ANALYZING THE SETTING BEHAVIOUR OF SELF COMPACTING CONCRETE MANUFACTURED IN NORTH CYPRUS

A THESIS SUBMITED TO

THE GRADUATE SCHOOL OF APPLIED SCIENCES

OF

NEAR EAST UNIVERSITY

By

FAIZ HABIB ANWAR

In Partial Fulfillment of the Requirements for
The Degree of Master of Science
In
Civil Engineering

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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 materials and results to this work.

Name, Surname: FAIZ HABIB ANWAR

Signature:

Date:

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All praise is for ALLAH, lord of all that exists. Oh ALLAH, send prayers and salutations upon our beloved prophet Muhammad, his family, his companions and all those who follow his path until the last day.

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Dedicated to the loving memory of my late father, Dr Habib Ahmad Daba may his gentle soul rest in perfect peace, Ameen.

ABSTRACT

Self Compacting Concrete (SCC) is still an innovative concrete all around the world. It is able to flow through congested reinforcements and consolidate fully under its own weight due to its fluid nature. SCC is still a new concept in North Cyprus (NC) and thus, not much information on SCC manufactured locally in NC is available. Study on the behaviour of SCC particularly in its fresh state needs to be carried out under NC conditions in order to check for its performance and feasibility with NC conditions. Thus, setting behaviour of Self Compacting Paste (SCP) was evaluated in this study under NC conditions. This study also provided an insight on the compressive strengths of SCC mixtures manufactured using locally available materials in North Cyprus under two locally expected temperatures.

This study was carried out on SCP prepared using Cement I (Portland cement), Cement II (Portland Slag Cement) and superplasticisers locally obtained in North Cyprus. Four (4) pastes mixes were studied; mixture 01 (CEM II with admixture), mixture 02 (CEM I with admixture), mixture 03 (CEM II with no admixture) and mixture 04 (CEM I with no admixture).

Pastes setting behaviour show some differences when they were used with and without admixtures. One of the main findings of this study is that mixture of CEM II with admixture set faster than mixture of CEM I with admixture with approximately 2 hours difference at both temperatures despite the fact CEM I hydrates faster than CEM II without admixture. Thus, cement-admixture combination is very important, and therefore trial mixes should be made on the available materials for the manufacture of SCP in North Cyprus. Compressive strengths of SCC mixtures produced were also evaluated and it was found to be higher in mixture of CEM II with admixture and mixture of CEM I with admixture with approximately 100% increase compared to their corresponding control mixtures.

Keywords: *Self Compacting Concrete, Setting Behaviour, Concrete Material Availability in North Cyprus, cement-superplasticizers combinations, effect of temperature during concrete manufacture*

ÖZET

"Kendiliğinden Yerleşen Beton", tüm dünyada hala özellikleri araştırılan yeni bir beton tipidir. Bu beton tipi, akışkan niteliği ile donatılar arasından rahatlılkla akarak, kendi ağırlığının etkisi altında tamamen yerleşebilme özelliğine sahiptir. Kendiliğinden yerleşen beton, Kuzey Kıbrıs'ta daha yeni üretilmeye başlanmış, ve bu nedenle de malzemelerin bu tür beton üretimi için uygunluğunu inceleyen çok sayıda çalışma bulunmamaktadır. Bu çalışma, Kuzey Kıbrıs'ta yerel malzemeler ile üretilmiş "Kendiliğinden Yerleşen Beton"un ülke şartları (özellikle sıcaklık) altındaki davranışını içermektedir.

Yürütülen çalışmada Tip I çimento (Normal PÇ) ile Tip II çimento (Cürüflu Çimento), ülkede temin edilebilen süperakışkanlaştırıcı katkı maddelerı ile kullanılmıştır

Çalışmada varılan en öremli bulgulardan bir taresi ise tek başına kullanıldığında yavaş priz aldığı bilinen. Tip II çimentonun mevcut katkı maddeleri ile kullanıldığında, Tip I (Normal) Portland çirentoya kıyasla çok daha erken priz aldığının gözlemlenmesidir. Bu nedenle, Kuzey Kıbrıs'ta yerel malzemelerle üretilecek "Kendiliğinden Yerleşen Beton"lar için çimento- katkı maddesi kombinasyonunun önceden araştırılması kritik önem taşımaktadır.

Çalışmada üretilen karışımların basınç dayanımları da ayrıca incelenmiştir. Her iki tip çimentonun da katkı malzemeleri ile kullanımı daha yüksek basına dayanımı kazanılmasına yardımcı olmuştur.

Anahtar Kelimeler: *Kendiliğinden Yerleşen Beton, Priz alma davranışı, Kuzey Kıbris'taki mevcut beton malzemeleri, Çimento-süperakışkanlaştırıcı kombinasyonları, Beton dökümünde sıcaklık etkisi.*

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SCC	Self Compacting Concrete
SCP	Self Compacting Paste
ST	Setting Time
SD	Standard Deviation
NC	North Cyprus

CHAPTER ONE

INTRODUCTION

1.1 Overview of Self Compacting Concrete

In most civil engineering works, structures are constructed basically using two commonly known structural materials; steel and concrete. Steel can be defined as structural material made from iron and manufactured based on some given properties and standards. Concrete being the most popular known structural material can be defined as a composite construction material made by the use of cementing materials as well as, aggregate (fine and coarse), and water. In the case where a special property is needed, additions and admixtures are added in a measured proportion to the concrete mix to modify its original properties. Good knowledge of concrete and its constituents is therefore very vital, as most constructions are being carried out using concrete. Handling, transportation, placing, compaction and curing are some of the operations involved in concrete that affect the ultimate quality of concrete.

Compaction being one of the vital processes involved in concreting operation poses some problems which are mainly due to poor compaction:

1. Decrease in the ultimate strength of the hardened concrete.

2. Decrease in the long term durability as high porosity would imply high permeability.

As a result of the latest advancement in concrete technology, a special type of concrete that is able overcome the above problems, flow through reinforcements and consolidate fully under its own weight is produced. This type of concrete is called Self Compacting Concrete.

Self-compacting Concrete is an innovative concrete mix that is able to flow through congested reinforcements and consolidate fully under its own weight. It’s highly fluid nature makes it suitable for placing in difficult conditions and in sections with complex and congested reinforcements to fill all available spaces within the formwork without the need of any vibration either manually or mechanically. It is also referred as Self Consolidating Concrete and Self Leveling Concrete (Neville and Brooks, 2010).

Good SCC can be achieved by the use of finer aggregate to avoid blockage, use of viscosity modifying agents to maintains stability, use of superplasticizers to achieve high fluid concrete mix, low water/cement ratio and good shape and gradation of aggregates.

1.2 Significance of Setting Time

In most constructions involving concreting, many activities are involved which occur in series with time period of completion attached. Setting is a stage which plays an important role in the overall completion period. Time and method of curing depends on the setting time of the concrete. Additionally, setting times can give some indication of whether or not cement is undergoing normal hydration. Practical significance of setting time can be best seen in the following:

1. Curing and Hardening
2. Strength gain and formwork removal

The above processes tend to be dependent on the setting process. Thus, setting behaviour of concrete is very vital in concrete constructions. Some significant differences can be observed in setting behaviour of pastes prepared from different SCC mixtures due to interaction between the different constituent's materials in the mixtures. Change in setting time may be observed between the cement pastes prepared from different SCC mixtures, as different types of cements and admixtures can be used in the manufacture of SCC.

1.3 Previous Study

Several studies have been carried out on setting time of cement paste and concrete mostly with normal mix condition (normal cement paste and concrete). Nevertheless, some few studies have been carried out on setting time of Self Compacting Paste (SCP) mostly using advanced method of setting time measurement; no studies were carried out on setting time of SCP using Vicat and/or Gilmore approach. Two studies that have been conducted on measuring and predicting setting time of SCP are discussed below.

1. Prannoy Suraneni from university of Illinois, Urbana conducted a research on setting time of self compacting pastes (SCP) and SCC using Ultrasonic Wave Reflection measurements. The study was aimed at using longitudinal P-wave and Shear S-wave Ultrasonic wave reflection to measure the setting and stiffening of self compacting pastes and concrete. Standard penetration measurements were also conducted and the results were compared with the S-wave and P-wave results. The effect of superplasticizers and fly ash were found to increase the time of set and water/cement ratio was found to have a linear relationship with the time of set, thus, time of set also increased with increase in water/cement ratio. Results from both reflections were found to be similar. Initial set from S-wave has shown some slight differences from the penetration test while final set from the ultrasonic wave reflections was found to be similar with penetration test (Suraneni, 2011).

2. Another study on setting time of self compacting concrete was conducted by Akhmad Suryadi and Triwulan Puji Aji from Supuluh Nopember Institute of Technology, Surubaya. The study was aimed at whether using Artificial Neural Networks (ANNs) will be a feasible tool in predicting initial setting time of self compacting concrete. Results from the study proved that setting time of self compacting concrete can be predicted using Artificial Neural Networks (ANNs) (Suryadi et al, 2011).

1.4 Need for the Study

SCC is a new concrete in North Cyprus and so, there are no available studies to show if the available materials are adequate to manufacture SCC in North Cyprus or if SCC made from the available materials would have a good performance under North Cyprus conditions. As seen earlier, studies on setting time have been carried out using different approach and special knowledge is needed in conducting those tests. Study on setting behaviour of SCP using the one of the known laboratory methods of measuring setting time will provide insight in cement and concrete studies. Using Vicat apparatus Method will ease the measurement as it can be carried out easily within some limited period of time. The study will be aimed at analyzing the setting behaviour of SCC manufactured in North Cyprus. It will provide information regarding setting processes based on materials available and temperature condition of North Cyprus.

1.5 Structure of the Study

This study has a main focus of investigating the setting behaviour of SCC manufactured in North Cyprus. The study will be carried out based on the SCC mix design currently used by one of the leading companies in North Cyprus (Tüfekçi Company) and other supplementary mix designs aiming to control the effect of other parameters. In this study, the most common type of cement used in North Cyprus (CEM II/B-S: Portland Slag Cement) and the most common type of cement found in most part of the world (CEM I: Ordinary Portland Cement) will be used together with admixtures (available in North Cyprus) for pastes and concrete mixtures. Setting time test using Vicat apparatus Method will be carried out under North Cyprus temperature conditions (high and low) on the prepared pastes and then compared. Compressive strength of SCC mixtures to be manufactured will also be measured and compared.

CHAPTER TWO

LITERATURE REVIEW

This Chapter will discuss on the literature of SCC; history of SCC, materials used in SCC, categories of SCC, properties of SCC, test methods for SCC, general mix design employed, manufacture of SCC, advantages and limitations of SCC. It will further discuss on setting time and its significance.

2.1 Overview of Concrete

Use of concrete in civil engineering constructions has proven to provide a beneficial role in both economic and commercial aspect. Concrete being it a composite material is preferred and more practical to be used. The use of cement paste only is not practical and will lead to many structural problems, thus, mixing cement paste with measured amount of aggregate produces a more durable concrete, less prone to shrinkage, less heat generated, less prone to chemical attack and is more economical as volume is increased with the addition of aggregates. Concrete specification needed for a given structure may not be the same as specification needed for another. This gives diversity in the use of concrete in civil engineering construction as different properties and specifications can be used to obtain varieties of concrete to be used in different projects. For instance, when durability is the first priority in a given work, cement content, type of cement, aggregates and water/cement ratio will be the prime factors to be considered (Neville and Brooks, 2010).

Many processes are involved in concreting operation; mixing, transporting, placing, compaction and curing. Compaction is one the key processes whereby the fluid concrete mass is compressed so as to remove the entrapped air and have more aggregate packing to achieve a more dense mass of concrete(Neville and Brooks, 2010). Compaction has two stages; aggregate set in motion and removal of the air trapped. Compaction depends on shape and gradation of the aggregates and is achieved by the process of vibration. During the mixing process, air is entrapped in the concrete which reduces the strength by some certain amount, thus, compaction is necessary in order to achieve maximum ultimate strength, durability and bond between the concrete and reinforcements. Poor compaction leads to many problems in the concrete which affect the overall performance of the structure.

2.2 History of Self Compacting Concrete

Due to the problem of poor compaction, a special type of concrete which has the ability to flow and consolidate fully due to its own self weight was developed known as Self Compacting Concrete. SCC is an advanced construction material which is able to flow through heavy and congested reinforcement and consolidate fully under its own weight completely filling the formwork. Its highly fluid nature makes it suitable for placing in difficult conditions and in sections with complex and congested reinforcements (Neville and Brooks, 2010). Consolidation is fully achieved due to its own self-weigh and is found to offer some economic, social and environmental benefits over the normal vibrated concrete in construction.

SCC first came to existence in 1980’s in Japan due to some problems within the construction industries. Problems were faced in construction using normal vibrated concrete which necessitated the development of a special type of concrete that will overcome such problems. Lack of uniform and complete compaction is one of the main problems which led to poor performance of most concrete structures since full compaction within heavy reinforcement and completely filled formwork was not guaranteed (Okaruma and Ouchi, 2003). Furthermore, there was gradual decrease in number of skilled worker in construction industries, thus, producing a durable concrete structure without the need to employ more skilled workers was also a prime objective in the construction industries in Japan. These reasons led to the development of a concrete which needs few skilled workers and is able to compact and consolidate due to its own weight without the need of external compaction (Neville, 2002). Since its development, the concrete has been used in concrete structures by large construction companies to improve long term durability with limited number of skilled workers.

The need for the development of SCC was put forward by Prof. Hajime Okamura of university of Tokyo in 1986. Further studies mainly on its workability were carried out by Ozawa and Maekawa from the same university. The first SCC was produced in 1988 using the already known materials and technologies employed in high workability concrete and concrete used for underwater constructions (Okaruma and Ouchi, 2003).

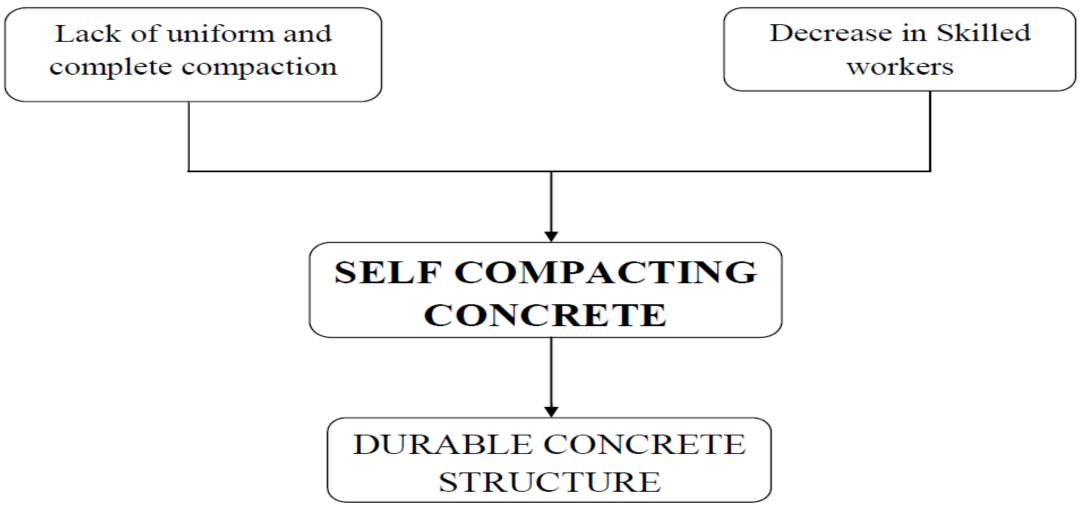


Fig. 2.1: Necessity for Self Compacting Concrete

Due to its performance with regards to some of its hardened properties such as drying/hardening, shrinkage and heat of hydration, and based on following stages it undergone from the fresh state to the hardened state, it was first given a name "High Performance Concrete". These stages are (Okaruma and Ouchi, 2003):

- Fresh Stage: Self Compactibility
- Early Stage: Avoidance of defects
- Hardened Stage: protection against external factors

Furthermore, it was also regarded as concrete with high durability due to its low water/cement ratio (Neville, 2002). After the discovery of SCC by the researchers in Japan, large construction companies took over the idea and concept. Each company used its own in-house research and development facilities and brought forth its new SCC knowledge and technologies based on their own mix design ratio and testing methods. Skilled workers were also trained by these companies as technicians for handling SCC in large constructions.

