Some Properties of Self Consolidating Concrete Produced by Recycled Concrete Aggregates

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ABSTRACT

A lot of countries are producing Self-Consolidating Concrete (SCC), also called Self-compacting Concrete that has many advantages compared to normal concrete.

No specific or standard mix for achieving SCC is fixed nowadays. Meanwhile, some recommendations are indicated such the water to binder ratios should be less than 0.5, and the mixes should contain lower coarse aggregates and higher paste content comparing with conventional mixtures.

The present research shows the results and analysis of experimental tests carried out to study the properties of self-consolidating concrete based on using two types of aggregates: normal (SCC) and recycled (RA-SCC). While the referring test corresponding to the use of normal recycled aggregates in the mix of SCC is fixed, the tests related to recycled aggregates self-consolidating concrete cover different mixes according to the amount of recycled aggregates per ratio to the normal aggregates content.

The principal aim of this research is to improve the materials sustainability since the use of recycled aggregates will reduce the demand on the normal aggregates resulting from quarries. The scientific objective is to determine the effect of using recycled aggregates on the behavior of the SCC, also the possibility of using completely recycled aggregates instead of normal aggregates in the SCC mix.

This study is composed of three parts. The first part is based on preparing the mixes of SCC and RA-SCC with local available aggregates in Lebanon. The second part is based on studying the effect of using different amounts of recycled aggregates on SCC by testing the workability of SCC and RA-SCC fresh mixes using slump test. The final part concerns the tests related to some hardened properties of SCC and RA-SCC such as compressive strength, flexural strength, and durability, using two types of equipment's: the destructive and non-destructive such as Schmidt hammer and pundit tests.

The results have shown that the presence of recycled aggregate improves some properties of the SCC for special amounts. On the other hand the presence of recycled aggregate had a negative effect on the rheological properties of the SCC by reducing the workability of concrete, because recycled aggregate absorb more water than normal one.

The most important result is the possibility to use 100% recycled aggregates in the composition of self-consolidating concrete which improves the sustainability in the green construction.

Keywords: Self Consolidating Concrete, Recycled aggregates, Compressive strength, Flexural strength, Durability, Pundit test, Schmidt hammer.

ÖZ

Dünyada pek çok ülkede "kendinden yerleşen" veya diğer bir adı ile "kendinden sıkışan" beton kullanılmaktadır. Bu betonun normal betona kıyasla pek çok avantajı vardır.

Kendinden yerleşen beton için herhangi bir karışım tasarım yöntemi yoktur. Buna rağmen bazı karışım önerileri vardır. Bunlardan bazıları normal betona kıyasla su/çimento oranının 0,5' den düşük olması, daha az iri agrega içermesi, ve daha fazla pasta içeriğinin olmasıdır.

Bu araştırmada normal agrega ve geri dönüşümlü agrega kullanılarak üretilen kendinden yerleşen betonun deneysel sonuçlarının analiz edilmesi ile kıyaslanması yapılmıştır.

Bu araştırma sonunda normal agrega yerine geri dönüşümlü agrega kullanılarak sürdürülebilirlik için yol gösterici olma amaçlanmaktadır. Böylece beton üretiminde kullanılan normal agrega miktarında azalma hedeflenmektedir.

Yapılan çalışma üç bölüme ayrılmıştır. İlk bölüm Lübnan'da mevcut normal agrega ve geri dönüşümlü agrega ile üretilecek olan kendinden yerleşen beton tasarımı yapılmasıdır. İkinci bölümde üretilen normal agrega ve geri dönüşümlü agrega içeren kendinden yerleşen betonların taze mühendislik özelliklerinden olan işlenebilirkiliğin çökme deneyi ile ölçülmesidir. Son bölümde ise her iki betonun da çeşitli yaşlarda ve şartlarda basınç mukavemeti, eğilme mukavemeti, durabilite, ve tahribatsız deney metodları ile (beton çekici, ultrason) ölçümlerinin yapılmasıdır.

Sonuçlara bakıldığı zaman ise geri dönüşümlü agrega ile üretilen kendinden yerleşen betonun pek çok özelliklerinde normal agrega betonuna göre iyileşmeler görülmüştür. Fakat özellikle taze betonun işlenebilirliğinin geri dönüşümlü agrega kullanıldığı zaman kötü yönde etkilendiği görülmüştür. Bunun esas nedeni ise geri dönüşümlü agreganın su emme kapasitesindeki fazlalıktır.

