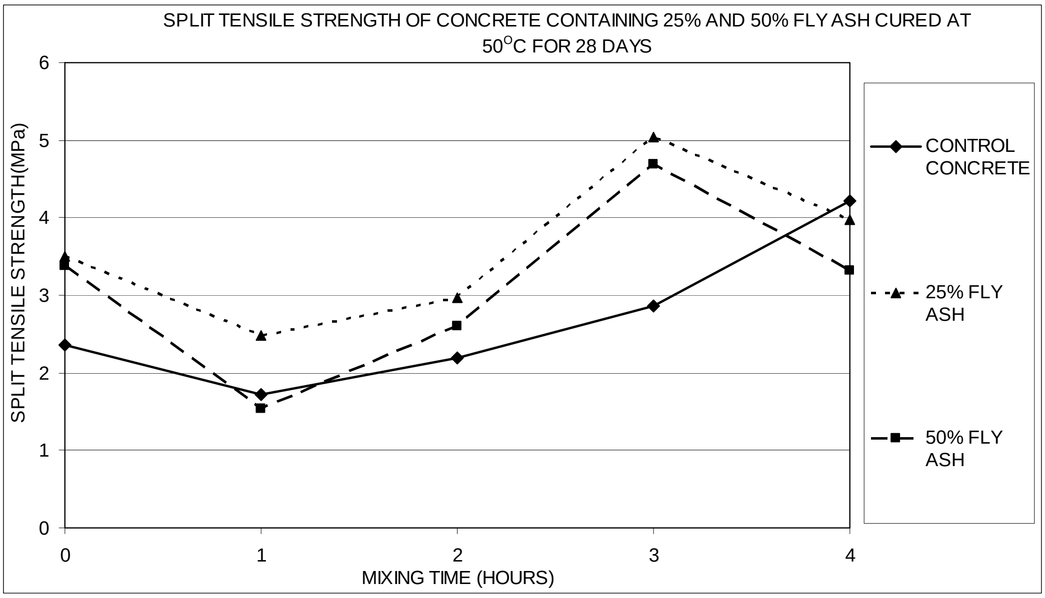

Figure 4.39 Effect of prolonged mixing on 28 day split tensile strength of concrete mixtures containing fly ash at amounts, 25% and 50% (cured at 50°C).

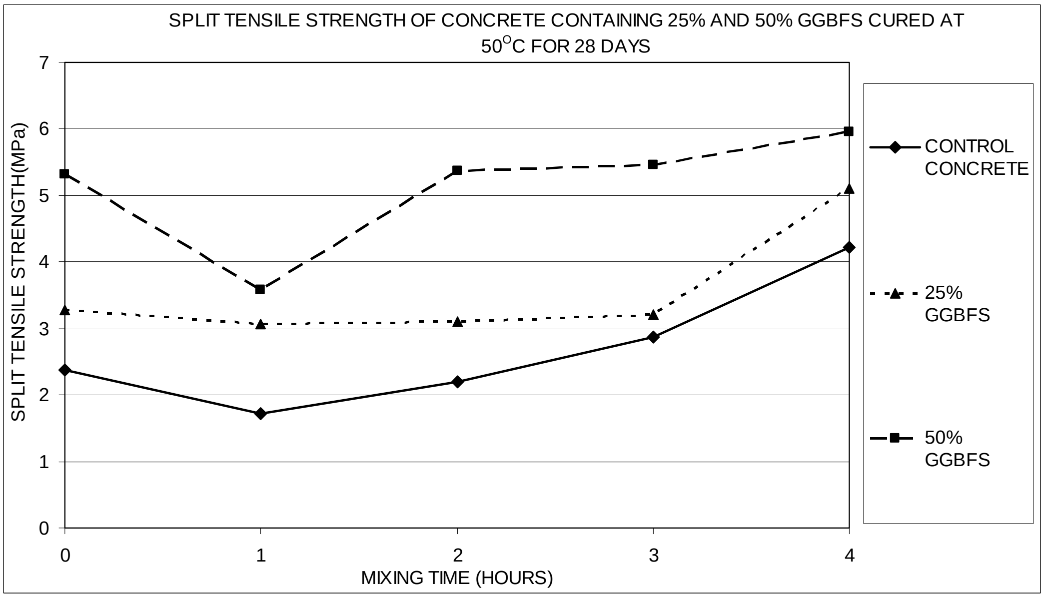

Figure 4.40 Effect of prolonged mixing on 28 day split tensile strength of concrete mixtures containing GGBFS at amounts, 25% and 50% (cured at 50°C).