Several publications were carried out on SCC since its existence around 1988 and most of these publications focused on the fresh properties (filling ability, passing ability and segregation resistance), design models, mix constituents and rheology. The first publication was carried out at university of Tokyo in 1992 where a high performance concrete was produced which possessed similar properties with today's SCC (Goodier, 2003). Furthermore, subsequent research papers were published; “super-workable concrete”, “self-consolidating concrete”, “highly-workable concrete”, “self-placeable concrete” and “highly fluidized concrete” all with similar properties with today's SCC. The first paper on the actual application of SCC was published in Japan in 1995 followed by a subcommittee set up by Japanese Society of Civil Engineers (JSCE) in 1997 to establish recommendations for the practical application of SCC which was published in 1999(Goodier, 2003). First International workshop on SCC was held at Kochi University of Technology Japan in 1998 which focused on SCC development in different countries with regard to mix design and rheology. The second international workshop was held at the University of Tokyo in 2001 which focused on the durability of SCC and its overall cost in construction.

A conference on Concrete Structures in the 21th Century was held in 2002 in Japan and contained 6 publications on SCC all focused on extending SCC knowledge to new application such as composite structures and sheet piling(Goodier, 2003). Furthermore, organizations across the world mainly from Europe have taken research on its properties and its use, thus, putting to practice in construction industries. In the early 1990's there was only limited knowledge about this type of concrete which was mainly within Japan. The fundamental and methodology was hidden by the large construction companies to achieve commercial benefits. Many trade names were given to this type of concrete by different companies. Kajima Co used NVC (Non-vibrated concrete) and Maeda Co used SQC (Super quality concrete) (Okaruma and Ouchi, 2003).

In Europe, the development of SCC started from the Scandinavian countries particularly Sweden in early 1990's and several publications were carried out. Some of these publications include papers presented on mix design models by Swedish Cement and Concrete Research Institute (CBI). Further works include a work on SCC use in housing carried out by CBI where half-scaled house walls were casted using different filler materials (Goodier, 2003). Further researches were made for the mix design and underwater construction and this led to the discovery of in-cooperating admixtures in the SCC mixes which produced a satisfactory performance as the SCC developed in Japan. Further researches were carried out by different organisation and international bodies across the world, private companies carried out research mainly for product development (Commercial purpose), educational institutes carried out the research mainly for material properties (pure research); Brite-EuRam projects for test methods and RILEM (International Union of Testing and Research Laboratories of Materials and Structures) projects for casting of SCC (Goodier, 2003).

The CBI and Swedish National Road Authority (SNRA) worked together on SCC for bridge construction where all tests and trials were carried out. It was first used in the construction of a transportation system in Sweden in the mid 1990's (Stegnaier, 2005). In the bridge project, it was found that the hardened properties of SCC are superior to that of normal vibrated concrete and the overall cost of the bridge construction was reduced by 5-15%.

The CBI project (SCC use for housing) led to the first European project carried out by a multi-national, industry lead project "Brite EuRam project" from 1997 and ended in 2000 and since then SCC has found its increasing use in all European countries(EFNARC, 2005). The project was aimed at developing a new-vibration free production system to lower the overall cost of concrete construction and consisted two parts; the first part was the development of SCC with or without steel fibers and the second part focused on full-scale experiment in civil engineering constructions.

The development of SCC in Europe extended from Sweden and began to spread to other European countries such as France, Germany, Switzerland, Italy, Belgium, Spain, Holland, Greece, Czech Republic and UK. Further work was carried out to develop test methods for

SCC to meet the European standardization from 2001 to 2004 by 12 European partners led by University of paisley, Scotland. SCC development and knowledge are increasing across the world as many publications are going on and codes for the use of SCC are being developed by American Concrete Institute (ACI) and American Society for Testing and Materials (ASTM).

Fig 2.2: First Bridge with SCC in Sweden (Goodier, 2003)

2.3 Constituents Used in SCC

Composition of materials used in SCC are almost the same as those used in normal vibrated concrete except for some modifications due to its self compactibility property which include differences in the proportion of aggregate (fine and coarse) with that of normal vibrated concrete. Admixtures such as viscosity-modifying agent (VMA) and superplasticisers are added in small quantities due to some variations in the amount of water or in the proportions of aggregate to maintain stability. The use of water reducers (HRWR, super-plasticizers) may also be required in maintaining low water/powder ratio in the concrete mix.

Size, shape and gradation of aggregate also affect the behavior of SCC. SCC can be produced with different aggregate sizes but the finer the aggregate the more flowable the concrete and less effect of segregation. Furthermore, better grading (particle size distribution) yields better results with reduced superplasticizers dosage and volume of paste.

Better packing gives more dense concrete mass with fewer voids and also has an effect on the fresh properties with less effect on the final strength. Naturally Rounded aggregates are preferred than angular and elongated aggregates to achieve full self compactibility and flowability but crushed aggregate has a beneficial effect on the strength of concrete. The finely powdered materials used are fly ash, silica fume, lime stone powder, glass filler and quartzite filler as additives. Pozzolanic materials help the SCC to flow better where their reaction in SCC as well as in normal vibrated concrete provides more durable concrete to permeability and chemical attacks. The constituent materials used in an ordinary SCC are:

2.3.1 Aggregates

In concreting operations, about ¾ of the concrete volume contains aggregate, thus, concrete cannot be produced without measured amount of aggregates. SCC being it an innovative concrete also contains both the fine and coarse aggregate just the same way as the normal vibrated concrete. Aggregates offer some economic and technical benefits in concrete due to their physical, chemical and thermal properties. They are well known to be cheaper than cement thus incorporating aggregates with cement paste reduces the overall cost of the concrete. Furthermore, mixing the cement paste with a measured amount of aggregates increases the overall volume stability, having a cohesive mix and thus increase in durability(Neville and Brooks, 2010). As stated earlier, aggregates in SCC differ in proportion with that of the normal vibrated concrete. There some factors that affect the choice of an aggregates in SCC. These are:

1. Moisture content and water absorption: aggregates may be saturated or surface- dry when mixed with cement paste due to the excess water in the paste. This is due to some considerable amount of water being held at their surface over some period of time where the fine aggregates hold water on the surface more than the coarse

aggregates. On the other hand, water absorption is the amount of water contained in an aggregate both in saturated and in surface-dry conditions and the total water content of an aggregate will be the summation of moisture content and water absorption. SCC being a concrete with less tolerance to variation in the amount of water needs to be carefully monitored as more fine aggregates and low water/powder ratio are needed.

2. Shape and Gradation: aggregate's origin and process of formation affect the final shape of aggregate formed as many processes take place on the parent rock (origin). These processes may be physical and/or mechanical. The physical processes are weathering and abrasion while the mechanical process is usually crushing. Many shapes are formed due to this processes which include rounded, angular, elongated, irregular and flaky. Careful choice needs to be made in SCC in order to have a good passing ability, thus, rounded aggregate are preferred to be normally used in SCC. On the other hand, gradation refers to the particle size distribution in concrete which normally contains two forms, fine and coarse. Good gradation in SCC will produce a concrete with good passing ability and resistance to segregation as poorly graded concrete will contain more voids and will need more superplasticer dosage.

3. Variations of the fine material: there are basically three types of fine materials present in aggregates; clay, silt and dust. These fine materials have a great effect on the bond between the aggregate and cement paste as good bond is necessary in order to have a required durability and strength. These materials may form a coating well or loosely bonded to the aggregate or in the form of loose particles. They interfere with the bond between the aggregate and cement paste. Shrinkage may also be resulted and may lead to increase in the amount of water needed in the concrete especially in their loose form. Increase in the amount of water in SCC may lead to problem in one or more of its fresh properties thus, it is necessary to control the clay, silt and dust content in SCC aggregates.

In SCC, amount and size of coarse aggregates to be used should be maintained to ensure cohesion and bond strength between the particles. These also affect the aggregate packing and voids content. Different sizes of coarse aggregates can be used in SCC which depends on the application of the final structure. Aggregate size of (16 – 20) mm are the commonly used for coarse aggregate in SCC which include gravels and lightweight aggregates. In some rare cases of huge construction mostly bridges, 40mm sized aggregates can be used as in the case of Akashi-kaikyo Suspension bridge in Japan. Generally as concrete is considered to be a two phase material (mortar and aggregate), SCC is not an exceptional, and thus the coarse aggregates do have some effects on the fresh properties of SCC. The spacing between reinforcement is the main determining factor for maximum aggregate size thus coarse aggregate defined in EN12620 are suitable for SCC. There is no exception on the size of fine aggregates to be used thus, the most common sizes of fine aggregate (usually less than 5mm) used in normal concrete can also be used in SCC with the above factors taken into consideration(Liu, 2009).

Generally, local availability influences the type of aggregate to be used. Naturally rounded aggregates (spherical) are preferred than the crushed and elongated aggregates to achieve full self compactibility and flowability despite the fact that crushed aggregates have a positive effect on the overall strength of concrete. Lightweight aggregate needs more viscosity as they tend to float thus needs more viscosity modifying agents (VMA). Aggregates from recycled concrete are also used in SCC but they do tend to influence the filling ability as their water absorption is not consistent (Rafat and Aggarmal, 2008). Furthermore, blockage may occur if the spacing between the reinforcement is small compared to the aggregate size used. Alternatively, there will be no blockage when the total volume of the coarse aggregate in the concrete mixture is not morethan 32% of the total concrete volume. A value of 35% is accepted when there is good shape and well graded concrete mixture (Rafat and Aggarmal, 2008). Table 2.1 shows some of the properties of both coarse and fine aggregates that are normally used in the production of SCC.

Table 2.1: Properties of Coarse and Fine Aggregates (Rafat and Aggarmal, 2008)

PROPERTIES	FINE AGGEREGATE	COARSE AGGEREGATE
Specific Gravity	2.66	2.67
Fineness Modulus	2.32	6.86
Bulk Density (kg/m^3)	1780	1540

Specific gravity is the ratio of the weight of a given volume of solid material to the weight of equal volume of distilled water at a given temperature. Differences in specific gravity of aggregate may be used to track and remove some deleterious materials present in an aggregate.

Fineness modulus is an index that defines the summation of cumulative percentage of particles retained on a standard sieve divided by 100 and is used in estimating the quantity of coarse aggregate to be used in a given concrete mix design.

Bulk density is defined as mass per unit volume of a bulk aggregate materials where by the volume include volume of the individual particles and volume of voids between the particles.

2.3.2 Powder Materials

Powder materials are the smallest fine solid materials in concrete which have a great effect on the fresh and hardened properties of the concrete. The materials consist of cement and additions. SCC requires high powder content when compared with the normal vibrated concrete in order to fill the voids between the aggregates and help in greater collision between the aggregates. The packing of the powder material is an important requirement to achieve a satisfactory concrete mix which depends on the shape, size and behavior during mixing. The acceptable powder sizes depends on standards as Europe uses a size of less than 125µm while Japan uses a size of less than 90µm but a size of 100µm powder material is a general accepted value which plays an important role in the filling ability and segregation resistance(Rafat and Aggarmal, 2008).

Segregation is greatly reduced using fine materials than the coarse materials due to their high water retention property but using a fine material less than 20μm requires high dosage of superplasticizers

1 Cement

Almost all type of Portland cement can be used in the production of SCC. In many cases, the choice depends on specific requirement. The composition of cement affects SCC performance as superplasticisers are first absorbed by the C_3A and C_4AF in the cement during mixing thus dispersion characteristics of superplasticizers depend on the content of C_3A and C_4AF in the cement. The C_3A and C_4AF content also affect retention property due to their initial rapid hydration (Liu, 2009)

2 Additions

SCC produced only from cement are susceptible to attack by thermal cracking and are expensive, thus, some percentage of the cement must be replaced by finely powder materials known as additions. These additions are finely powdered materials used to improve or modify certain property as it helps to reduce heat of hydration and thermal cracking by regulating the cement content. It also helps in improving cohesion and segregation resistance.

They may be inert or semi-inert which include fly ash and limestone. Most common additions used are type II known as pozzolanic addition (Fly ash and silica fumes) which in itself possesses little or no cementitious property but when in the presence of moisture in powdered form and at ordinary temperature reacts with lime (calcium hydroxide) to form components having cementitious property(Liu, 2009).

When additions are added, pozzolanic reactions takes place where the lime (calcium hydroxide) reacts with SIO_2 and AL_2O_3 from the pozolana to produce silicates and hydrates of calcium and aluminum respectively. This pozzolanic reaction helps in filling the voids thus improving the bond strength between the paste and aggregates. It also helps in lowering the permeability thus increasing the overall strength and durability, reduces the shrinkage and prevention against chemical attack.

Some of the common type II additions used which may be pozzolanic or hydraulic are fly ash, Silica fume and Ground granulated blast furnace slag

Silica Fume: shape and size of silica fume result in some positive effects in SCC paste. Its spherical shape and high fineness give a good cohesion property with good segregation resistance. On the other hand, cold joints may be produced due to rapid surface hardening.

Fly Ash: it also results in some positive effects just like the silica fume where the cohesion is increased but the high cohesive property may cause flow resistance in the paste.

Ground Granulated blast slag (ggbs): mostly found in Portland cement (CEM II and CEM III) which helps in reducing heat of hydration. In some region, it is added during the mixing stage as an addition. High amount of ggbs may result in instability which may cause problem of inconsistency.

Other additions added in order to achieve a good SCC paste include metakaolin, natural pozzolana, ground glass, air cooled slag, and mineral fillers

Table 2.2: Reactivity of Addition (EFNARC, 2005)

TYPE I	Inert and Semi Inert	Mineral filler (limestone) Pigments
TYPE II	Pozzolanic	Fly Ash conforming to EN 450 Silica fumes conforming to EN 13263
	Hydraulic	Ground Granulated blast furnace slag (ggbs)

2.3.3 Admixtures

These are also added to improve and/or modify certain properties where chemical admixtures are preferred. The choice of admixtures on the SCC and absorption capacity depends on amount of certain compounds such as carbon contents, Alkalis and C_3A. Fineness can also have an effect of the type of admixtures to be used. In addition to these, physical and chemical properties of binder may also influence the type of admixtures, and thus compatibility has to be taken into consideration (Rafat and Aggarmal, 2008). The most common admixtures used in SCC are High Range Water Reducing Admixture (HRWRA) or Superplasticisers and Viscosity-Modifying Agent (VMA).

Superplasticizers help in water reduction thus achieving excellent flow with good fluidity. It also helps in dispersing effect during transportation and application. Inorganic Superplasticisers are commonly used which are divided into two categories depending on their reaction mechanism on the particle. Both of these categories give the paste a good consistence retention property through electrostatic repulsion forces and steric repulsion forces induced on the particles. There are the superplasticisers which result in electrostatic repulsive forces by generating a negative charge on the particles thus causing dispersion. The steric repulsion based superplasticisers are weaker than the former as they produce a thick layer on cement particles with some negative charge causing dispersion. Temperature, powder contents, mixing methods and water contents tend to affect the absorption of superplasticisers which in turn affect the overall consistence performance of SCC. Superplasticisers tend to delay the setting time by slowing down the rate of hydration reaction.

Viscosity Modifying Agent (VMA) reduces bleeding, segregation and helps in improving the stability of the concrete mixture by increasing the cohesion. Sufficient VMA can also bring down the powder requirement thus achieving the required stability. VMA are also divided into two depending on the reaction mechanism (Absorption Characteristics) in the SCC paste. There are the absorptive VMA that have their effect on cement particles thus increasing the viscosity of the concrete. The amount of absorptive VMA used affect the presence of superplasticisers, the greater the Absorptive VMA, the less superplasticisers absorbed thus loss in consistency. There are also the non-absorptive VMA that have their effect on water thus increasing the plastic viscosity. In this type, the amount used have no effect on the presence of superplasticisers used thus consistency is retained. With this unique property, sufficient amount of non-absoptive VMA with suitable superplasticisers can be used to produce a good SCC with required filling and passing ability. Since the amount of absorptive VMA added has an effect on the superplasticisers used, compactibility between these two is a very important criteria for producing a good consistence SCC paste. Some absorptive VMA show poor SCC paste with some given superplasticisers as cellulose-derivative VMAs were found to be incompatible with naphthalene-based superplasticers(EFNARC, 2005). With this effect of loss of consistency, powder-type SCC are preferred than VMA-type SCC as more superplasticers are required to compensate the effect of consistency loss due to VMAs. VMAs are found to delay the setting time of SCC by slowing the rate of hydration reaction, its early strength of the final strength.