Anahtar Kelimeler: Kendinden yerleşen beton, geri dönüşümlü agrega, basınç mukavemeti, eğilme mukavemeti, durabilite, ultrason, Schmidt çekici

DEDICATION

Dedicated to

My lovely Father and Mother

To my Dearest Brothers and sister

To my Friends

For their Love Endless Support and

Encouragement

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LIST OF SYMBOLS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS EN	British European Standards
Fr	Flexural Strength
Id	Durability Index
RA	Recycled Aggregates
RA-SCC	Recycled Aggregates self-consolidating Concrete
RC	Recycled Concrete
RCA	Recycled Concrete Aggregates
RILEM	Reunion Internationale des Laboratoires et Experts des Materiaux, Systemes de Construction et Ouvrages (French: International Union of Laboratories and Experts in Construction Materials, Systems, and Structures)
SCC	Self-Consolidating Concrete
SP	Super Plasticizer
UPV	Ultrasonic Pulse Velocity
VC	Vibrated Concrete
VMA	Viscosity Modifying Admixture
W/C	Water Cement Ratio

Chapter 1

INTRODUCTION

1.1 General

Self-consolidating concrete (SCC) has been used to replace normal concrete, as time has been evolved and most importantly as we enter a highly industrialized age. SCC is considered different than other types of concrete because after casting into the formwork, the concrete itself does not require any sort of vibration. The compaction of this concrete is accomplished with hardly accessible parts, no additional external force except for the gravity that is a result of the concretes own weight. The filling ability and stability of SCC in the fresh state can be defined by its ability to flow, viscosity (assessed by rate of flow), passing ability and segregation resistance (EFNARC, 2002).

Different bibliographical researches have been done to get the latest mixes and results for SCC and even RA-SCC. The literature has shown that using fine recycled aggregates in the SCC will cause higher shrinkage in concrete than that of natural aggregate concrete. Also the recommendations given by (R. El Dalati, 2008) have shown that the amount of recycled aggregates from random origins should not exceed 20 % of the total amount of normal aggregates. These recommendations have also shown that while respecting this ratio of 20% and adding super-plasticizer, the strength of concrete may recapitulate and even overcome the original value for normal concrete. Otherwise, some researchers have limited the ratio of replacement normal aggregates by fine recycled aggregates to 30% of the total amount of aggregates (Evangelista and de Brito, 2007).

The recycled aggregates (RA) which may be used in the SCC are made from construction and demolition waste (Dhir RK, Limbachiya MC, Leelawat T., 1999).

The recycled aggregates quality is lower than natural aggregates since the mass to volume ratio of RA is typically less than the natural aggregates i.e. RA tends to have higher water absorption with respect to natural aggregates (Lin YH, Tyan YY, Chang TP, Chang CY., 2004). Also (R. El Dalati, 2007) has shown that the porosity of concrete based on RA is higher than that of normal concrete. That was the reason of getting lower strength without any addition.

The long term purpose of this research is to study the effects of recycled aggregates in the production of self-consolidating concrete.

1.2 Aim and Objective of this Study

The main goal of this experimental research is to study the effect of using the recycled coarse and fine aggregates on some rheological and mechanical parameters of SCC.

To achieve this goal, the following objectives are maintained:

1. To prove that we can use recycled fine and coarse aggregates for SCC production.

2. To produce a general literature survey about SCC and recycled aggregates characteristics including their mechanical and physical properties.

3. To study the properties of fresh RA-SCC such as slump flow test.

4. To study the properties of hardened RA-SCC such as compressive strength, flexural strength and durability using destructive and non-destructive tests i.e. Schmidt hammer and ultrasonic pulse velocity (pundit test).

1.3 Implemented Work

1. An assessment and evaluation of many previous publications in the recycled aggregates self-compacted concrete field.

2. Standards such as British European Standards, ASTM and ACI references were a guide in order to define, implement and execute lab trials for this study.

3. Destructive tests were carried out in order to investigate the physical and mechanical properties, such as compressive strength, workability, flexural strength and durability. Also some non-destructive tests have been done to compare the results such as Schmidt hammer and Ultrasonic Pulse Velocity (pundit test).

Chapter 2

LITERATURE REVIEW

2.1 Self-Consolidating Concrete

2.1.1 Introduction

As a result to the rapid growth of urban areas, reinforced concrete is considered to be one of the most extensively consumed utility.

In the recent years, a new concrete mixture of high performance has gained a wide acceptance as it reduces noise pollution vibration and makes the construction process faster in duration. It is called self-compacting concrete or self-consolidating concrete (SCC). This type of concrete is known to flow below its load along with sustaining adequate segregation resistance (Gaimster, 2003).