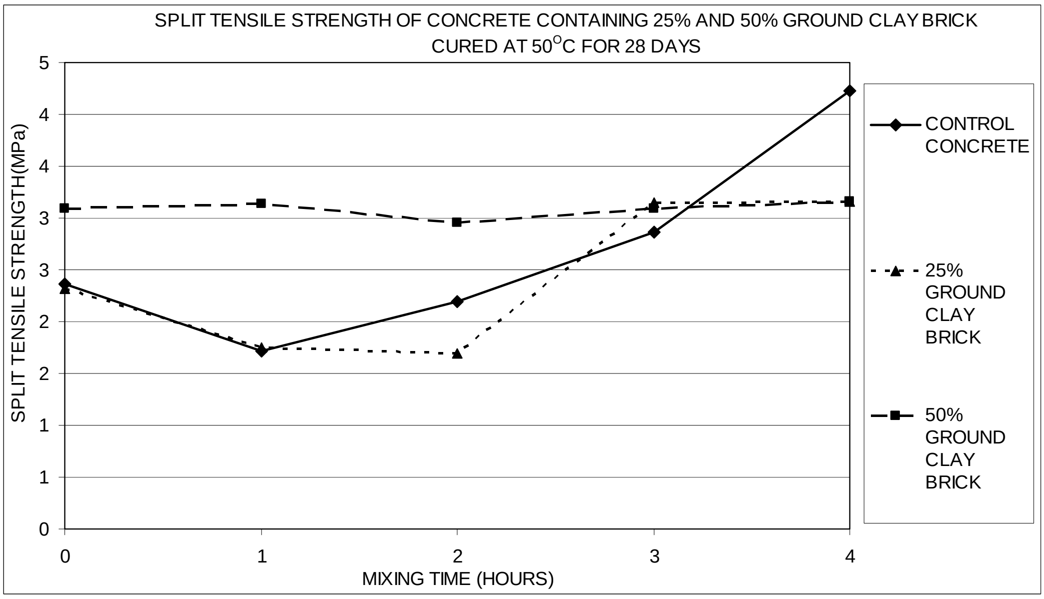

Figure 4.41 Effect of prolonged mixing on 28 day split tensile strength of concrete mixtures containing ground clay brick at amounts, 25% and 50% (cured at 50°C).