Other materials used in producing SCC are pigments, fibres and water. Pigments are used to achieve an acceptable colour density. Care should be taken when using pigments as it can affect its properties thus trials are necessary. In the same vein, fibres are needed in the mix proportion as it helps in its stability. Care should be taken as it might hinder the flow within the reinforcements.

2.3.4 Water

Water plays a vital role on SCC paste on both the fresh and the hardened properties. Water decreases both the yield stress and the plastic viscosity. Concrete is much more prone to segregation if only water is added to increase the filling ability. Because of this, SCC could not have been developed until suitable superplasticisers were produced.

Too much water also leads to undesirable effects on strength and durability. That is, too small and too large W/P ratios both result in poor filling ability Water in the fresh concrete includes freely movable water and the water retained by the powder (additions and cement), sand and VMA. Coarse aggregate does not confine water. It is the free water that controls the performance of SCC. Free water is one of the main factors determining the filling ability and segregation resistance. The moisture variation in sand of 3~4% led to a W/C ratio variation of ± 0.1. It is therefore important to correctly estimate aggregate's moisture content (Liu, 2009). Testing-SCC project recommended that the moisture content of aggregates should be more than the level of SSD. Water content is another important factor to maintain consistence retention besides superplasticisers types; that is, the higher the W/C ratio, the lower the consistence loss for the same initial consistence

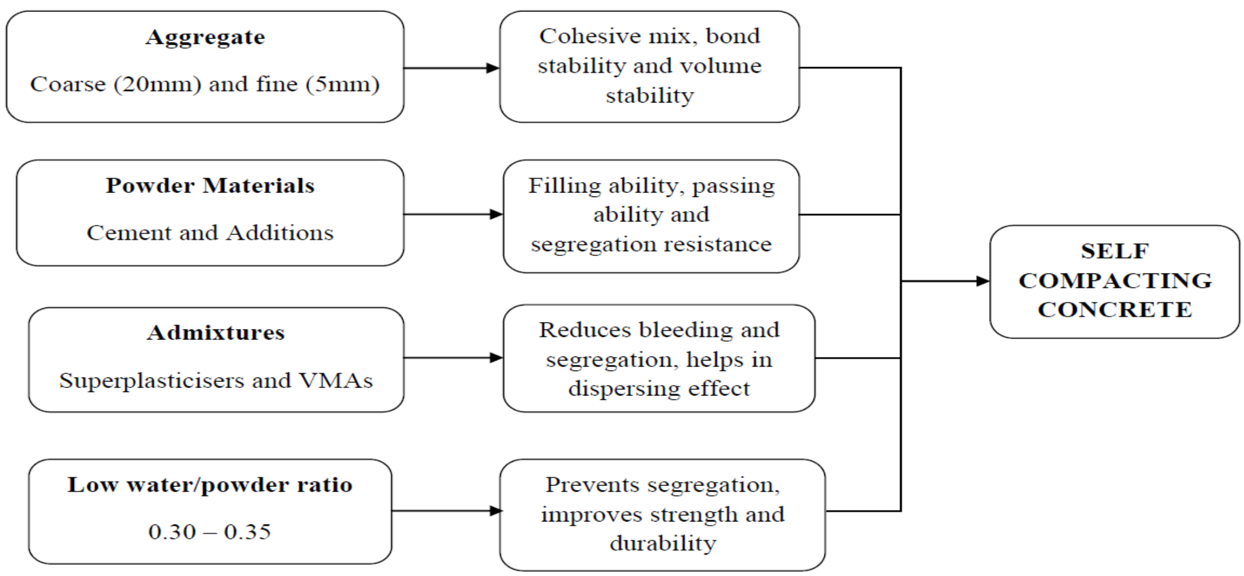


Fig 2.3: Typical SCC Mix Composition

2.3.5 Categories of SCC

SCC has some distinctive properties both in fresh and hardened state just like normal vibrated concrete. In SCC, the fresh properties are the more critical properties to be considered so as the concrete to achieve its purpose of self compactibility. These properties vary by the available categories of SCC. The following are the available SCC categories which depend on the presence of Viscosity Modifying Agents (VMA) (Liu, 2009)

1. Powder SCC: known for its high powder content, low water/powder ratio with the addition of superplasticisers to achieve both consistency and plastic viscously.
2. VMA SCC: known for its high VMA content and high superplasticisers dosage to achieve both plastic viscosity and passing ability with high water/powder ratio compared to powder SCC. The powder content is lower in VMA SCC than in powder SCC.
3. Combined SCC: known to be a mixture of powder type with small amount of VMA so as to improve the strength of powder SCC. Both the powder and water/powder ratio contents are less than in powder SCC.

Table 2.3: Categories of SCC

CATEGORIES	POWDER CONTENT	SUPERPLASTICISERS	VMAs	WATER/POWDER RATIO
Powder SCC	High	Low	Low	Low
VMA SCC	Low	High	High	High
Combined SCC	Low	Low	Low	Low

2.4 Properties of SCC

2.4.1 Fresh Properties of SCC

The main characteristics and performance of SCC are influence its properties in its fresh state. The fresh properties of SCC are generally influenced by the variation of some factors such as fineness and moisture content of the aggregates, type of superplasticiser and changes in the surrounding conditions such as temperature and humidity

SCC mix design is focused on the ability to flow under its own weight without the need of manual or mechanical vibration, ability to flow through heavily congested reinforcement, and the ability to obtain homogeneity without segregation. In order to achieve the above purposes, SCC must have certain properties in its fresh state. These properties include filling ability, passing ability, segregation resistance, robustness and consistence retention(Liu, 2009). The first three are the vital properties which are interdependent. A slight variation in one property may cause a corresponding change in the other two properties.

1 Filling Ability

Filling ability defines the ability of SCC to deform (change shape) and to be able to fill the formwork completely under its own weight. This mechanism has two phases; deformation capacity which relates to the distance it can flow and deformation velocity which relates to the time it will take for the flowing, thus, to achieve good filling ability, the two phases must occur concurrently (Liu, 2009). In order to have SCC mix with a good filling ability, a proper size, shape and gradation must be done as this influence the filling ability. Use of superplasticisers with low coarse aggregate contents should be employed to reduce the inter-particle friction among the particles by dispersing cement particles. The filling ability may vary with application as the filling ability required in columns may be different from that required in beams (Liu, 2009)

2 Passing Ability

Passing ability defines the ability of SCC to overcome obstacles under its own weight without hindrance, this determines the ability of the SCC mix to pass through complex, constricted openings and spaces of the reinforcements without any blockage (resistance to blockage). It is recommended that the ratio of the aggregate size to the opening size should be at least 1:2 to avoid blockage. Special laboratory test are employed to determine the passing ability of SCC mix. As discussed earlier, size, shape and gradation play a vital role in SCC to achieve its self compactibility. The use of fine powder material with low coarse aggregates and viscosity modifying agents yields a good passing ability with increased viscosity leading to better distribution and particle packing(EFNARC, 2005).

3 Segregation Resistance

Resistance to segregation both during and/or after transportation and placing processes can be referred as the requirement of SCC mix to have a dynamic stability in its fresh state. The SCC mix has to be homogenous throughout the mixing stage as it contains different type and sizes of materials with differences in their specific gravities. Segregation can take different phases; it can be between aggregates and paste or between water and paste which can be in dynamic or static form. Dynamic segregation occurs during the mixing stage while the static occurs after the mixing as the aggregates settle below while water rises thus causing bleeding which leads to low strength and durability. Use of viscosity modifying agents coupled with high fine powder content with low water/powder ratio lead to increase in viscosity, having a homogenous paste, thus, and reducing segregation(EFNARC, 2005).

4 Robustness in SCC

This is the ability of the concrete to maintain and resist any change in one of the fresh properties listed above. It defines the ability of the concrete to withstand any environmental change. SCC is known to be more robust than the normal vibrated concrete due to high content of powder and additions but the aggregate properties and superplasticisers can pose some noticeable effect on its robustness. In-cooperating the use of Viscosity Modifying Agents with good powder selection helps in increasing the viscosity thus improving the robustness of SCC(Liu, 2009).

5 Consistence Retention: This is mostly required during transportation and placing is the ability of SCC to retain its freshly properties which is required to last up to 90 minutes. Consistency in SCC is normally lost when there are differences between the powder used and superplasticisers in their water absorption behaviour. Furthermore, composition of cement and additions, water/powder ratio can also affect the consistency property of SCC(Liu, 2009).

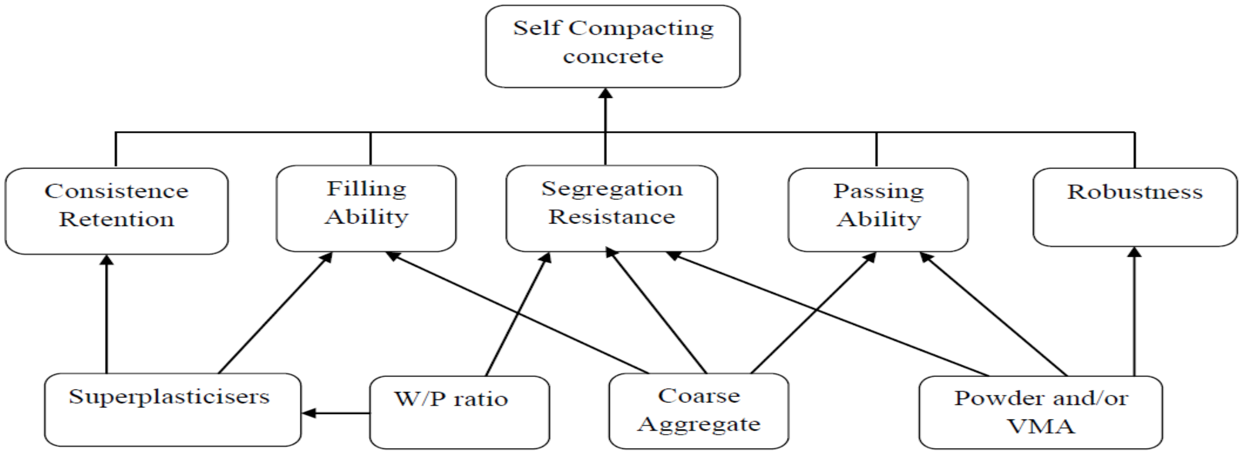


Fig. 2.4: Summary of Fresh Properties of SCC

2.4.2 Test Methods for Fresh SCC

Several test methods are available to evaluate these fresh properties of SCC. The tests have not been standardized by organizations worldwide. In the early development of SCC, test methods on the fresh properties of SCC have been developed. The first methods developed were the box test and U-test which evaluate the filling ability and passing ability. In both test, the height at the right section is measured. Later the box test and V-funnel test were used in the evaluation of the fresh properties as the V-funnel measures the segregation resistance of SCC mix. An alternative method for evaluating the segregation resistance was introduced which is Fill box test. SCC is known to be affected with a slight variation in one of fresh properties, thus, one test will not be sufficient to evaluate the properties. The following summarizes some of the tests employed in evaluating the fresh properties of SCC(Liu, 2009).

1 Slump Flow Test/T50 Slump flow test

This method is used in evaluating the flowability/filling ability of SCC in the absence of obstruction and is made to flow on a flow table. The basic equipment is the same as for the conventional slump test. Slump flow is used to measure the deformation capacity under its weight without any external compaction. T50 is the time of the concrete to cover 50cm diameter spread circle which gives the deformation velocity(Tande and Mohite, 2007). T50 = 2-5 seconds. Deformation capacity increases with increase in the slump flow while the deformation velocity decreases with a higher T50 value. Inconsistence paste remains at the center of the flow table which signifies a poor viscous paste(Tande and Mohite, 2007).

Fig 2.5: Slump flow test

2 V-Funnel Test

This method is used in evaluating the paste deformability, consistency and segregation resistance of SCC. A V-funnel with 75mm square opening at the bottom, 495mm by 75mm at the top and a height of 572mm with 150mm long square long pipe is used. In this test, two timings are observed (T0 and T5). T0 is the time taken for emptying a concrete filled V-funnel which runs between 6 to 12 seconds. T5 is the time taken for emptying the concrete filled V-funnel completely in 5 minutes. If there is an interruption due to non-uniform distribution, there will be delay in the flow and paste will thus be segregated(Tande and Mohite, 2007).

Fig 2.6: V-funnel test (Liu, 2009)

3 L-Box Test

This method is used in evaluating the passing ability of SCC using a rectangular L-shape section containing vertically placed reinforcement. The concrete is poured onto the vertical section and is made to flow through obstructions (reinforcements) to the horizontal section. At a stable flow, the height H1 and H2 are measured and the ratio of H2 to H1 gives the blocking value/blocking ratio which ranges from 0.8 to 1.0 for a good passing ability (Tande and Mohite, 2007). A blocking value of 0 indicates that the paste is segregated.

Fig 2.7: L-Box test

4 U-Type and Box-Type Test

This method is also used for testing flowability of SCC through an obstacle with coarse aggregates having the maximum size of less than 25 mm. Amount of aggregate passed through the obstacle are measured for self-compactibility(Tande and Mohite, 2007)**.**

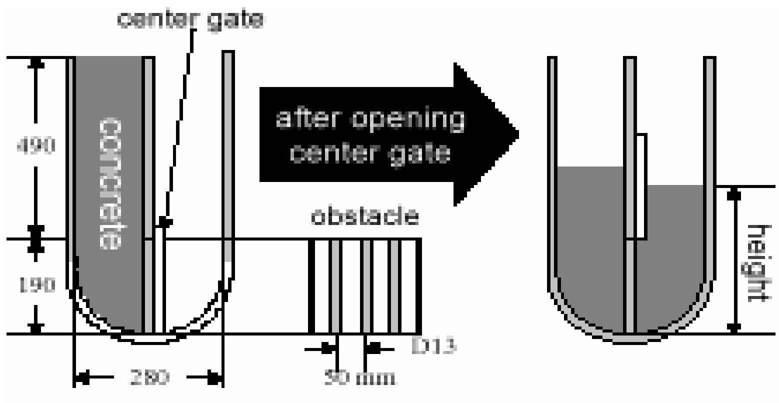


Fig 2.8: Box test(Tande and Mohite, 2007)

Other test for testing fresh properties of SCC include Fill Box test which is used in evaluating the flowability/filling ability of SCC using a 1m transparent rectangular box which contains obstacles (reinforcements) at intervals through which the concrete flows. The box is filled concrete and the difference in concrete height is measured. J-Ring Test which is used in measuring the passing ability of SCC. It comprises of a slump cone and vertical reinforcements where the concrete passes through and flow on the plate(Liu, 2009). The passing ability is evaluated by the difference in height between the inside flow and outside flow (Step height) and Sieve Stability test which is used in measuring the segregation resistance using a 5mm sieve(Tande and Mohite, 2007). It evaluates the static segregation by measuring the segregation index through allowing the concrete/mortar to pass through the sieve for a given period of time. A higher value of segregation index indicates a low segregation resistance.

Table 2.4: Summary of test on fresh properties of SCC

FRESH PROPERTIES	TEST METHODS	MATERIALS	VALUES
FILLING ABILITY	Slump Flow	Concrete	Average flow diameter: 650 – 800 mm
	T50	Concrete	Time to flow 50cm: 2 – 5 sec
PASSING ABILITY	L-Box	Concrete	Ratio of heights at beginning and end of flow: 0.8 – 1.0
	J-Ring	Concrete	Difference in heights at the beginning and end of flow: 0 – 10 mm
SEGREGATION RESISTANCE	V-Funnel	Concrete/mortar	Time for emptying of funnel (T0): 6 – 12 sec
	Sieve Stability test	Concrete/mortar	5 – 15% sample passing through 5 mm sieve

2.4.3 Hardened Properties of SCC

Concrete is known to have certain properties both in fresh and hardened state, thus, SCC is not an exceptional. The concrete mixes used in SCC are practically the same as those used in the normal vibrated concrete except they are mixed in different proportions and with the addition of admixtures to meet some certain and special requirements, as such, SCC has certain properties in its hardened state just as the normal vibrated concrete. This section explains briefly some of the properties of SCC in its hardened state which is known to be dense and homogenous. Strength is regarded as the main engineering property of concrete in its hardened state as it explains the both the strength and durability. In addition, elastic modulus, shrinkage, creep and bond strength are also regarded as hardened properties.