The Self-consolidating concrete (SCC), one of the latest achievements of concrete technology, was first established by Japanese researchers in the 1980s. It is considered a concrete that can flow readily under its own weight to completely fill the formwork and requires no mechanical vibration. This kind of concrete must achieve magnificent deformability and great stability to ensure high filling capacity of the formwork with complicated shapes, deep and narrow sections and congested structural members (Erdem TK et al., 2009).

Due to the characteristics stated by Vachon and Daczko (2002), the self-consolidating concrete allows both designers and architects to explore their imagination in achieving what was not achievable using normal concrete such as lighter, slender and larger bridges in addition to underwater structures. This makes the SCC a material that will develop infrastructures further in the future in terms of construction industries and their surrounding areas (urban or rural). However, in the United Kingdom e.g. the environment and health protection is required, Rola D. (2013) states that the use of SCC mainly reduces the vibration-induced noise pollution.

2.1.2 Brief History and Development of Self-Consolidating Concrete

In the last two decades, the development of the SCC has improved the durability properties of concrete. In addition, Japanese studies concluded that unsuitable consolidation of the fresh concrete was the main cause affecting the durability of concrete owed to unskilled labor on jobsite (Y. Obied, 2014).

In 1986, the idea behind high durability of concrete with no consolidation to achieve full compaction was set. However, some modifications occurred on the main draft of the conception. The use of local raw material was permitted in Japan after publishing the guidelines for the usage of SCC (Collepardi, 2003).

On the other hand, non-consolidating concrete was widely used in the industrial and construction domains in the latest 80 ''s in order to either higher placing ratio or to permit hard placing (Collepardi, 2003).

Okamura lead others to announce self-consolidating concrete in 1989 (Ozawa et al, 1989). Then some researches started all over the world, in order to investigate the advantages of SCC in the engineering field (Byun et al., 1998; Daczko and Vachon, 2006; Skarendahl, 1998; Khayat and Aitcin, 1998; Tangtermsirikul, 1998; Walraven, 1998). The SCC strategic rules have been distributed by a teamwork in Europe at the end of 90 ’’s (EFNARC., 2002, BE96.-3801, 1996).

SCC was used by huge construction companies not only for the durability properties but also for logistic characteristics i.e. SCC can be used with short time and less post de-molding jobs (Daczko and Vachon, 2006).

SCC has been lately used in adjusting and repairing concrete due to its special properties where it provided sufficient filling and pouring of congested areas and ensured well finishing. (Jacobs and Hunkeler; Khayat and Morin, 2002).

After the Japanese evolution of Self-Consolidated Concrete, it has been the main component of cast in place and precast cases in many areas all over the world (RILEM 174-SCC, 2000).

Also, SCC has been used in the precast concrete industry especially in US plants since year 2000 (Y.Obied, 2014). Moreover, in US, the consumption volume for SCC in the precast industry was 135000 m^3 since fifteen years ago. Then, SCC has been rapidly jumped to one million and eight hundred thousand cubic meter since twelve years ago (ACI 237, 2007). For year 2002, 40 % of the industries that produced precast concrete have used SCC and new plants have been built behind the idea of SCC. However, ready mix plants are still in there beginning step of using SCC in the US (Vachon and Daczko, 2002).

2.1.3 General Background of Self-Consolidating Concrete

SCC is well known by its high flow-ability and limited viscosity; which give it the ability to flow without being blocked by the reinforcements. Moreover, SCC will de-air itself upon casting. Once all the characteristics mentioned above are present we can classify the concrete mixture as a self-compacting one.

SCC is specified as "the most revolutionary development in concrete construction for several decades". It offers a lot of advantages for the pre-cast and pre-stressed concrete industry and for casting in place because of a number of factors including the following (Okamura 1997; Okamura and Ouchi 1999):

- **Eliminating vibration and lowering noise level:** In fact, it decreases the number of labors required to achieve onsite vibration.
- **Placing and filling:** SCC has the ability to fill all the corner in the formwork and placing in easily way.
- **Acquiring an enhanced surface finishing:** SCC provides an identical finished surface with few defects as shown in Figure 1.

Figure 1: Finished surface produced by SCC without any defects

- **Improving durability:** SCC has a dense matrix, a high consolidation, and a bond around reinforcement which leads to improve the structural durability.

2.1.4 Fresh State Properties of SCC

SCC fresh properties are directly related to the self-compact ability when compared to conventional properties, which in turn was known as the rheology of fresh concrete. However, while relating to handling in practice, it is assigned as workability constraints (RILEM 174-SCC, 2000).