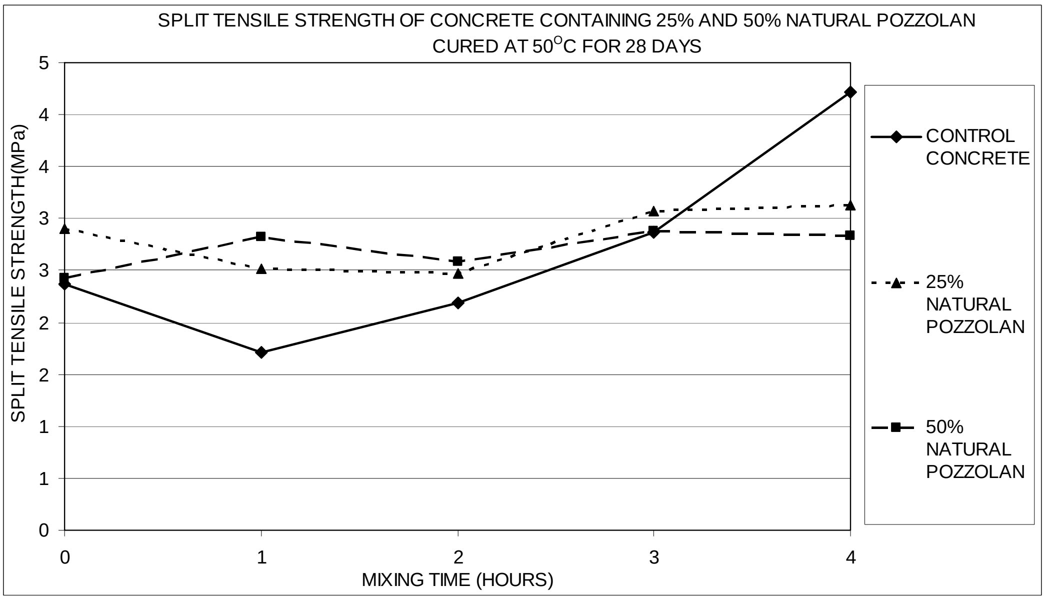

Figure 4.42 Effect of prolonged mixing on 28 day split tensile strength of concrete mixtures containing natural pozzolan at amounts, 25% and 50% (cured at 50°C).

CHAPTER 5

CONCLUSION

Prolonged mixed concrete at hot weather conditions, which has been containing mineral, air entraining, set retarding-water reducing admixtures and the reaction of this concrete to the retempering operation with superplasticizer have been investigated during this thesis study. Following results have been derived from the data obtained:

Using fly ash at ratios of 25% or 50% or natural pozzolan and ground clay brick at ratio 25% as mineral admixture can be solutions for slump loss problem, which is an effect of prolonged mixing on concrete at high temperature. But for mixing time over 2 hours at 40ºC, it is not enough to use these mineral admixtures. Some supplementary methods like retempering are needed to avoid high slump losses.

The entrained air in concrete may somehow increase as a result of prolonged mixing at high temperature, although the literature states that prolonged mixing make the entrained air content of concrete decrease. This effect may become depending on the prehydration of concrete as a result of prolonged mixing and hot weather, which may result in disordering of entrained air.

On the other hand using superplasticizer as a retempering agent has decreased the high amount of air in the prolonged mixed concrete to the level which can be tolerable. By this way, the slump retention operation has been made without using any retempering water, which can make the strength of concrete decrease by increasing water/cement ratio. The compressive strength and split tensile strength test results are better than primary stage of concreting in all mixtures when the superplasticizer has been used as a retempering agent.

In general, ground clay brick and natural pozzolan mixtures have given lower strength values, when they are compared with other mineral admixtures. However the compressive strength values have not decreased due to prolonged mixing process, especially at mixtures where 50% cement replacement with GCB and NP has taken place.

Ground granulated blast furnace slag mixtures have given higher compressive strength values at primary mixtures (after 5 minute mixing) and other stages of concreting. On the other hand, the mixtures prepared using GGBFS have higher slump losses. Ground granulated blast furnace slag mixtures also have stable compressive strength at different stages of mixing. The retempering action is less effective on GGBFS containing mixtures from compressive strength point of view with respect to other mixtures.

Using fly ash is also beneficial when high temperature curing is considered since fly ash concretes can gain strength faster with high temperature curing. The compressive strength behavior of mixtures containing ground clay brick is very alike to the fly ash containing mixtures.

Using natural pozzolan may be beneficial to a certain amount, from slump loss point of view. On the other hand since the particle shape of natural pozzolan is not regular and water absorption capacity is higher, at amount 50%, starting mixture needs the greatest amount of water and the slump loss is very rapid. The natural pozzolans should be identified, based on their surface texture when they are going to be used for reducing slump loss.

The retempering process using superplasticizer is not harmful to the strength since the retempering material does not increase the water/cement ratio to the harmful degrees with respect to starting mixture. Also increasing the compactability of fresh concrete and balancing the amount of air in concrete, it makes strength value increase to certain degrees.

Since high slump loss has been widely seen especially at hot climates, it would be better to replace some part of cement with mineral admixtures at those conditions. Also using a high range or middle range water reducer will be beneficial for retempering operations where needed. It is also important that the set retarding effect of superplasticizer should have been in tolerable limits since long setting times of retempered concrete may result in defects at structure or unwanted effects on construction program.

The effect of fly ash on slump retention due to prolonged mixing is greater with respect to other mineral admixtures examined during this study. Together with the good strength behavior at the hot climates, it would be better to use fly ash among the mineral admixtures experienced during this study against the slump loss problem.