1 Durability

Durability defines the overall performance of a concrete structure in relation to its service life. Assessment of durability in concrete will be based on both physical processes and chemical processes that occur in concrete. The physical processes may include heating/cooling process and freezing/thawing process while the chemical processes may include sulphate attack and alkali-silica reaction. The overall durability of a concrete can be defined based on three basic parameters; chloride conductivity, oxygen permeability and water sorptivity(Liu, 2009).

However, due to some differences between SCC and normal vibrated concrete, there are some corresponding differences in their durability. Use of superplasticisers, high content of powder and Viscosity Modifying Agent in SCC resulting to a better microstructure and homogeneity lead to these differences. Good dense and homogenous structure in SCC makes it more durable than the normal vibrated concrete but SCC is more prone to spalling and freezing/thawing processes than in normal vibrated concrete(EFNARC, 2005).

2 Strength

Strength defines the ability of the hardened concrete to carry the applied design load without any risk of failure. Different types of load are applied to a member which can be tensile or compressive in convention, thus the strength of a concrete is evaluated based on both tensile and compressive strength.

Compressive Strength: SCC compressive strengths are comparable to those of normal vibrated concrete made with similar mix proportions and water/cement ratio. There is no any significant difference in compressive strength between SCC and a normal vibrated concrete, thus the overall strength of SCC is similar to normal vibrated concrete. The strength of SCC is found to be higher with finer materials due to better microstructure of the paste(Liu, 2009). It also depends on the powder composition and water/powder ratio. The compressive strength can reach a value of 100MPa at 28 days.

Tensile Strength: Tensile strengths are based on the indirect splitting test on cylinders. For SCC, the tensile strengths and the ratios of tensile to compressive strengths are in the same order of magnitude as the normal vibrated concrete.(Liu, 2009).

Bond Strength: is the bonding between reinforcement and concrete and with effective bonding, the overall structural strength is improved. Weak bond may result from bleeding, segregation, water and air trapped. The water and air trapped may cause an effect called "top bar effect" which causes the bond strength to be higher in the lower part of the concrete than the higher part(Liu, 2009). Pull-out tests have been performed to determine the strength of the bond between concrete and reinforcement of different diameters. In general, the SCC bond strengths expressed in terms of the compressive strengths are higher than those of normal vibrated concrete.

3 Elastic Modulus

This defines the relationship between the stress and strain with modulus of elasticity (E) as the slope. It is used in determining the elastic deformation in structural members. The stress-strain relationship for concrete is a non-linear with its elastic moduli; static modulus (Es) and dynamic modulus (Ed)(Liu, 2009). These moduli are found to be dependant of the elastic modulus of the individual particles, aggregate contents and powder contents. With the lower content of coarse aggregate in SCC, the elastic modulus of normal vibrated concrete is higher than in SCC. SCC and normal vibrated concrete bear a similar relationship between modulus of elasticity and compressive strength expressed in the form $E/(f_c)^{0.5}$, where E = modulus of elasticity, f_c = compressive strength. This is similar to the one recommended by ACI for conventional normal weight concrete (Liu, 2009).

4 Shrinkage

This characterized by the concrete volumetric change causing tensile stresses which lead to some durability problems. It can be autogeous shrinkage and/or drying shrinkage(Liu, 2009). Autogeous shrinkage results from the volumetric difference between the hydration product with the cement and water while drying shrinkage results from the atmospheric evaporation. In SCC, high powder content and use of superplasticisers result to increase shrinkage compared to normal vibrated concrete but with limestone powder and a denser microstructure, shrinkage is reduced(EFNARC, 2005).

5 Creep

It defines the characteristics of the longitudinal deformation in concrete with constant applied force. Creep depends on the water/power ratio and is found to be higher with increased porosity but decreases with higher amount of aggregate. Due to the low content of coarse aggregate in SCC, creep may be higher in SCC than in normal vibrated concrete (Liu, 2009).

2.5 Mix Design Principles

SCC mixtures contain some cementitious materials that provide a certain degree of stability to the concrete. Mix design methods are very vital as different materials with different characteristics are used in SCC. These are employed to create a balance between the fresh properties of SCC in order for the mix to reach its expected performance. There are no specific standard methods used in mix design of SCC but several proposals and developments have been made from different conceptions. Okamura and Ozawa from the University of Tokyo developed a mix design method based on their local availability (Okaruma and Ouchi, 2003). Furthermore, the UCL method and CBI method were developed in UK and Sweden respectively (Liu, 2009).

Both the normal vibrated concrete and SCC have mix design methods with some differences. In SCC mix design, material properties and characteristics are very important to be considered. The materials depend on the local availability which helps in reducing cost thus proximity is considered in SCC mix design. Some researchers have set out guidelines for the mix design of SCC. These are (Liu, 2009):

1. Volume ratio of aggregate is reduced to compensate the cementitious material.
2. Amount of coarse aggregate, particle size and total volume should be controlled.
3. Viscosity enhancing admixtures are also used

The general purpose method developed by Okamura and Ozawa from the University of Tokyo is based on local availability (Japanese materials). It is composed of two parts; Mortar and aggregates (coarse)(Liu, 2009). Mortar is considered as the prime phase for the production of SCC that ensures the required fresh properties and viscosity for aggregate mobility. Mortar contains the powder materials which include cement and additions, fine aggregate, admixtures and water. Water content of SCC mixture has the estimated value of about 160–190 kg/m^3 together with viscosity modifying agents specially suited for SCC applications. The coarse and fine aggregates are fixed while superplasticisers and water/powder ratios are varied to achieve self- compactibility which contradicts the case of mix design in normal vibrated concrete where water/cement ratio is fixed in order to achieve required strength(Liu, 2009).

In SCC, self compactibility is the main objective thus with a low water/powder ratio, strength is not a problem. With fixed amount of coarse and fine aggregate, trial test are performed with different amount of superplasticisers dosage and water/powder ratio to obtain the required amounts. The trial tests include U-flow, slump flow and funnel test. The following gives the summary of generalized mix design method commonly employed(Liu, 2009).

1. Coarse aggregate takes 50% of the concrete volume which in total is made up of between 28% - 38.6% of the total paste volume.
2. Fine aggregate takes 40% of the mortar volume which in total takes up to between 38.1% - 52.9% of the total paste volume.
3. Air content takes between 4% - 7% of the concrete volume (Air entraining agents)
4. The amount of superplasticers and water/powder ratio are obtained from trial tests on mortar

2.6 Manufacture of SCC

SCC as defined earlier as a concrete which flows, fills and consolidates without any external vibration, it has some unique characteristics that make it a special type of concrete. The most common characteristics known for SCC are its high filling ability, passing ability, absence of vibration thus noise and health dangers are eliminated. Furthermore, increased durability, high strength, low permeability, homogeneity, and a dense, uniform and excellent surface texture finish are also some added characteristics of SCC that make it to be special and unique concrete. Despite these characteristics, SCC is known to be less tolerant to variations especially in aggregate moisture content, shape, grading, size and distribution of aggregate thus care should be taken at all stages of production(EFNARC, 2005).

Due to high sensitivity of SCC in material variations, storage of the constituents to be used in the production becomes important as additional care and attention are needed. Aggregates should be stored with extra care in order to avoid non-required mixture of different type of aggregates. When additional supply of aggregate is needed, performance and conformity test may be necessary to ensure consistency. The production of SCC can be ready-mixed and/or site-mixed depending on the choice of the contractor. In concrete structures, compaction is not 100% achieved (compaction grade 1) as a value of 0.93 to 0.98 compaction grade is achieved for normal vibrated concrete when full external compaction is used. A compaction grade of 0.98 to 1 is achieved in SCC which spreads throughout the structure thus required compressive strength is achieved(Borimi, 2013).

2.6.1 Mixing Equipment

There are no differences in mixing equipments used in SCC with those used in normal vibrated concrete. Some of the common mixers used in concrete production are paddle mixers, free fall mixers and truck mixers. In SCC production, force action mixers are more suitable and duration of mixing is normally morethan the normal concrete production which is due to activities of the constituents in SCC. Trial tests may be necessary prior to production in order to ascertain the performance and conformity of the constituents and also the efficiency of the mixer.

In the process of mixing, an undesired formation in the mixture may be formed known as "balling" which occurs mostly in free fall mixers. This can be avoided by mixing the concrete first as a normal concrete with low consistency until a uniform mix is obtained, then further water and superplasticisers will be added to a required level of consistency for SCC(EFNARC, 2005). When VMA are needed, direct adding on the dry constituents is not accepted thus they are added after water and superplasticisers are added. Addition of admixtures needs to be measured by calibrated containers and accurate dispensing equipments. It should be noted that when new batches of different constituents are added during production, adjustments in the level of superplasticisers is necessary to achieve the required consistency. The followings are some of the common mixers used in concrete production(EFNARC, 2005).

1. Free fall mixers: In SCC mix, a measured amount of water is first added (2/3 by volume) to the mixer followed by cement and aggregates. The constituents in the mixers are mixed to obtain a uniform mix with a low consistency. Water and superplasticisers are added onto the uniform mix the followed by VMA (when needed) to obtain a final mix with a high consistency. The mixing speed of the mixer is required to be 10 – 15 rpm and duration may be longer for efficient mixture(EFNARC, 2005).
2. Force action mixers: In SCC mix, aggregates are added together with cement then followed by a measured amount of water and superplasticisers. VMA are added (when needed) at the final stage with the remaining amount of water.

2.6.2 Production of SCC

The production of SCC has no any significant differences with the production of a normal concrete. The slight differences are due to high sensitivity of SCC in the properties of its constituents especially the aggregates. The type of application of the final structure will also determine the sequence of production as different mix design will be used for different purposes. It should be noted that worker involved in the production and delivery of SCC receive good and adequate training prior to production from a person with previous experience of SCC. This training may include observing trial batches being produced and tested(EFNARC, 2005).

There are basically three known methods used in the production of SCC based on the available categories explained in the earlier sections. There are Powder SCC, VMA SCC, and Combined SCC which are based on the amount of the constituents used. Evaluation of aggregates to be used is necessary before production so as to check for any noticeable changes in moisture content, shape and size of aggregate. Performance tests may be necessary when introducing new batches in order to evaluate the changes between the different constituents. When there is limited experience in a given mix design, further tests and additional recourses may be necessary based on the initial production of SCC.

2.6.3 Transportation

SSC has to be transported from the point production to point of casting normally by a means of trucks. The transportation has to be carefully monitored so as to provide a continuous supply for a given casting process. It is necessary to provide a balance between production process, transportation process and casting process to avoid break in supply. Trucks to be used in the transportation process have to be clean and moist and instruction regarding handling of SCC form point production to point of casting must be given to the truck drivers during transportation. Some of the necessary delivery informations needed by the casting personnel are given below(Bakhtiarian et al, 2011):

1. Guidelines for admixtures if necessary
2. Time of production
3. Values for target and acceptable slump flow

2.6.4 Pouring and formwork Criteria

In SCC, pouring techniques have some special modifications from the known techniques in concreting process. Some of the modifications based on experience are given below(Borimi, 2013):

1. Pouring rate should not be too slow to avoid setting before adding a new layer of concrete
2. The best solution is pouring SCC from below the formwork to avoid air to be entrained and the pump hose should be maintained slightly below the surface of poured concrete
3. SCC can flow up to 10m - 15m without problems and thin section of 5cm - 7cm can be filled without any problem
4. Special applications as drilled foundation piles fit perfectly with SCC: after drilling the hole and filling with SCC the cage enters easily

Formwork in SCC can be done by all known materials in formwork process. It should be noted that surface quality and temperature may affect the choice of material to be used in SCC. SCC is known to be sensitive to temperature than the normal vibrated concrete during hardening process, thus, it will be necessary to insulate the formwork to maintain both the temperature and setting time. Furthermore, when a good surface quality is required, wooden materials are preferred than plywood and plywood is preferred than steel(Bakhtiarian et al, 2011). Formwork sealing process has no difference with the sealing in normal vibrated concrete as bad sealing may result in leakage of the paste. Due to cohesive nature of SCC, formworks are made to be a little loose than in case of normal vibrated concrete(Borimi, 2013).

Fig 2.9: SCC Pouring process(Borimi, 2013)

2.6.5 Surface finish

One of the good and attractive features of SCC is its surface finish which shows a good surface just as in normal concrete with good and complete vibration. SCC surface are first seen as roughly leveled surface then followed by final finishing. In some cases, tiny voids may be present on the SCC surface and this may be due to problems in mix design ratio, pouring process and/or formwork surfaces(Borimi, 2013).

2.6.6 Curing Operation

Curing is the process of maintaining moisture content and temperature in concrete structure for some period of time to ensure maximum strength and durability. Generally, curing influences the mechanical properties of concrete. Bleeding water may lead to surface drying, thus, curing should be carried out immediately after placing. Curing operation can be in different forms depending on the climatic conditions and some other factors; water/moist curing, sealed curing and/or air curing. These forms can be applicable in SCC curing. Studies showed that water curing produces higher tensile and compressive strength followed by sealed curing and then air curing in SCC[R18]. This is because the higher the moisture content in a structure, the higher the tensile and compressive strength gained.

Under the same curing operation, type of additions in SCC used also influence some mechanical properties as silica fume produces higher compressive strength than fly ash under the same curing conditions(Borimi, 2013). Heat treatment can also be applied to SCC which is carried out by the use of hot air method(Gesoglu et al, 2012). Heating cabinets with steel forms of good conductivity are used humidity will be maintained by placing water filled container in the cabinets. In this process of curing, mechanical properties are found to be varied with SCC type and water/powder ratio. With high temperature, compressive strength of SCC in powder type will be higher than VMA type and with higher water/powder ratio, there will low gain in compressive strength. Under heat treatment, combined type SCC has higher ultimate strength than the other types(Gesoglu et al, 2012)

The curing process of SCC has close similarities with the process employed in superplasticised high performance concrete. Due to little or no bleeding water, SCC dry faster than the normal concrete thus SCC curing is necessary immediately after casting to prevent surface shrinkage cracking.

2.7 Advantages of SCC

SCC has numerous advantages which some are already been stated in the previous sections. It is already known that this type of concrete has the ability to consolidate under its own weight and flow by itself between the congested reinforcement to fill all available void spaces within the formwork without the need of vibration either manually or mechanically.

The most prominent and important advantages are faster placement with less labour and increase the in overall strength, durability and productivity of the concrete structure(Okaruma and Ouchi, 2003).

Furthermore, additional advantages of SCC can be seen in its excellent surface finish which is risk-free, high dense and more homogenous concrete quality across the entire concrete cross-section is achieved especially around the congested reinforcements(Liu, 2009). In addition, there is high early strength of concrete which gives room for further casting with the same formwork. A quieter construction site, or pre-casting factory, is an added advantage to construction, noise disturbances from vibrators and other mechanical equipments is greatly reduced and thus SCC can eliminate many of the health and safety issues associated with concrete vibration.

The successful use of SCC is best seen in projects where the available space would have made normal concrete virtually impossible to place and where the surface finish quality was paramount. Higher installation performance since no compaction work is necessary which leads to reduced construction times, especially at large construction site(Okaruma and Ouchi, 2003).

It can be seen that SCC has both engineering and environmental benefits which make it accepted in construction industries across the world. The following are some of the engineering benefits gained from using SCC

1. Ease in placing in complex geometric reinforcements
2. Durability is greatly improved and greater freedom in design
3. Thinner concrete sections are no more a problem.
4. Faster construction
5. Allows for innovative architectural features
6. Homogeneous and uniform concrete
7. Better reinforcement bonding for slender components

Apart from engineering benefits, some environmental benefits are given below

1. Reduced noise-level in the equipments within construction sites and thus overcoming problems arising from vibration.
2. Safer and more favourable working environment.
3. Accelerated project work schedules in the overall project.
4. Reduced equipment wear

2.8 Limitations of SCC

With all the benefits of SCC discussed, it has limitations. Higher powder and admixture contents are required than normal vibrated concrete and so material cost is higher. The cost can increase up to 20% to 60% when compared to similar grade of normal vibrated concrete. For this reason, increase in cost for very large structures, by using SCC was outweighed by savings in labour costs and construction time(Liu, 2009).