2.1.4.1 Slump Flow Test

It is a parameter used to determine the diameter of the free flow of self-consolidating concrete with obstacles nonattendance. This technique is guided by rules (ASTM C 1611, 2005.), by few modifications to calculate the conventional concrete slump. The experimental trial is not difficult and it can be performed in the sites and the labs. Two factors can be achieved: the flow spread (workability) and the flow time T50 (workability rate along a flow distance) (De Schutter, 2005). Slump flow tools are specified in Figure 2.

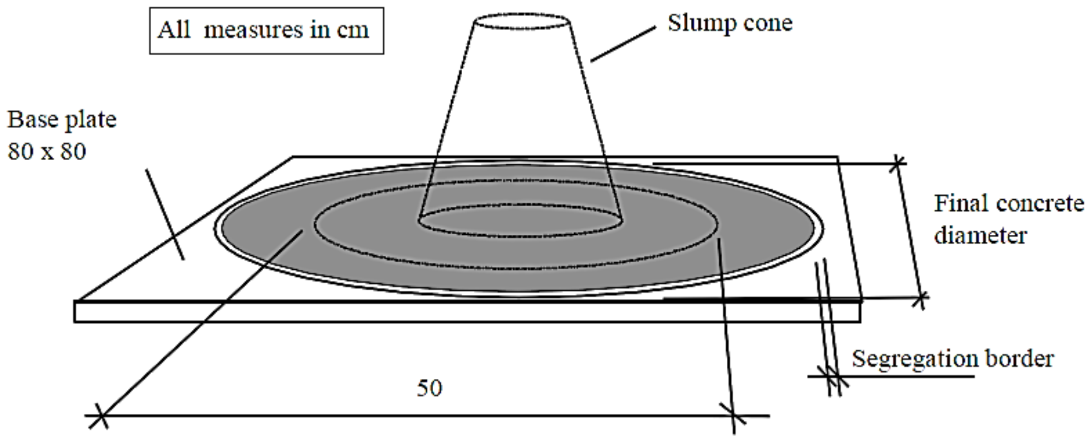

Figure 2: Tools of Slump Flow

The slump flow range for SCC is between 450 mm and 760 mm. When slump flow increases, the more SCC can pass, and the quicker it can fill the molds (ACI 237, 2007).

2.1.4.2 Deformability

Deformability is the ability of a material to change its shape. It has been shown that the SCC is able to totally fill all the areas to reach corners of the formwork in both horizontal and vertical ways while preserving its homogeneity (Rola.D, 2013).

Kennedy (1940) mentions that it should be sufficient mortar to wrap the aggregate particles used for the SCC mix. This extra addition of the paste will be useful in lowering the friction between the aggregate particles and provide better flow-ability. The workability will be too much affected if there is no paste layer between the aggregates because it will raise the friction among the particles thus affects workability and flow. Figure 3 displays layers formed of cement paste within the aggregate particles by adding paste (Oh et al., 1997).

Figure 3: Paste layer around aggregates.

2.1.4.3 Passing Ability

In order to be more accurate in measuring ability of passing, it is important to pay attention to the shape and reinforcement capacity, the ability of filling and the maximum aggregate size.

The essential element is the confinement space where SCC continuously flow filling the formwork. In general, the gap is interrelated to the reinforcement spacing. However, if the reinforcement is not overfilled, the gap between the formwork and the reinforcement won’t be necessary as SCC can rim the bars.

Moreover, for known aggregate contents and physical properties, the workability of SCC is directly related to the rheological characteristics of paste, the thresholds of which were determined by the model (Qiong Wu, Xuehui An, 2013).

Whenever the space between the particles decreases, the contact between the particles increases. This will lead to an increase in the internal stresses during the deformation of the mix, especially when it is adjacent to interferences causing blockage. The investigation have shown that the increase of internal stresses absorbs the energy needed for flowing, and reducing the coarse aggregate content can effectively reduce the risk of block-age (Okamura and Ouchi, 1999).

2.1.5 Hardened Properties of SCC

In terms of concrete structures, engineers emphasize on certain concrete properties such as compressive strength, tensile strength, modulus of elasticity, creep, shrinkage, coefficient of thermal expansion, bond to reinforcement, shear force capacity in cold joints, and fire resistance.

These concrete properties across a time interval are critical and may vary. To ensure that these properties follow certain concrete standards, some researchers have carried out tests particularly focusing on the circumstances and the sizes of the mechanical element (EN1992-1 – Eurocode 2).