CHAPTER 6

RECOMMANDATIONS

Based upon the results of this investigation, the following recommendations can be made for further researchers.

This study has not been concentrated on a special mineral admixture. New researches can be focused on a special mineral admixture to find the optimum dosage for least slump loss. The Portland cement replacement ratios can be specialized for each mineral admixture by trying different ratios to find the optimum ratio. The study can be divided into smaller parts with more detailed processes.

The primary mixtures have been prepared with the aim, constant slump, 15cm. The amount of water reducing admixture for concrete mixtures containing different admixtures has been same, but the amount of water has changed depending on different water absorption capacities of mineral admixtures. This study has been focused on slump values, so water content is not a problem for it. On the other hand, in the further studies which will focus on strength, this may cause unbalanced results since the water/cement ratios of initial mixtures will change depending on extra water added to bring the slump value to the desired result. At those studies, the amount of water reducer added during preparation of mixture should be changed, instead of changing the amount of water.

This study has been conducted at hot weather conditions. It can be repeated at normal temperatures to find out the behaviours at normal conditions.

As a result of prolonged mixing, the amount of air has increased to high levels, out of control, in this study. This uncontrolled increase in entrained air due to prolonged mixing and hot weather conditions may be studied more deeply in further studies.

The superplasticizer used for retempering process in this study has been a high range water reducing admixture which does not have the property of set retarding. Since these kind of chemical admixtures are expensive commercially, less expensive admixtures are used for retempering process of concrete in commercial works. So these admixtures are needed to be studied that if they are also capable of retempering prolonged mixed concrete without any harmful effect.

The natural pozzolan used during the experimental study has not been very efficient from slump loss point of view, especially for the replacement ratio, 50%. This can be caused by surface texture or mineralogical properties. The studies with different kind of natural pozzolans can be proceeded to have a certain idea about the reaction of using natural pozzolans as mineral admixture in the prolonged mixed and retempered concrete.

REFERENCES

1) Erdoğan, T.Y., Beton, (in Turkish), Metu Press, Ankara, Turkey, 2003.

2) TS 11222, Hazır Beton, Türk Standartları Enstitüsü, Ankara, 2000

3) ASTM C94, Standart Specification for Ready-Mixed Concrete, Annual Book of ASTM Standards, 2001

4) Entroy, H.C., The Variation of Test Cubes, Cement and Concrete Association Research Report 10, 1960

5) Metcalf, J.B., The Specification of Concrete Strength, Part II, Report LR 300, 1970

6) Samarai, M., Ramakrishnan, V., Malhotra, V.M., "Effect of Retempering with Superplasticizer on Properties of Fresh and Hardened Concrete Mixed at Higher Ambient Temperatures", Proceedings Third International Conference, Ottowa, Canada, 1989

7) Kırca, Ö., Turanlı, L., Erdoğan, T.Y., Effect of Retempering on Consistency and Compressive Strength of Concrete Subjected to Prolonged Mixing, Cem. Concr. Res., 32, 2002, pp.441– 445.

8) Hampton, J. S., Extended Workability of Concrete Containing High-Range Water-Reducing Admixtures in Hot Weather., In Development in the Use of Superplasticizers. ACI Spec. Publ. SP 68, Detroit, 1981, pp. 409-22.

9) Soroka, I., Ravina, D., Hot Weather Concreting with Admixtures, Cement and Concrete Composites 20, 1998, pp.129-136

10) Kırca, Ö., Effects of Prolonged Mixing and Retempering on Properties of Ready-Mixed Concrete, M.Sc. Thesis in Civil Engineering Department at METU, Turkey, 2000

11) Dewar, J. D., The Workability of Ready-Mixed Concrete, RILEM, Leeds, U.K., 1973

12) Dewar, J. D., Manual of Ready- Mixed Concrete, Second Edition, Chapman & Hall, U.K.,1992

13) Başkoca, A., Özkul, M.H., Artırma, Ş., Effect of Chemical Admixtures on Workability and Strength Properties of Prolonged Agitated Concrete, Cement and Concrete Research, Vol. 28, No. 5, 1998, pp. 737–747

14) Dewar, J. D., Some Effects of Prolonged Agitation of Concrete, Cement and Concrete Association, TRA/137, 1962

15) Erlin, B., Hime, W. G., Concrete Slump Loss and Field Examples of Placement Problems, Concrete International, 1, No. 1, 1979, pp. 48-51.