Quality control is necessary as increase in powder and admixture contents also leads to higher sensitivity of SCC to material variation than in normal vibrated concrete.

2.9 Setting Time

Setting time and hydration reaction are very important aspect in cement and concrete studies in that they occur simultaneously. These terms are used to explain the behavior and stages of cement paste from the beginning of mixing (fluid state) up to the early stage of hardening (rigid state). The hydration reaction explains the chemistry and the reactions that take place immediately after the powder (cement) becomes in contact with water with evolution of heat. On the other hand, setting means the change that occurs in the paste from its fluid state to a rigid state accompanied by change in temperature thus having a stiff paste. This is caused by hydration of chemical compound like C_3A and C_3S where by the latter sets first due to addition of gypsum which delays the formation of calcium aluminate hydrate(Neville and Brooks, 2010). It is observed that setting time decreases with increase in temperature provided the temperature is kept above 30^o. Below 30^o, a reverse action is observed where by the setting time decreases at low temperatures. There are two forms of setting; initial set and final set.

1. Initial set defines the stage in which the paste starts to show some characteristics of hardening with a rise in temperature which corresponds to the final stage of induction period in hydration reaction. ENV 197-1:1992 defines the setting time of a 42.5MPa cements to have the minimum of 60 minutes while for cements with higher strengths, minimum of 45 minutes is given(Neville and Brooks, 2010)

2. Final set defines the stage of hardening which corresponds to the highest temperature and the time is defined to a maximum of 10 hours(Neville and Brooks, 2010).

Setting can also occur in an undesired way and the process is very quick with some heat generated. It can be in the form of flash set of false set. There are some laboratory destructive tests that are employed to determine the initial and final set of a paste(Neville and Brooks, 2010). Vicat apparatus and Gillmore apparatus are defined under many standards. Setting time is affected by some certain factors which are:

1. Fineness of the powder particle: fineness of the powder materials used particularly cement has some influences on the setting time of cement paste as it is referred to as the total surface area available for cement hydration. This is because with more fine materials, rate of cement hydration is faster, thus, cement paste harden faster.

2. Climatic conditions: particularly temperature and humidity have influences on setting time of cement paste. With an increase in temperature and relative humidity, setting is reduced since the cement hydrates and hardens faster. Alternatively, there will be delay in setting due to low temperature.

3. Water/cement ratio: setting time is also affected by the amount of water contained in cement paste. Setting will be delayed with higher water/cement ratio.

4. Chemical composition of cement: this also influences the setting time of cement paste as different compounds of different properties are contained in the cement. There are also many types of cement which contain different compositions, thus, their properties particularly the fresh property will differ.

2.9.1 Significance of Setting Time

In all most all constructions, many activities are involved which occur in series with time period of completion attached. Some activities depend on the completion of others while some occur simultaneously which all depend on the setting time of the preceding activity. Thus, setting time plays an important role in the overall completion period. The point of interest in setting to the engineers and contractors is the duration it takes for the process to occur thus a good knowledge of the setting time is very important especially in places where there are some noticeable climatic changes. The study of setting time of Self Compacting Concrete is very important being it a special and an innovative concrete used in modern constructions. Few studies have been carried out on the setting time of concrete mostly by non-destructive test methods like ultrasonic wave method and electrical methods. The setting times were obtained from varying water/cement ratio where a linear relationship was obtained, with increase in water/cement ratio there is a corresponding increase in setting time, thus setting is delayed. For construction purposes, the initial set must not be too soon and the final set must not be too late. Additionally, setting times can give some indication of whether or not cement is undergoing normal hydration. Practical significance of setting time can be best seen in the following (not limited):

1. Curing: this involves the duration between the casting of the structure and the removal of the formwork from the structure. The removal of the formwork is carried out when the structure gains some considerable amount of strength to be able to stand without failure.
2. Hardening and Strength gain: involves the ability of the structure to be able to withstand some amount of applied load without noticeable destructive penetration. This normally occurs after the initial setting time has been reached, thus, setting time is important in the early usage of the structure especially in renovations and maintenance.
3. Overall completion period: projects involve series of activities which take place simultaneously. Most of the activities need to attain their initial and/or final setting time before the next activity commences. Thus, a good knowledge of setting time is important so as to be able to plan the activities accordingly especially in limited time situations.

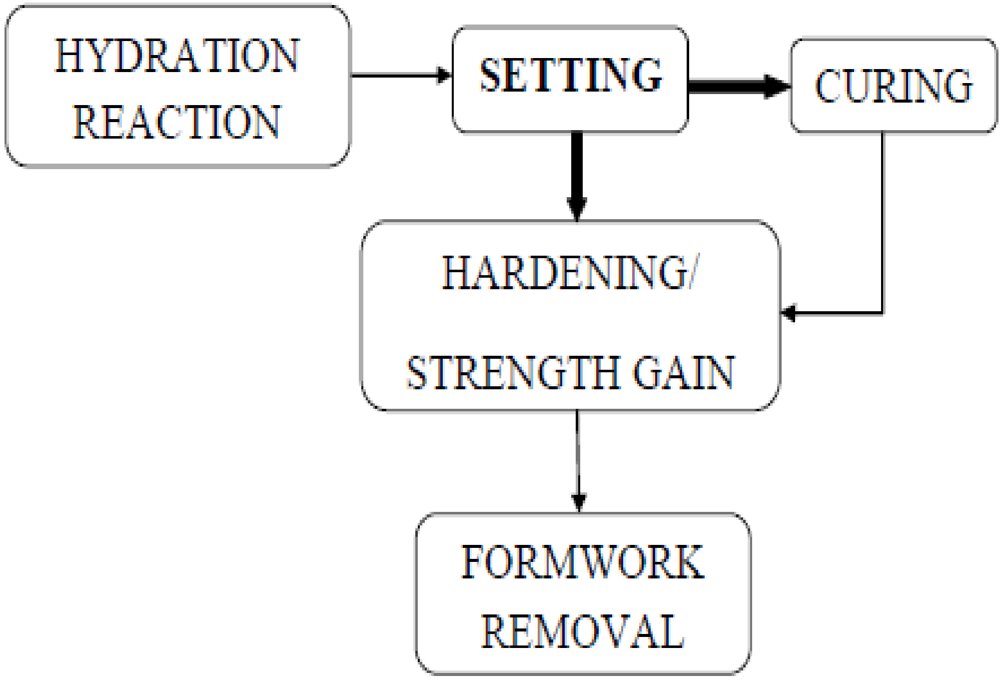


Fig 2.10: Significance of Setting Time

CHAPTER THREE

MATERIALS AND METHODS

As earlier mentioned in chapter one, this study will be based on SCC manufactured in North Cyprus with the locally available materials obtainable from one of the leading SCC manufacturing company in North Cyprus (Tüfekçi Company) with the main focus on its setting behaviour. This chapter explains in details the materials used in conducting this study and the methodology employed based on Tüfekçi Company mix design.

3.1 Materials Used

This section will explain the materials locally available in North Cyprus used for this study.

3.1.1 Cement

- CEM I (CEM I 42.5R**)** is Portland Cement containing purely clinker compounds with no additions.

- CEM II/B-S (CEM II/B-S 42.5N) is Portland Slag Cement containing clinker compounds and Slag as an addition in definite proportion.

Higher amount of C_2S and lesser amount of C_3S in CEM II leads to slow hydration reaction which results to low heat of hydration and slow early strength. Lesser amount of C_3A in CEM II leads to good sulphate resistance property which also helps in low heat of hydration.

3.1.2 Water

Ordinary tap water was used in the mixing process in carrying out this study for both the setting behaviour measurement and manufacture of SCC mixtures.

3.1.3 Admixture

Admixtures are added to SCC in achieving excellent flow with good fluidity which gives its property to flow and consolidate without the need for vibration. Admixture used in this study obtained from Tüfekçi Company was DRACO LEVELCON DX 50 conforming to EN 934-2 that was used for both setting behaviour measurements and SCC manufacture.

3.1.4 Aggregates

Aggregates locally available in North Cyprus were used in this study obtained from Tüfekçi Company. Three categories of the aggregates were used as larger aggregates for SCC not exceeding 20mm. Both fine and coarse aggregates were used and the sizes used are shown: Fine aggregate: 0 – 4mm and Coarse aggregate: 5 – 12mm and 12 – 19mm

3.1.5 Sieve Analysis

Determination of distribution of aggregate size in concrete manufacture is important especially in SCC which requires finer aggregates. Sieve Analysis gives the best gradation to be used to achieve a good and sound concrete through the gradation curve. Good gradation determines the final strength of the concrete as poorly graded concrete will be susceptible to durability problems. Thus, carrying out this process was found necessary as SCC which is regarded as high strength concrete requires good gradation to achieve its unique properties which uses finer particles compared to normal concrete. This method was used to determine the particle size distribution and gradation for the aggregates used in manufacturing SCC mixtures.

Weighing balance, oven for maintaining uniform temperature of 105°C and sieves with square openings conforming to ASTM E-11 were the apparatus used for this test. Sample of aggregates available in North Cyprus were used which were obtainable from Tüfekçi Company having sizes of 12 – 19mm, 5 – 12mm and 0 – 4mm. These samples were heated in an oven to a temperature of 105°C, allowed to cool to room temperature and weighed using weighing balance. Two equal portions were made from the samples where first sieve operation was conducted with first portion and another sieve operation conducted with the other portion.

The sieving operation was conducted on the samples placed on the uppermost sieve (25mm) and was continued for sufficient period of time using progressive sieves in descending order until no more than 1% by mass of the residue remains. In each sieving operation, the mass retained on individual sieve was recorded. The cumulative mass retained, percentage cumulative mass retained and percentage passing will be computed. The sieving operation for the other portion was then conducted using the same procedure and then mean will be taken for computation of gradation.

Computation of the sieve analysis test was carried out and result obtained was presented in Table 1 of the appendix which was used in plotting the gradation curve. From the curve, the red line represents the well-graded aggregates used in the manufacture of SCC in the study. Out of the total aggregates used, 59% were fine aggregates (0 – 4) mm and 26% were coarse aggregates (5 – 12) mm and 15% were also coarse aggregates (12 – 19) mm

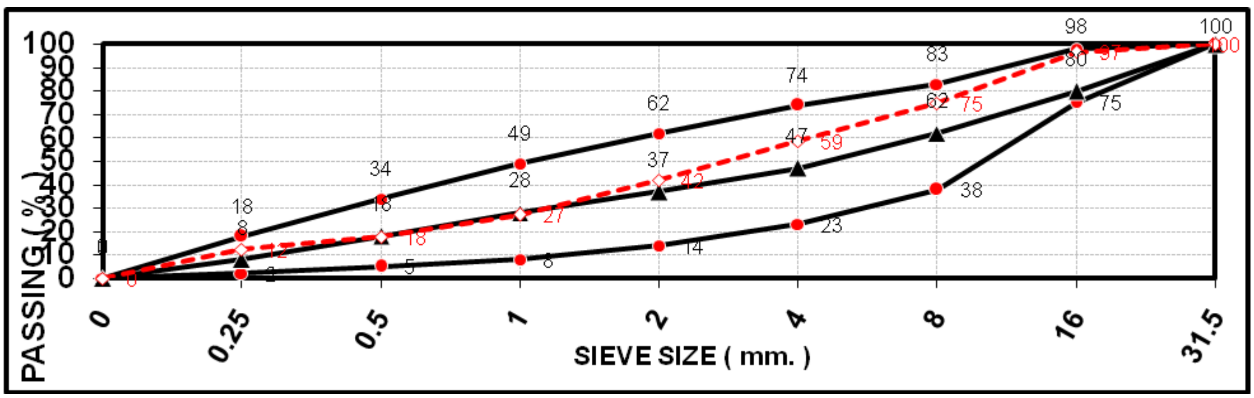


Fig 3.1: Gradation Curve

Material property tests were carried out to ensure that good and durable aggregates were used with excellent shape and gradation.

3.1.6 Los-Angeles Test

In order to ensure good and durable aggregates are used, as SCC is regarded as a durable concrete, abrasion resistance test is necessary. Thus, Los Angeles abrasion test was carried out on the coarse aggregates used in manufacturing SCC for this study was found necessary and test was conducted to determine the resistance of the coarse aggregates to impacts so as to ensure that the concrete will be durable and resistance to some external impacts conforming to ASTM C 131.

A rotating cylinder with metallic spheres known as Los Angeles abrasion testing machine were used together with sieves of 19mm, 12.5mm and 9.5mm and 1.7mm. Two classes of aggregate size were used; aggregates passing 19mm but retained on 12.5mm and aggregates passing 12.5mm but retained on 9.5mm. 3000g of each of the classes obtained, washed and heated in an oven at a temperature of 105^0c for 24 hrs and 2500g was then weighed out from the 3000g heated making a total of 5000g for the two classes. Test Specimen Grading B (11 metallic spheres) was employed, 5000g of the test sample was placed in the testing machine through the machine opening and closed tightly. The testing machine was then set into 30 – 33rpm for 500 revolutions. Sieving operation was conducted using 1.7mm sieve on the contents collected from the testing machine after the revolutions and mass retained on the 1.7mm recorded.

Total mass of coarse aggregates used (A) = 5000g

Total mass of sample aggregates retained on 1.7mm sieve (B) = 3353.4g

Los Angeles abrasion value $LA = \frac{(A - B)}{A} X100$

$$LA = \frac{(5000 - 3353.5)}{5000} X100$$ Los Angeles value = 33%

There is no fixed value limit for the test value as different locations have different aggregate type. North Cyprus adopts U.S specification which limit the Abrasion test value to a range between 25% to 55%, thus, the obtained value confirmed that the aggregates used are hard enough and suitable for constructions

Fig 3.2: Los Angeles Testing Machine Used in this Study

3.1.7 Methylene Blue Test

Deleterious materials (clay materials) are sometimes found in aggregates which can have an adverse effect on the aggregate's performance. Crushed aggregates (aggregates available in North Cyprus) undergo series of processes like washing during the production to remove all the adhered unwanted clay materials but some will not be removed completely. A test will be necessary to detect the presence of these clay materials when using aggregates in manufacture of concrete especially SCC since uniform and homogenous mass concrete is expected. This test is known as Methylene Blue Test conforming to AASHTO TP 57-06.

For the purpose of the study, this test was found necessary to detect the presence of clay materials in the aggregates used so as to manufacture a good and durable concrete. For clay materials greater than 1%, aggregates will be said to be unsuitable. The apparatus used; weighing balance, 200g sample of dried fine aggregates, Methylene blue test apparatus, 2mm sieve, 500ml of water, and quantitative filter paper.

Sample of aggregates obtained from available aggregates in Tüfekçi Company, heated at a temperature of 105°C until is dried then the dried sample sieved with 2mm sieve. The Methylene Blue test apparatus was set up as shown below and 200g of the dried sample taken from the sieve sample was used. 500ml of water obtained and test apparatus was set into 600rpm with the additions of the 200g of the sample. 1ml of Methylene was added to the mixture at interval of 3mm and readings were taken consecutively using a quantitative filter paper. The readings were taken until the required indication was observed on the quantitative filter paper. Readings obtained from the test are shown below:

Number in first reading (A) = 10 Number in second reading (B) = 14

Mass of fine aggregates used = 200g

Weight of Methylene Blue in A = 10ml

Weight of Methylene Blue in B = 14ml

$$A= \left(\frac{10}{200}\right)x10 = 0.5\%$$

$$B = \left(\frac{14}{200}\right)x10 = 0.7\%$$

It can be seen in both cases that the values obtained were less than 1% conforming to AASHTO TP 57-06 which indicates that aggregates having a value of 1% from Methylene Blue test can be used, thus this indicated that the aggregates are suitable to be used in construction.

Fig 3.3: Methylene Blue test Apparatus Used in this study

3.2 Methodology

This section will explain in details the methods employed in carrying out this study

3.2.1 Setting Behaviour Measurement on Cement Pastes

Study on the setting behaviour of pastes prepared based on SCC mix design is the main focus of this study as SCC can be manufactured with different type of cements which have different setting behaviour. Study on this behaviour was carried out on pastes prepared based on SCC mixtures with admixtures and without admixture (for control purpose) and their setting times were compared. The pastes used are given in table 3.1:

Table 3.1: SCP for Setting Behaviour Test

CEM I	CEM II
Paste prepared with material combination of Mixture 02 having standard consistency	Paste prepared with material combination of Mixture 01 having standard consistency
Paste prepared with material combination of Mixture 04 having standard consistency	Paste prepared with material combination of Mixture 03 having standard consistency

Vicat Apparatus: Vicat apparatus shown below conforming to EN 196-3 was used in this study for standard consistency and setting behaviour measurements

Fig 3.4: Vicat Apparatus used in this study

3.2.1.1 Determination of Standard Consistency

Standard consistency test of pastes shown in table 3.1 above was carried out to ascertain the required w/c ratio for consistent pastes. 400g of cements (CEM I and CEM II) for each mixture obtained from the available samples in Tüfekçi Company, 1% (by cement mass) of DRACO LEVELCON DX 50 admixture (for mixture 01 and mixture 02) conforming to EN 934-2 and water were used in preparing the pastes. Apparatus used were Vicat Apparatus shown above, Glass graduates, trowel, cement mixer, and stop watch. Standard consistency test was carried out on the prepared pastes using a 10mm plunger at 27°C±1°C until some certain resistance defined by standards (EN 196-3) against penetration of plunger was obtained.

Cement mixer was used in mixing the cement pastes using measured amount of water and placed into the ring by plunging 10 times at intervals until the ring was full. The paste was set and the plunger attached to the rod was allowed to rest freely on the paste. Readings were taken from the Vicat apparatus scale. The procedure was repeated until a value of 5 – 7 mm from the bottom was recorded which confirmed that the paste has a normal consistency. Table 3.3 shows the normal consistent pastes used for setting behaviour measurements.

Table 3.2: Paste Mixes Used in this Study

Materials	**Mixture 01**	**Mixture 02**	**Mixture 03**	**Mixture 04**
Cement	CEM II	CEM I	CEM II	CEM I
Admixture	1% by Cement	1% by Cement	NIL	NIL
w/c ratio	0.24	0.24	0.30	0.30

3.2.1.2 Determination of Setting Time (Vicat Method)

Setting behaviour test was carried out on the normal consistent pastes (table 3.3) where Periodic penetrations conforming to EN 196-3 were recorded. Four set of test were carried out on each paste mixture at varying temperatures (29°C±1°C and 19°C±1°C). These temperatures were selected because concrete constructions in North Cyprus are mostly carried out around these ranges. During summer period, concrete constructions are mostly carried in the morning (mostly between 8am to 11am) where the temperature is maximum around 29°C±1°C. During winter period, concrete constructions are mostly carried out during day time where temperature is expected to be around 19°C±1°C.

1. Setting Behaviour Test for Pastes without Admixture

Setting time of pastes prepared based on mixture 03 and mixture 04 were determined. 400g of cements (CEM I and CEM II) for each mixture obtained from the available samples in Tüfekçi Company and defined amount of water were used. Apparatus used were Vicat Apparatus shown above, Glass graduates, trowel, cement mixer, and stop watch and periodic penetrations were carried out on the pastes at 29°C±1°C and 19°C±1°C.

Cement mixer was used in mixing CEM II with measured amount of water (mixture 03), placed into the ring by plunging 10 times at intervals until the ring was full and stop watch was started. Initial setting time was measured using 1mm needle attached to the rod, lowered onto the surface of the cement paste thereby allowing the needle to settle freely for 30 seconds and readings were taken from the Vicat apparatus scale which gives the penetration depth. Subsequent readings were taken with the same needle at intervals of 10 minutes with 10mm away from any previous penetration spot.

The time at (4±1) mm penetration from the bottom was determined and the results were recorded. The time between the initial contact of cement with water and the penetration at (4±1) mm gives the initial setting time Final Setting was measured using angular needle (5mm in diameter and 0.5 mm at the tip) where the needle makes an impression on the paste surface but the cutting edge fails gives the final setting time from the initial contact with water. Three

(3) more readings were obtained by repeating the whole procedure with the same mix at both temperatures.

Alternatively the whole procedure was repeated with Mixture 04 where CEM I was used instead of CEM II.

2. Setting Behaviour Test for Pastes with Admixture

Setting time of pastes prepared based on mixture 02 and mixture 04 were determined. 400g of cements (CEM I and CEM II) for each mixture obtained from the available samples in Tüfekçi Company, 1% (by cement mass) of DRACO LEVELCON DX 50 admixture conforming to EN 934-2 and defined amount of water were used. Apparatus used were Vicat Apparatus shown above, Glass graduates, trowel, cement mixer, and stop watch and periodic penetrations were carried out on the pastes at 29°C±1°C and 19°C±1°C.

Cement mixer was used in mixing CEM II and admixture with measured amount of water (mixture 01), placed into the ring by plunging 10 times at intervals until the ring was full and stop watch was started. Initial setting time was measured using 1mm needle attached to the rod, lowered onto the surface of the cement paste thereby allowing the needle to settle freely for 30 seconds and readings were taken from the Vicat apparatus scale which gives the penetration depth. Subsequent readings were taken with the same needle at intervals of 10 minutes with 10mm away from any previous penetration spot.

The time at (4±1) mm penetration from the bottom was determined and the results were recorded. The time between the initial contact of cement with water and the penetration at (4±1) mm gives the initial setting time Final Setting was measured using angular needle (5mm in diameter and 0.5 mm at the tip) where the needle makes an impression on the paste surface but the cutting edge fails gives the final setting time from the initial contact with water. Three (3) more readings were obtained by repeating the whole procedure with the same mix at both temperatures.

Alternatively the whole procedure was repeated with Mixture 02 where CEM I was used instead of CEM II.

3.2.2 Studies carried out for SCC mixtures

Four (4) different mixtures were prepared having different material combination. Mixture 01 and Mixture 02 were manufactured with admixture (DRACO LEVELCON DX 50) while Mixture 03 and Mixture 04 were manufactured without admixture mainly for control purposes. There will be no direct comparison between concrete and paste as SCC mixtures were manufactured in order to check the feasibility of SCC manufactured using locally available material with North Cyprus temperature conditions, providing information on its performance mainly their compressive strength at 7 days and 28 days.

Table 3.3: Mixtures of SCC to be used in the Study

Mixture 01 ▪ CEM II ▪ Defined w/c ▪ Measured aggregates ▪ Selected admixture ▪ Slump S5	**Mixture 02** ▪ CEM I ▪ Defined w/c ▪ Measured aggregates ▪ Selected admixture ▪ Slump S5
Mixture 03 ▪ CEM II ▪ Defined w/c ▪ Measured aggregates ▪ No admixture ▪ Slump S5	**Mixture 04** ▪ CEM I ▪ Defined w/c ▪ Measured aggregates ▪ No admixture ▪ Slump S5

Mixture 01 contains SCC mixture manufactured using the available mix design used by Tüfekçi Company.

- Cement: CEM II
- Slump: S5
- Water/cement ratio: 0.48 and Admixture 1.5% by mass of cement

Mixture 02 contains SCC mixture manufactured using same mix design in Mixture 01 with CEM II replaced by CEM I. Mixture 03 contains SCC mixture manufactured with CEM II, no admixture and high w/c ratio and Mixture 04 contains SCC mixture manufactured with CEM II, no admixture and thus, high w/c ratio.

Table 3.4: Mix Design Used in SCC Manufacture

Components	**Weights/35 litre(kg) (Mixture 01 and 02)**	**Weights/35 litre(kg) (Mixture 03 and 04)**
Cements	12.25	12.25
Water	5.88	8.70
Admixture	0.18375	Nil
0 – 4mm	39.53	39.53
5 – 12mm	17.5	17.5
12 – 19mm	10.02	10.02
Total	**85.36**	**88.00**

3.2.2.1 Slump Flow Test

Slump flow test on the fresh SCC manufactured in this study was carried out to evaluate the filling ability and consistency of the mixtures. The slump flow test was carried out on all the mixtures. A value of 220mm was obtained the control mixtures. A diameter value of 45cm was obtained on mixtures containing admixtures. The results obtained show that SCC mixtures have standard consistency.

Fig 3.5: Slump flow test carried out in this study

3.2.3 Compressive Strength Measurement

As stated in the previous sections, SCC mixtures were manufactured based on locally available material with North Cyprus temperature conditions to check their performance mainly the compressive strength at 7 days and 28 days. After determining the aggregates properties, Trial mixes were carried out to obtain required w/c ratio to achieve slump S5 for Mixture 03 and Mixture 04. Sieve analysis results were used in plotting the gradation curve and required amount of aggregates in good proportion for gradation were obtained. The table 2 of the appendix shows the mix design used by Tüfekçi Company for their heavy concrete production per $1m^3$ (1000 litre) for all the 4 mixtures which was converted to concrete manufacture per 35 litre for laboratory studies.

After all material property tests and trial mixes were carried out, SCC mixtures each having required w/c ratio, slump S5 and measured aggregates were manufactured using concrete mixer under normal atmospheric condition. Coarse aggregates were first placed into the mixer followed by fine aggregates and cement. The mixer was turned on and admixture was added to 2/3 of the water to be used followed by the remaining water. Six (6) cubes of each of the mixtures were made with 150x150x150 mm size cubes and cured under normal curing condition. Table 3.4 shows the mix design used in SCC manufactured in this study

CHAPTER FOUR
RESULTS AND DISCUSSION

This chapter will give the results obtained from the test conducted in this study together with the discussion of the results

4.1 Setting Behaviour Test

As stated earlier, the main purpose of this study is to analyse the setting behaviour of Self Compacting Paste based on SCC mix design. Setting behaviour measurements were conducted by measuring the setting time of the paste where four results were obtained for each mixture at varying temperatures.

Normal temperature of 29°C±1°C was considered the higher temperature during conducting the test while lower temperature of 19°C±1°C was considered and maintained using Air Conditioner. Table 4.1 and Table 4.2 show the computed values for mean and standard deviation of the setting behaviour of pastes at both temperatures. Standard Deviation was calculated using the following formula

$$\text{S.D} = \sqrt{\frac{\sum x^2 - \left(\frac{x}{2}\right)^2}{n-1}}$$

Where

x = setting time value,

n = 4 (number of readings)

Table 4.1: Setting Behaviour at 29°C±1°C

	Mixture 01	Mixture 02	Mixture 03	Mixture 04
1ST (mins)	131	224	189	130
2ND (mins)	143	248	165	122
3RD (mins)	138	236	191	126
4TH (mins)	147	254	179	138
Mean (mins)	139.75	240.5	181	129
S.D	6.898	13.304	11.888	6.831

Table 4.2: Setting Behaviour at 19°C±1°C

	Mixture 01	Mixture 02	Mixture 03	Mixture 04
1ST (mins)	165	264	185	159
2ND (mins)	157	278	193	151
3RD (mins)	164	249	201	153
4TH (mins)	148	269	187	143
Mean (mins)	158.5	265	191.5	151.5
S.D	7.853	12.138	7.188	6.608

4.1.1 Setting Behaviour of SCP Mixtures

From the results obtained, it can be seen clearly that setting times of pastes under study were less at higher temperatures regardless of the mixture type. In this study, water reducing admixture (superplasticiser) was used which is known to reduce water requirements by certain percentages (10% to 15%). This gives the cement paste high strength and workability at low w/c ratio by its fluidity/dispersion effect. The following figures show the setting behaviour of all the pastes used under study at different temperatures.

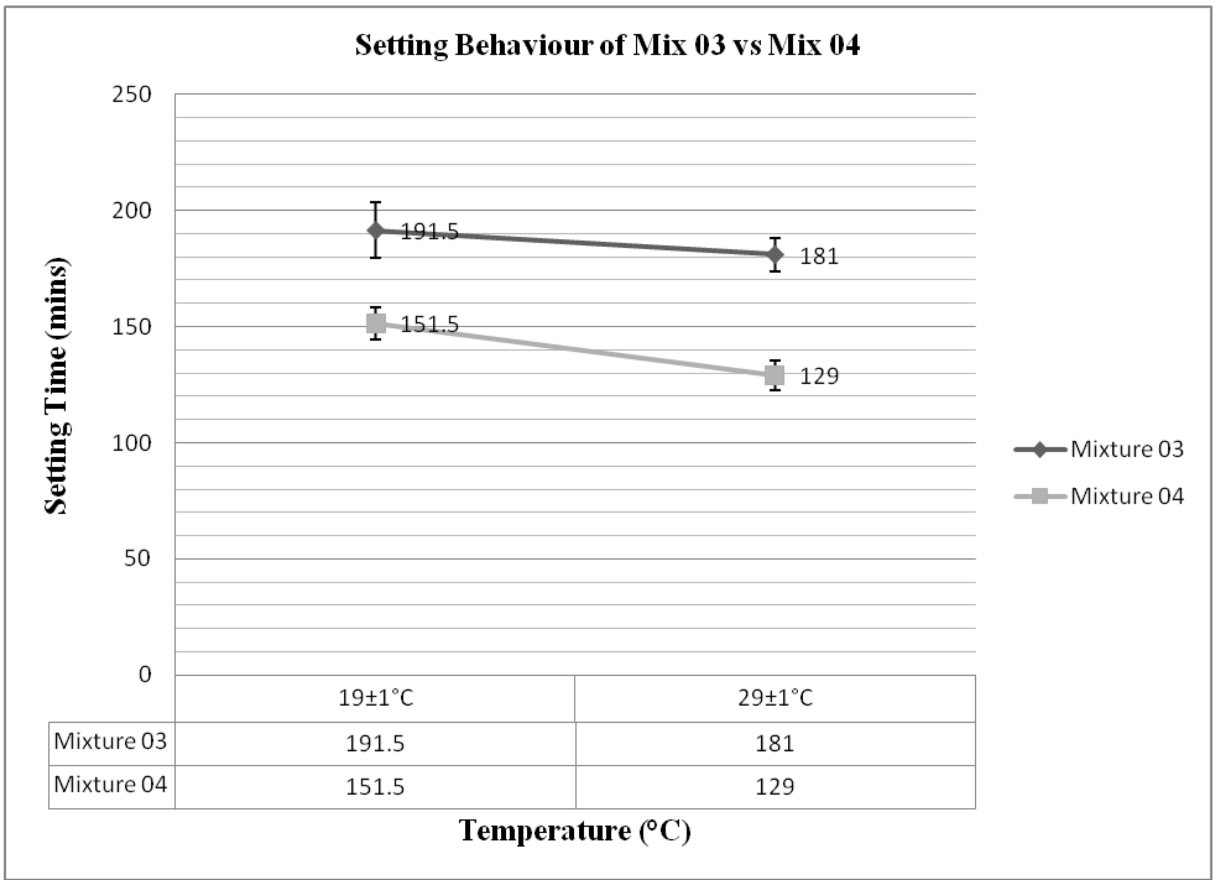


Fig 4.1: Setting Behaviour of Mixture 03 and Mixture 04

Setting behaviour of mixture 03 (CEM II with no admixture) with mixture 04 (CEM I with no admixture) based on temperature changes is shown in Figure 4.1 where setting time of both mixtures against temperature is represented. It can be seen that with increase in temperature, setting time decreases for both mixtures. Mixture of CEM I with no admixture set faster than mixture of CEM II with no admixture with about 40 – 50 minutes difference at both temperatures. This may be due to the slow hydration reaction of CEM II (including slag) which leads to slow setting process compared to CEM I (only clinker compounds) having higher rate of hydration. Thus, concrete manufactured based on CEM I with no admixture may set faster than concrete manufactured based on CEM II with no admixture in concrete constructions in North Cyprus.