16) Nishibayashi S., Yoshino A., Hideshima S., Takada M., Chikada T., "A Study on Superplasticized Concrete Containing High Volumes of Blast Furnace Slag", ACI SP-119, 1989, pp. 445-455.

17) Neville, A.M., Properties of Concrete, Longman Scientific &Technical, England, 1981

18) Mindess, S., Young, J.F., Concrete, Prentice Hall, Inc., New Jersey, 1981

19) Verbeck, G. J., Helmuth, R. A., Structures and Physical Properties of Cement Paste, Proc. 5th Int. Symp. on the Chemistry of Cement, Tokyo, Vol. 3, 1968, pp.1-32

20) Fattuhi, N. I., The Settings of Mortar Mixes Subjected to Different Temperatures, Cement and Concrete Research , 18 , No. 5 , 1988, pp. 669-73

21) Erdoğan, T.Y., Admixtures for Concrete, Metu Press, Ankara, Turkey, 1997

22) ASTM C 618-99, Standard Specifications for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete, Annual Book of ASTM Standards, 2001

23) ASTM C 125-00a, Terminology Relating to Concrete and Concrete Aggregates, Annual Book of ASTM Standards, 2001

24) Roy , D.M. , Luke , K. and Diamond , S. , "Characterization of Fly Ash and Its Reactions in Concrete," Proceedings , Materials Research Society, Pittsburgh, 1984

25) McCarthy, G.J., Swanson, K.D., Keller, L.P. and Blatter, W.C., Mineralogy of Western Fly Ash, Cement and Concrete Research, 14, No.4, 1984, pp.471-478.

26) Malhotra, V.M., Ramezanianpour, A.A., Fly Ash in Concrete, Second Edition, CANMET,1994

27) Ovens, P.L., “Fly Ash and Its Usage in Concrete”, Concrete: The Journal of the Concrete Society, 13, 1979, pp.21-26.

28) Helmuth, R.A., Water-Reducing Properties of Fly Ash in Cement Pastes, Mortars, and Concretes: Causes and Test Methods. In Proceedings, 2nd

CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, Madrid, Spain, Apr. 21-25, 1986. Edited by V.M. Malhotra. American Concrete Institute, Detroit, MI, Special Publication SP-91, 1986, pp. 723-737.

29) Pasko, T.J., and Larson, T.D., Some Statistical Analyses of the Strength and Durability of Fly Ash Concrete. Proceedings of the American Society for Testing and Materials, 62, 1962, pp. 1054-1067.

30) Brown, J.H., The Strength and Workability of Concrete with PFA Substitution. In Proceedings, International Symposium on the Use of PFA in Concrete, University of Leeds, Leeds, UK, APr. 14-16, 1982. Edited by J.G. Cabrera and A.R. Cusens. Department of Civil engineering, University of Leeds, Leeds, UK, 1982, pp. 151-161.

31) Ravina,D., Mehta, K., Properties of Fresh Concrete Containing Large Amounts of Fly Ash, Cem. Concr. Res.,16, 2,1986, pp.227, 238

32) Ravina,D., Soroka, I., "Slump Loss and Compessive Strength of Concrete Made with WRR and HRWR Admixtures and Subjected to Prolonged Mixing", Cement and Concrete Research, 24, No.8, 1994, pp.1455-1462,

33)Ramakrishnan, V., Coyle, W.V., Brown, J.,Tlutus, A., and Venkataramanujam, P., Performance Characteristics of Concretes Containing Fly Ash. In Proceedings, Symposium on Fly Ash Incorporation in Hydrated Cement Systems. Edited by S. Diamaond. Materials Research Society, Boston, MA, 1981, pp. 233-243.