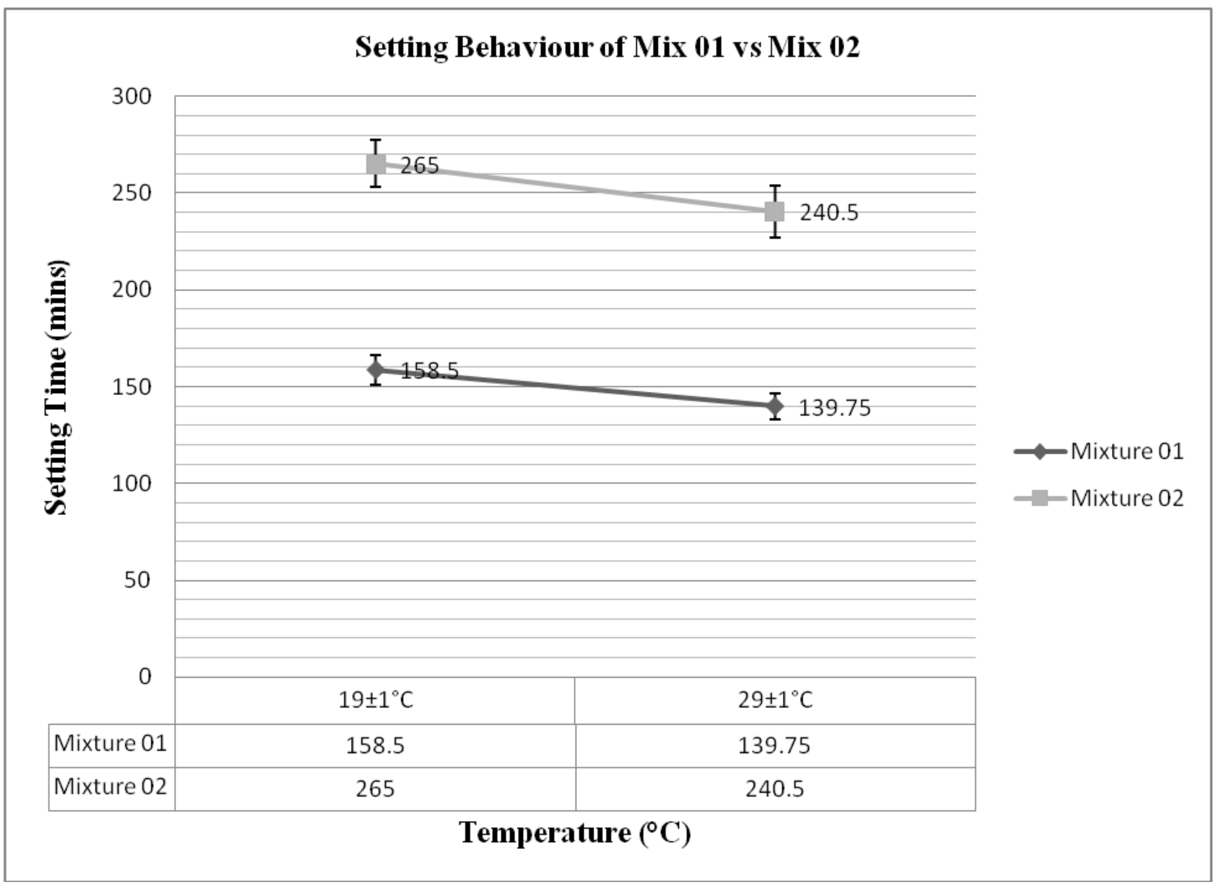
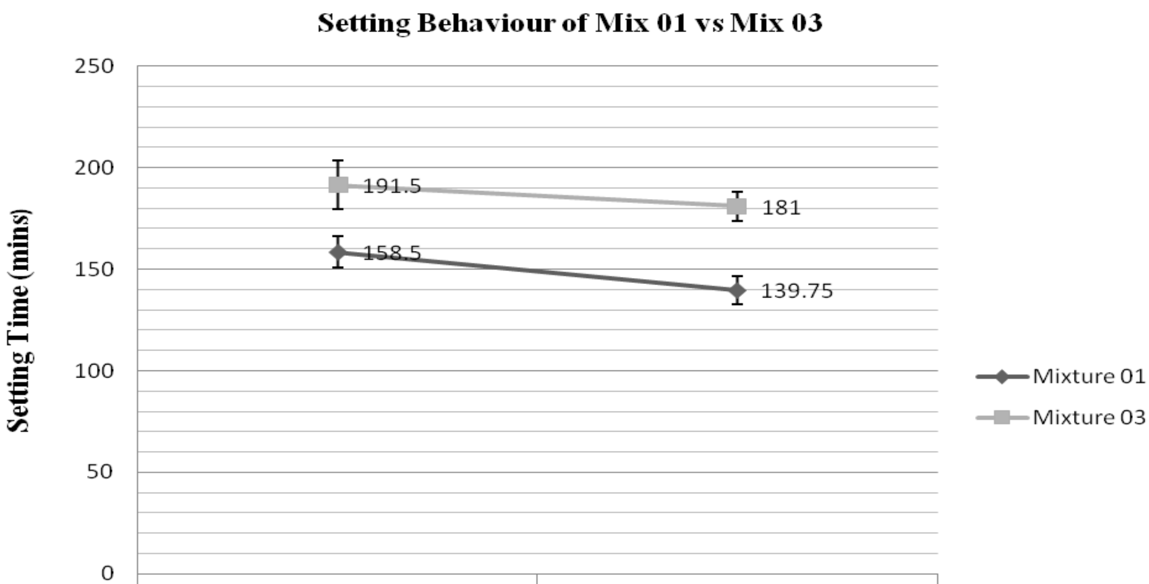


Fig 4.2: Setting Behaviour of Mixture 01 and Mixture 02

Setting behaviour of mixture 01 (CEM II with admixture) with mixture 02 (CEM I with admixture) based on temperature changes is shown in Figure 4.2 where setting time of both mixtures against temperature is represented. It can be seen that with increase in temperature, setting time decreases for both mixtures. The setting behaviour has a reversed action compared to mixtures of CEM II with no admixture and CEM I with no admixture which was due to the presence of admixture in mixture 01 containing CEM II and mixture 02 containing CEM I.

Mixture of CEM I with admixture set slower than mixture of CEM II with admixture with approximately 2 hours difference at all temperatures. This may be due to the fact that the effect of the admixture is influenced by cement composition. The fluidity effect of the superplasticisers is much more in CEM I with admixture than in CEM II with admixture. The fluidity effect caused a delay in the setting process in CEM I with admixture morethan in CEM II with admixture by delaying the hydration reaction.



	19±1°C	29±1°C
Mixture 01	158.5	139.75
Mixture 03	191.5	181

Fig 4.3: Setting Behaviour of Mixture 01 and Mixture 03

Setting behaviour of mixture 01 (CEM II with admixture) with mixture 03 (CEM II with no admixture) based on temperature changes is shown in Figure 4.3 where setting time of both mixtures against temperature is represented and it can be seen that with increase in temperature, setting time decreases for both mixtures. There was no much difference in setting behaviour of the mixtures which behaved similar to setting behaviour of mixtures of CEM II with no admixture and CEM I with no admixture. The difference in setting time was approximately 30 – 40 minutes at all temperatures.

Combination of cement with admixture also led to differences in the setting behaviour of the mixtures where CEM II with admixture set faster than CEM II with no admixture. The faster setting of CEM II with admixture may also be due to low w/c ratio present in the mixture. With high water content, the paste will remain plastic for longer time and so increase in setting time.

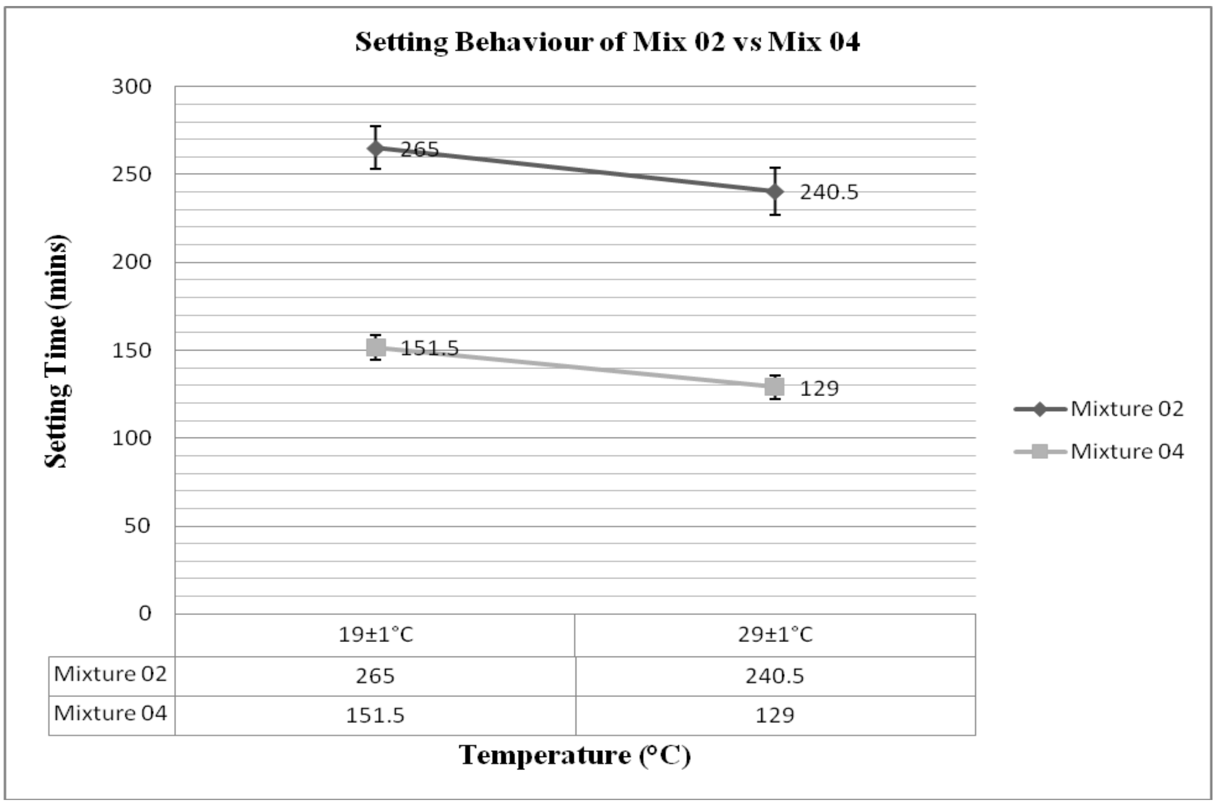


Fig 4.4: Setting Behaviour of Mixture 02 and Mixture 04

Setting behaviour of mixture 02 (CEM I with admixture) with mixture 04 (CEM I with no admixture) based on temperature changes is shown in Figure 4.4 where setting time of both mixtures against temperature is represented. It can be seen that with increase in temperature, setting time decreases for both mixtures. Setting behaviour of these mixtures containing the same cement type showed a reversed action with mixtures of CEM II with admixture and CEM II with no admixture.

Mixtures of CEM I with admixture and CEM I with no admixture exhibited similar setting behaviour with mixtures of CEM II with admixture and CEM I with admixture. The slow setting of CEM I with admixture may be due to the action of admixture in mixture which slows down the setting process thereby increasing the setting time despite the fact the both the mixture contain the same cement composition. Effect of water content is less than the effect of admixture in the mixtures. This is because figures 4.3 and 4.4 show setting behaviour of same cements type where a reversed action is observed. With similar cement type, the action of admixture affects the setting behaviour of concrete mixture. SCC manufactured based on CEM I with no admixture may set faster than SCC manufactured based on CEM I with admixture in concrete constructions in North Cyprus.

This study provided insight on the effects of different parameters. Type of cement, water content and admixture used are the main factor that affect setting behaviour of SCC pastes mixtures prepared in this study based on locally available materials in North Cyprus. Mixture of CEM I with no admixture set faster than all the mixtures, and mixture of CEM I with admixture having the lowest setting process. This shows that admixture used greatly affect the setting behaviour despite the fact that mixture of CEM I with no admixture contains higher w/c ratio. Type of cement also affect the setting behaviour as mixture 01 containing CEM II set faster than mixture 02 containing CEM I which might be due to effect C_3A content in the cements. The effect of water content can be seen in mixtures of CEM II with admixture and CEM II with no admixture, mixture of CEM II with admixture having low w/c ratio set faster than mixture of CEM II with no admixture having high w/c ratio.

4.2: Compressive Strength Test

SCC mixtures were manufactured based on locally available material with North Cyprus temperature conditions to check their performance mainly the compressive strength at 7 days and 28 days with no direct comparison between concrete and paste. Table 4.3 and Table 4.4 show the computed values for mean and standard deviation of the compressive strengths.

Table 4.3: Compressive Strength of SCC mixtures at 7 days

	Mixture 01	**Mixture 02**	**Mixture 03**	**Mixture 04**
Sample 01(MPa)	54.4	77.5	21.69	32.29
Sample 02(MPa)	47.2	75.1	26.9	31.79
Sample 03(MPa)	51.8	74.8	25.7	32.06
Mean(MPa)	51.1	75.8	24.8	32.0
S.D	3.646	1.480	2.728	0.250

Table 4.4: Compressive Strength of SCC mixtures at 28 days

	Mixture 01	**Mixture 02**	**Mixture 03**	**Mixture 04**
Sample 01(MPa)	74.2	83.6	34.69	38.5
Sample 02(MPa)	71.1	85.8	35.24	41.12
Sample 03(MPa)	73.4	82.6	34.76	41.07
Mean(MPa)	72.9	84	34.9	40.2
S.D	1.609	1.637	0.299	1.498

4.2.2 Compressive Strengths of SCC Mixtures

Compressive strengths of SCC mixtures manufactured were also evaluated so as to compare the strengths of SCC with and without admixtures. Compressive strengths based on cement type were also compared. The figures below show the compressive strengths of all the SCC mixtures manufactured in this study at 7 days and 28 days.

Compressive strengths of SCC mixtures manufactured in this study were greatly affected by certain factors. Cement type, water content and admixture used were the main factors that affect compressive strengths of SCC mixtures manufactured in this study based on locally available materials in North Cyprus. Higher compressive strengths were obtained in mixtures of CEM II with admixture and CEM I with admixture, thus, admixture used reduced the w/c ratio thereby increasing workability and strength. In mixtures containing same cement types, higher compressive strengths were obtained with mixtures having low w/c ratio. Mixtures containing CEM I have higher compressive strengths when compared with mixtures containing CEM II which may be due to slow hydration of CEM II

Figure 4.5 shows the compressive strength of mixture 03 (CEM II with no admixture) and mixture 04 (CEM I with no admixture) at 7 days and 28 days. It can be seen that mixture of CEM I with no admixture has more strength than mixture of CEM II with no admixture. This may be due to slow hydration of CEM II in mixture 03 which leads to slow hardening.