34) CUR REPORT , Fly ash as addition to concrete, Centre for Civil Engineering Research and Codes, Report, Gouda, The Nedherlands, 1991, pp.99-144

35) Malhotra, V.M., Mehta, K., Pozzolanic and Cementitous Materials, Advances in Concrete Technology, V.1, Gordon and Breach Publishers, Amsterdam, Netherlands, 1996

36) Carette, G.G. and Malhotra, V.M. "Characterization of Canadian Fly Ashes and Their Performance in Concrete "; Division Report, MRP/MSL, CANMET, Energy, Mines and Resources Canada, 1984.

37) ACI Committee 211.1-81, Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete, ACI Manual of Concrete Practice No:211, 1984, pp.1-81.

38) Bamforth, P. B., In Situ Measurement of the Effect of Particle Portland Cement Replacement Using Either Fly Ash or Ground Granulated Blast Furnace Slag on the Performance of Mass Concrete. Proceedings of the Institution of Civil Engineers, 69, 1980, pp.777-800.

39) Yuan, R.L., and Cook, J.E., "Study of a Class C Fly Ash Concrete"; Proceedings, First International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-Products in Concrete; Editor: V.M. Malhotra, Montebello, Canada, July 31-August 5, 1983.

40) Raba, F. Jr., Smith, S.L., and Mearing, M. "Subbituminous Fly Ash Utilization in Concrete"; Proceedings, Symposium on Fly Ash Incorporation in Hydrated Cement Systems, Materials Research Society, Boston, 1981, pp. 296-306.

41) Mehta, P.K. "Influence of Fly Ash Characteristics on the Strength of Portland Cement-Fly Ash Mixtures"; Cement and Concrete Research, V.15, 1985, pp.669-674.

42) Virtanen, J. "Freeze-Thaw Resistance of Concrete Containing Blast-Furnace Slag , Fly Ash or Condensed Silica Fume"; Proceedings, First International

Conference in the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-Products in Concrete, Vol. 2, Montebello, Quebec, Canada, pp.923-942, 1983.

43) Reground, M., Structure and Behavior of Slag Portland Cement Hydrates, "Proceedings, International Congress on the Chemistry of Cements (Paris), Editions Septima, Vol. 1, Paris, 1980, pp.10-18.

44) Polya, G.,Szego, G., Isoperimetric Inequality in Mathematical Physics, Princeton University Press, Princeton, New Jersey, 1951

45) Lange, F., Mörtel, N., Rudert, V., Dense Packing of Cement Pates and Resulting Consequences on Mortar Properties, Cem. Conc. Res., 27 (10), 1997, pp.1481-1488

46) Collins, F., Sonjayor, J. G., Effects of Ultra-fine Materials on Workability and Strength of Concrete Containing Alkali Activated Slag as the Binder, Cem. Conc. Res., 29 , 1999, pp.459-462

47) Meusel, J. W., and Rose, J. H., "Production of Granulated Blast Furnace Slag at Sparrows Point, and the Workability and Strength Potential of Concrete Incorporating the Slag," Fly Ash, Silica Fume, Slag and Other Mineral By-Products in Concrete, SP-79, V. M. Malhotra, ed., American Concrete Institute, Farmington Hills, Mich., V. 1, 1983, pp. 867-890.

48) Fulton, F. S., "The Properties of Portland Cement Containing Milled Granulated Blast-Furnace Slag," Monograph, Portland Cement Institute, Johannesburg, 1974, pp. 4-46.

49) Wood, K., "Twenty Years of Experience with Slag Cement," Symposium on Slag Cement, University of Alabama, Birmingham, 1981

50) Transportation Research Board/National Research Council Committee on Chemical Additions and Admixtures for Concrete,"Admixtures and Ground Slag for Concrete," Transportation Research Circular, No.365, Dec.1990, 50p.

51) ACI 226.1 R-87, Ground Granuleted Blast-Furnace Slag as a Cementitious Constituent in Concrete, ACI Manual of Concrete Practice, Part 1: Materials and General Properties of Concrete, Detroit, Michigan

52) Lea, F. M., 1971, The Chemistry of Cement and Concrete, 3rd Edition, Chemical Publishing Co., New York, pp. 454-489.

53) Clear C.A. “Formwork Striking Times for Ground Granulated Blastfurnace Slag Concretes; Test and Site Results”, Proc. Instn. Civ. Engrs. Structs & Bldgs, 1994

54) Wu, X., and Roy, D. M., “Zeta Potential Investigation During Hydration of Slag Cement,” Proceedings, M.R.S. Symposium, Boston, Research Society, 1982

55) Osborne, G. J., “Carbonation and Permeability of Blast-Furnace Slag Cement Concretes from Field Structures,” Fly Ash, Slag and Natural Pozzolans in Concrete, SP-114, V.M. Malhotra, ed., American Concrete Institute, Farmington Hills, Mich., 1989, pp. 1209-1237.

56) Civil & Marine Slag Cement Limited, The Effects of Ground Granulated Blast Furnace Slag in Concrete, www.civilmarine.com, January 2005

57) Malhotra, V.M. “ Comparative Evolution of Three Different Granulated Slags in Concrete” Report MSL /87-50 (OP), CANMET, Energy, Mines and Resources, Canada, Ottowa, 1986

58) Hogan, F. J., and Meusel, J. W., “Evaluation for Durability and Strength Development of a Ground Granulated Blast-Furnace Slag,” Cement, Concrete, and Aggregates, V.3, No.1, Summer, 1981, pp. 40-52.

59) ACI 233R-03 Slag Cement in Concrete and Mortar, ACI Manual of Concrete Practice, Part 1: Materials and General Properties of Concrete, Detroit, Michigan

60) Malhotra, V. M., Properties of Fresh and Hardened Concrete Incorporating Ground Granulated Blast Furnace Slag. In Supplementary Cementing Materials for Concrete, Ottawa: Canadian Government Publishing Centre., 1987, pp. 291-331

61) Admixtures and Ground Slag for Concrete.. Transportation Research Circular no. 365 (December). Washington: Transportation Research Board, National Research Council, 1990

62) Roy, D. M., and Parker, K. M., “Microstructures and Properties of Granulated Slag-Portland Cement Blends at Normal and Elevated Temperatures,” Fly Ash, Silica Fume, Slag and Other Mineral By-Products in Concrete, SP-79, V. M. Malhotra, ed., American Concrete Institute, Farmington Hills, Mich., V. 1, 1983, pp. 397-414

63) Duboyov., V.S., et al. Effects of Ground Granulated Blast Furnace Slags on Some Properties of Pastes, Mortars, and Concretes, Blended Cements, Ed.G.Frohnsdorff, ASTM Sp. Tech. Publ. No.897, Philedelphia, Pa,1986, pp.29-48

64) Frigione, G., Manufacture and Characteristics of Portland- Blastfurnace Slag cements, Blended Cements, Ed. G. Frohnsdorff, ASTM Sp. Tech. Publ. No.897, Philedelphia, Pa,1986, pp.29-48

65) Mayfield, B. Properties of Pelletized Blastfurnace Slag Concrete, Mag. Conc. Res., 42, No.150, 1990, pp. 29-36

66) ACI 232.1R-00 Use of Raw or Processed Natural Pozzolans in Concrete, ACI Manual of Concrete Practice, Part 1: Materials and General Properties of Concrete, Detroit, Michigan

67) Calcination on Natural Pozzolans, Symposium on Use of Pozzolanic Materials in Mortars and Concretes, STP No.99, American Society for Testing and Materials, West Conshohocken, Pa., pp. 43-92.

68) Nicolaidis, N. "Santorin earth- an active admixture in Greek Portland Cements" Proceedings, Thirtieth International Congress of Industrial Chemistry", Athens, 1957

69) Turanli, L., Uzal, B., Bektaş, F., Effect of Material Characteristics on the Properties of Blended Cements Containing High Volumes of Natural Pozzolans, Cement and Concrete Research, V.34, 2004

70) Targan, Ş., Olgun, A., Erdoğan, Y., Sevinç, V., Influence of Natural Pozzolan, Colemanite are Waste, Bottom Ash, and Fly Ash and the Properties of Portland Cement, Cem. And Concr. Res., V.33, 2003, pp.1175-1182

71) Mehta, P.K, "Concrete : Structure, Properties, Materials"; Prentice Hall, Inc., 1986, p. 202