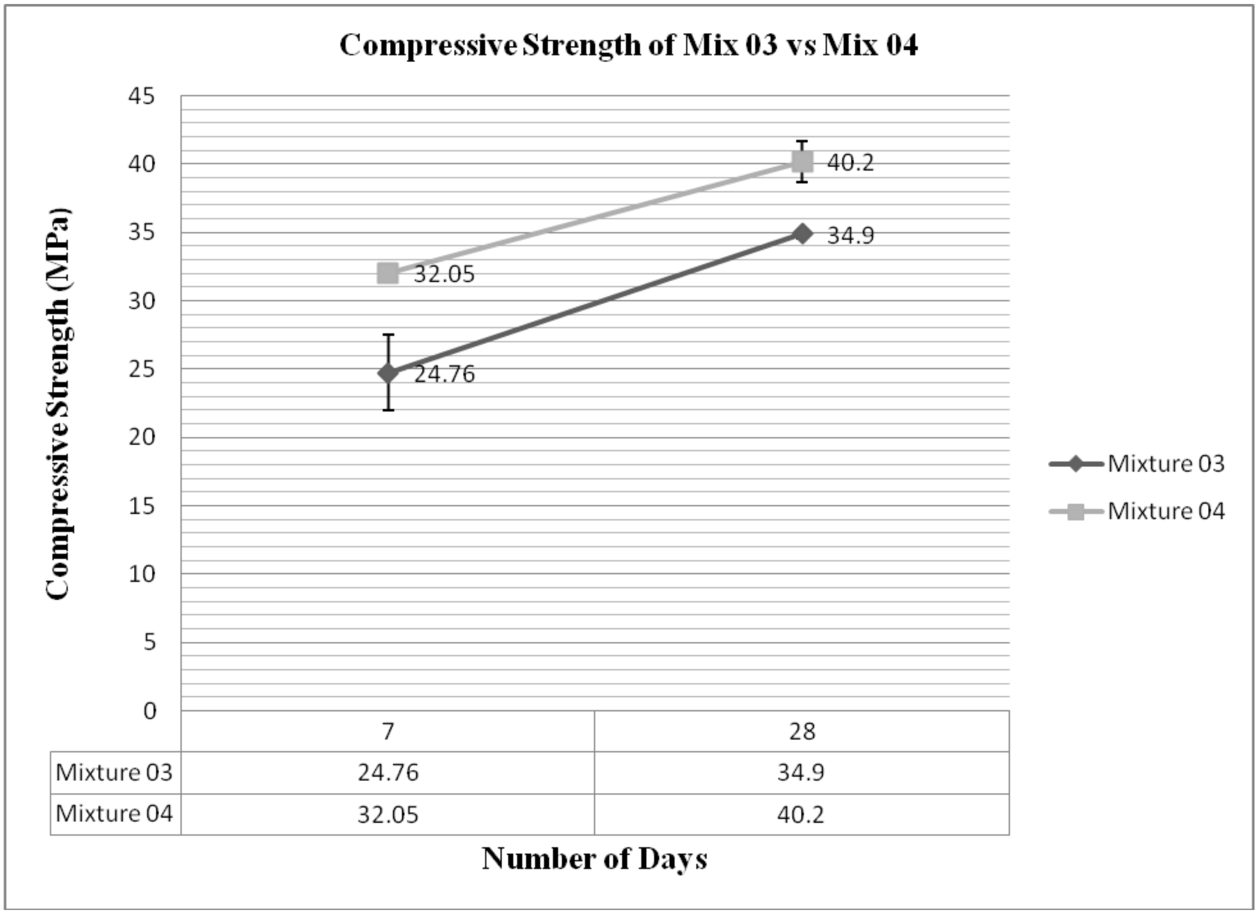
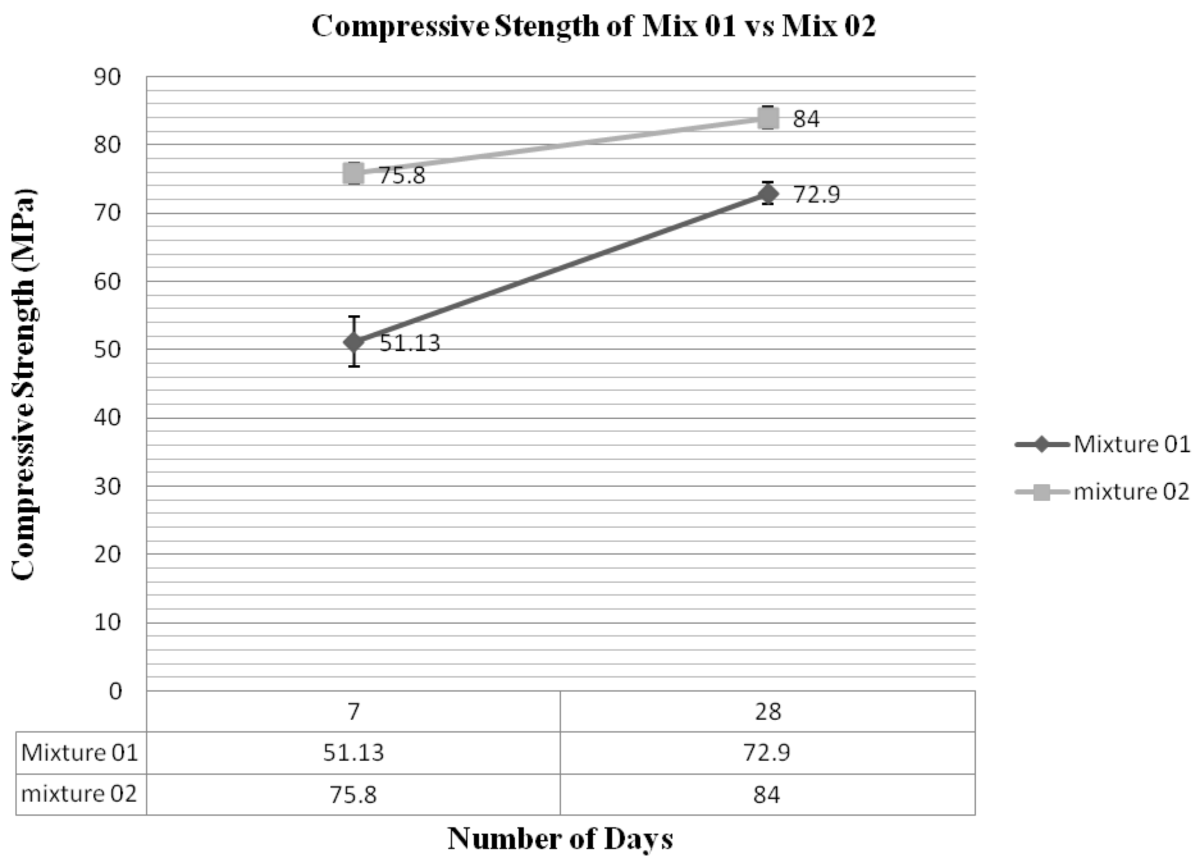


Fig 4.5: Compressive strength of Mixture 03 and Mixture 04

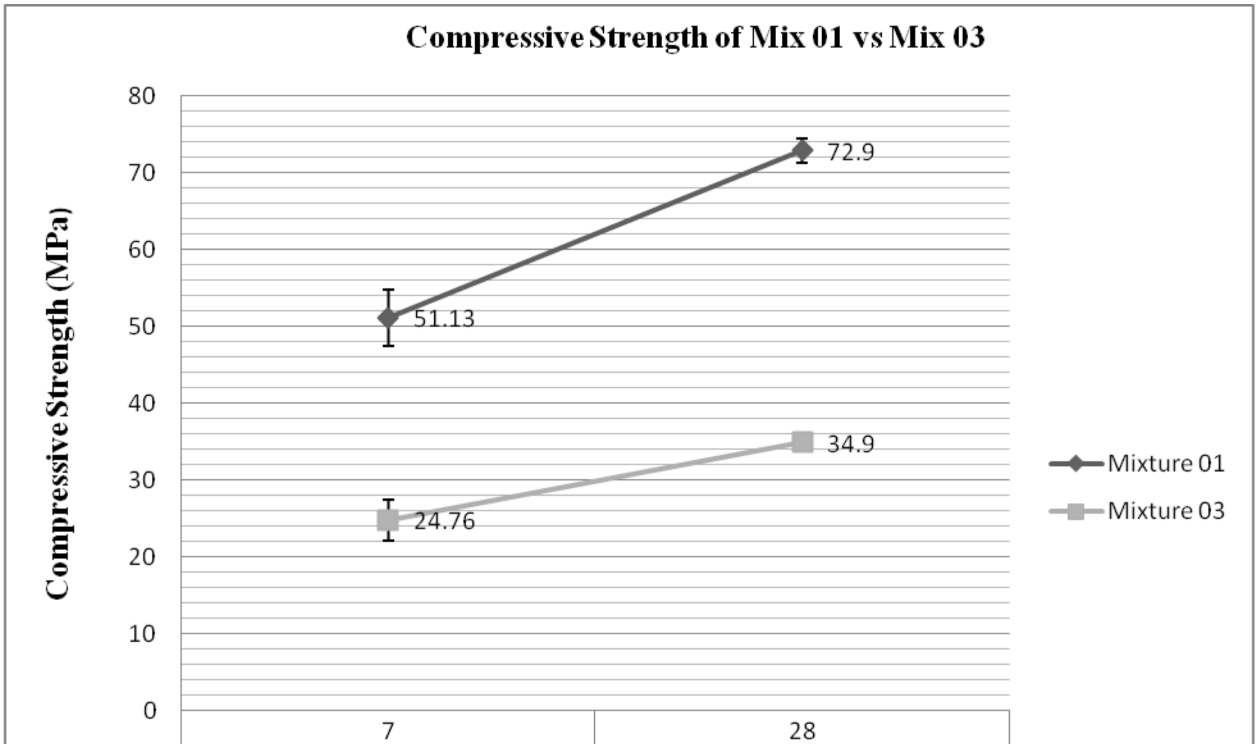
Figure 4.6 shows the compressive strength of mixture 01 (CEM II with admixture) and mixture 02 (CEM I with admixture) at 7 days and 28 days. It can be seen that mixture of CEM I with admixture has more strength than mixture of CEM II with admixture at both 7 and 28 days. It can also be seen that the difference in compressive values for 7 and 28 days in mixture CEM II with admixture is much compared to mixture of CEM I with admixture. These variations may be due to slow hydration of CEM II in mixture 01 which leads to slow hardening. Higher values of compressive strengths were obtained with these mixtures compared to mixtures of CEM II with no admixture and CEM I with no admixture having similar cement type orientation. This may be due to presence of admixture in mixture 01 and 02 which reduces the w/c ratio with increased workability and strength.



	7	28
Mixture 01	51.13	72.9
mixture 02	75.8	84

Fig 4.6: Compressive strength of Mixture 01 and Mixture 02

Figure 4.7 shows the compressive strength of mixture 01 (CEM II with admixture) and mixture 03 (CEM II with no admixture) at 7 days and 28 days. It can be seen that mixture of CEM II with admixture has more strength than mixture of CEM II with no admixture with higher compressive strength values almost doubled at both 7 and 28 days. This may be due to admixture present in mixture of CEM II with admixture which reduces the w/c ratio with increased workability and strength. The higher amount of water in mixture of CEM II with no admixture may also lead to low compressive strength as the mixture will be more porous. It can also be seen that the difference in compressive values at 7 and 28 days in both mixtures is much which may be due to slow hydration of CEM II.



	7	28
Mixture 01	51.13	72.9
Mixture 03	24.76	34.9

Fig 4.7: Compressive strength of Mixture 01 and Mixture 03

Figure 4.8 shows the compressive strength of mixture 02 (CEM I with admixture) and mixture 04 (CEM I with no admixture) at 7 days and 28 days. It can be seen that mixture of CEM I with admixture has more strength than mixture of CEM I with no admixture with higher compressive strength values almost doubled at both 7 and 28 days. This may be due to admixture present in mixture of CEM I with admixture which reduces the w/c ratio with increased workability and strength. The higher amount of water in mixture of CEM I with no admixture may also lead to low compressive strength as the mixture will be more porous. It can also be seen that the difference in compressive values at 7 and 28 days in both mixtures is not much which may be due to high rate of hydration of CEM I.

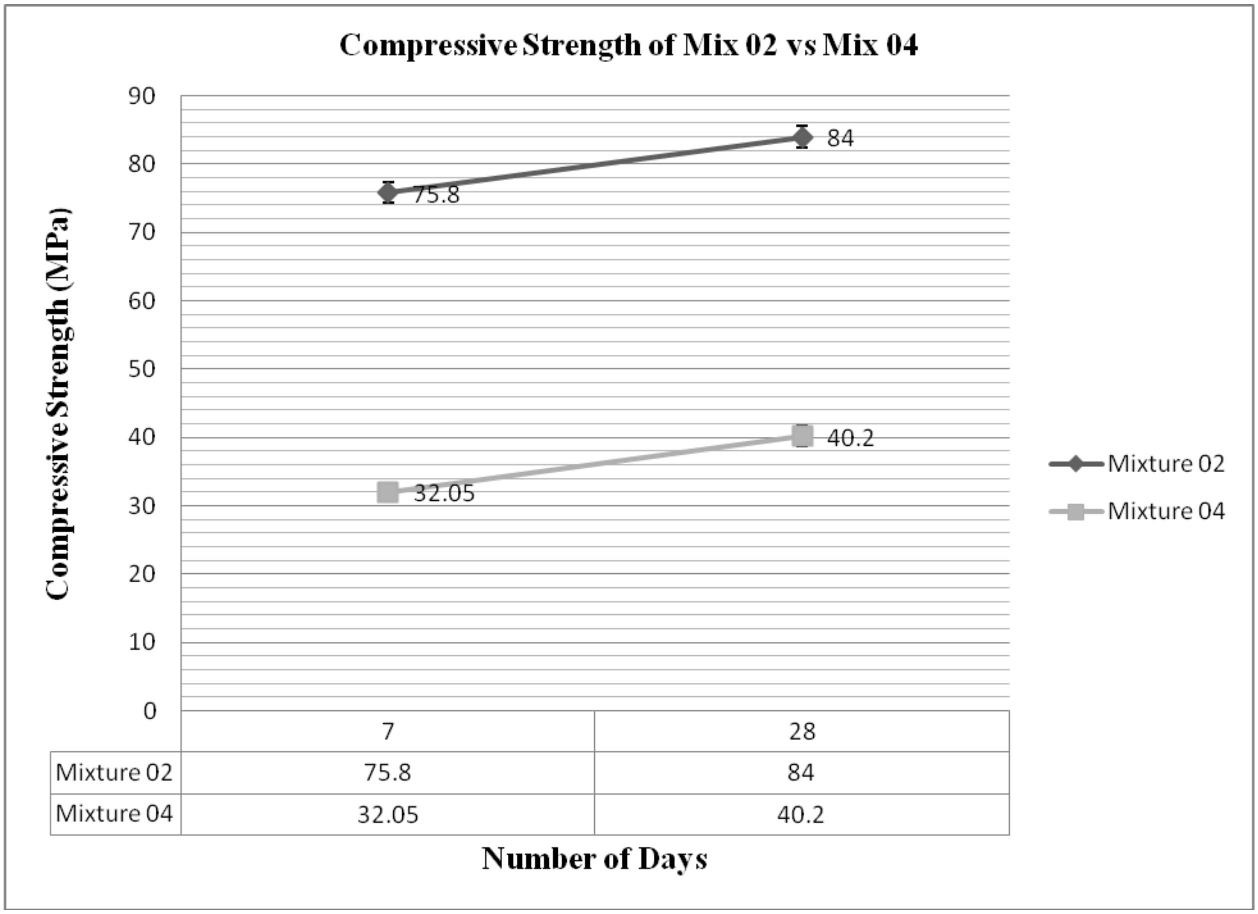


Fig 4.8: Compressive strength of Mixture 02 and Mixture 04

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Study on SCC manufactured based on the available materials in North Cyprus with temperature difference was carried out with main focus on setting behaviour of the SCC pastes. Compressive strengths of SCC mixtures manufactured were also evaluated. Following are the conclusions and recommendations drawn from the study:

1. A detailed literature review was carried out; SCC is a new type of concrete in North Cyprus and thus, not much available information on SCC manufactured in North Cyprus. This study provides insight on the setting behaviour of SCC produced by North Cyprus materials

2. Cement-admixture combination is very important thus, trial mixes should be made as the effect of admixture used was greatly influenced by cement type at both temperatures.

3. The fluidity effect of admixtures was more effective than the water content in mixtures of CEM I with/without admixture while water content was more effective than fluidity effect in mixtures of CEM II with/without admixture.

4. Mixtures of SCC with admixture produced a compressive strengths values much higher than mixtures of SCC without admixtures

5. Compressive strengths were found to be higher in mixture 01 (CEM II with admixture) and mixture 02 (CEM I with admixture) which increases the workability and overall strength and lower strengths in mixture 03 (CEM II with no admixture) and mixture 04 (CEM I with no admixture).

5.2 Recommendations

1. Mixture 01 (CEM II with admixture) set faster than Mixture 02 (CEM I with admixture) at both temperatures, thus, more attention should be paid on SCC manufacture using CEM II in North Cyprus.

2. Setting behaviour of the pastes behaved directly proportional to the temperatures changes; with high temperature, the setting process accelerates and with low temperature, the setting process is delayed.

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APPENDIX

Table 1: Gradation for Aggregates

SIEVE NO	AGGEREGATE (%)				
	(0 – 4) mm	(0 – 4) mm	5-12 mm	12-19 mm	GRADATION
31.5	100	100	100	100	100
16	100	100	100	78.0	97
8	100	100	60	0.8	75
4	94.0	94.0	12.1		59
2	70.0	70.0	2.0		42
1	46.0	46.0			27
0.5	30.0	30.0			18
0.25	21.0	21.0			12
%	30	29	26	15	

Table 2: Mix Design of SCC per 1m^3

Components	Volume(m^3)	Specific Gravity	Weights(kg)	Weights(kg)
Cements	116.2	3.01	350	350
Water	168	1.00	168	248.5
Admixture	4.90	1.07	5.25	
0 – 4mm	419.43	2.693	1129.52	1129.52
5 – 12mm	184.84	2.712	501.28	501.28
12 – 19mm	106.63	2.686	286.40	286.40
Total	**1000**		**2440.45**	**2515.70**