72) Townsend, C. L., "Control of Temperature Cracking in Mass Concrete," Causes, Mechanism, and Control of Cracking in Concrete, SP-20, American Concrete Institute, Farmington Hills, Mich., 1968, pp 119-139

73) Massazza, F., and Costa, V., "Aspects of the Pozzolanic Activity and Properties of Pozzolanic Cements," II Cemento 76: Jan.-Mar 1979, pp.3-18,

74) Elfert, R. J, "Bureau of Reclamation Experiences with Fly Ash and Other Pozzolans in Concrete," Information Circular No. 8640, U.S. Bureau of Mines, Washington, D.C., 1974, pp. 80-93.

75) Saad, M. N.A. de Andrade, W. P., and Paulon, V. A., "Properties of Mass Concrete Containing an Active Pozzolan Made from Clay," Concrete International, V. 4, No. 7, 1982, pp. 59-65.

76) Zhang, M. H., and Malhotra, V. M., "Characteristics of a Thermally Activated Alumino-Silicate Pozzolanic Material and its Use in Concrete," Cement and Concrete Research, V. 25, 1995, pp. 1713-1725.

77) Philleo, R. E., "Freezing and Thawing Resistance of High-Strength Concrete," NCHRP Synthesis of Highway Practice 129: TRB, National Research Council, Washington D.C., 1986

78) Ramachadran, V.S.,Concrete Admixtures Handbook, Noyes Publication, 1995

79) Mehta, P. K., "Studies on Blended Portland Cements Containing Santorin-Earth," Cement and Concrete Research, V. 11, 1981, pp. 507-518.

80) Heikal, M., El-Didamony, H., Ali, A.H., Pozzolanic Action of Homra With Lime, Indian J. Eng. Mater. Sci. 7, 2000, pp.154– 159.

81) Wild S, Gailius A, Hansen H, Pederson L, Szwabowski J., Copernicus research project: Recycling of Waste Clay Brick and Tile Material for the Partial Replacement of Cement in Concrete, Brussels: European Commission; 1998

82) Klimesch DS, Gutovic M, Ray A. Brick Waste a Supplementary Cementing Material in Autoclaved Building Products: International Conference on Role of Cement in Sustainable Development. in: Dhir RK, Newlands MD,

Csetenyi LG, editors. Proceedings of the International Symposium on Role of Cement Science in Sustainable Development. Scotland, UK: University of Dundee; 2003. pp. 283–90.

83) Gutovic, M., Klimesch, D.S., Ray, A., Strength Development in Autoclaved Blends Made with OPC and Clay-Brick Waste Construction and Building Materials v.19, 2005, pp.353–358

84) Farrell, M.O., Wild, S., Sabir, B.B., Pore Size Distribution and Compressive Strength of Waste Clay Brick Mortar, Cem. Concr. Compos. 23, 2001, pp. 81–91.

85) Erdoğdu, Şakir, Effect of Retempering with Superplasticizer Admixtures on Slump Loss and Compressive Strength of Concrete Subjected to Prolonged Mixing, Cement and Concrete Research, V.35, 2005, pp.907– 912

86) Ravina, D., Retempering of Prolonged Mixed Concrete with Admixtures in Hot Weather, Proc.t. ACZ, V.72, 1975, pp.291-295.

87) Ravina, D., Slump Loss of Fly Ash Concrete, Concrete Int., 6, 1984, pp.35-39

88) Al-Gahtani, H.J., Abbas, A.G.F., Al-Amoudi, O.S.B., Concrete Mixture Design for Hot Weather: Experimental and Statistical Analyses, Mag. Concr. Res. 50, 1998, pp.95–105.

89) Naik T.R., and Ramme, B.W. Effect of High-Lime Fly Ash Content on Water Demend, Time of Set, and Compresssive Strength of Concrete. ACI Materials Journal, 87, pp.619-626

90) Central Electricity Generating Board, pfa data book, 1967, Londan, UK

91) ACI 305R-99, Hot Weather Concreting, ACI Manual of Concrete Practice, Part 1: Materials and General Properties of Concrete, Detroit, Michigan