2.1.5.1 Compressive Strength

When using similar water-cement or cement binder ratio, it has been shown that SCC becomes slightly stronger than the traditional vibrated concrete. According to RILEM (2000), this might be due to the association between vibration and the interface of both the aggregates and hardened paste. Also as vibration is reduced, the interface between the aggregates and hardened paste has been improved. The tensile and compressive strengths have been the same for Self-Consolidated and normal concrete (RILEM 174-SCC, 2000).

2.1.5.2 Tensile Strength

In order to estimate the SCC and normal concrete tensile strengths, 3 familiar techniques are mostly assumed:

- ✓ Direct tensile strength.
- ✓ Splitting tensile strength.
- ✓ Bending tensile strength (3 or 4- points loading).

Because of a reasonably high degree of trouble through performance, the direct tensile strength examinations are somewhat rare. Consequently, the tensile strength is resulted from examination outcomes initiating from bending or splitting tensile strength.

2.1.5.3 Modulus of Elasticity

The quality and the quantity of the aggregate influence the modulus of elasticity of the concrete. In selecting an aggregate with a compacting high modulus of elasticity, the static modulus of elasticity for concrete will increase.

As a result of the aggregates substantial influence with the whole concrete stiffness, it is frequently supposed that self-consolidating concrete having greater paste content, is defined to be having less modulus of elasticity (Domone, 2007).

According to survey done by Domone (2007) the modulus of elasticity is higher with less compressive strengths for Self-Consolidated Concrete and Vibrated Concrete.

2.1.5.4 Creep and Shrinkage

Other than the properties that have been stated before, creep and shrinkage are dependent elements for many reasons. Two different opinions were noticed after several researches: the first one observed that shrinkage will increase when using SCC while the others noted opposite results (RILEM 174-SCC, 2000).

Relating the normal characteristics for same strength of both normal concrete and SCC, creep didn’t change when load remains constant (RILEM 174-SCC, 2000).

Different researches have reported that using limestone along with appropriate fine materials decreases SCC shrinkage (Montgomery and Bui Khanh, 1999).

2.1.5.5 Coefficient of Thermal Expansion

The thermal expansion coefficient of concrete ranges according to its structure, life time and moisture content. The thermal expansion coefficient varies from 8 to13 μ-strains/k, the norm rule defines that when there is enough data, the thermal expansion coefficient can be assumed from10 to 13 μ-strains/k for SCC (EN 1992-1-1).

2.1.5.6 Bond to Reinforcement

A concrete is referred to being reinforced according to the relative cohesion occurring among concrete and the steel bars. An adequate concrete cover is found such that it will act as a barrier/bridge to transmit bond stresses among concrete and steel bars.

Weak bonds frequently originates as a concrete failure encapsulate fully the steel reinforcements when placing and thus concrete segregation before hardening decreases the contact quality. SCC fluidity and cohesion minimize these negative effects, especially for top bars in deep sections (SONEBI M.; WENZHONG, Z.; GIBBS J., 2001).

Based on (EN1992-1 & EN206-1), the SCC embedded strands transfer length was accepted when related with the designed values.

The code formula should be applied even though cohesion parameters are normally improved when using SCC, for an assumed compressive strength.

2.1.5.7 Shear Force Capacity

After the processes of hardening and casting of the cement, the SCC surface is found to be rather smooth and impermeable. When the first layer is placed, the shear force capacity is found to be less than VC among the 1st and 2nd layers. Thus, it may not be enough to resist any shear force. Treating the surface with brushing, surface roughening or surface retarders must be enough to support carrying of such shear force (ISBN 90 3760 242 8 &TUE/CCO/A-2004-6).

2.1.5.8 Fire Resistance

The fire resistance may not vary according to (ISBN 90 3760 242 8) between SCC and normal concrete. According to (ISBN 0 7506 5104 0, 2003), low permeability in concrete is more prone to catching fire. However, it varies according to the type of aggregate used, the quality of the concrete itself and its moisture content. Moreover; with SCC being stronger, and less permeable, (ISBN 90 3760 242 8) states that it will perform similarly to whichever normal high strength concrete below fire situations.

2.1.5.9 Durability

Durability properties may vary according to reduction in carbonation, chloride penetration and water permeability (RILEM 174-SCC, 2000). In general terms, the type of the used filler to produce SCC, and the required quantity to produce the cement are also proven to influence the durability properties of the mix. Moreover; the methodology of achieving lower air voids is important in producing SCC with better freezing thawing characteristics. (RILEM 174-SCC, 2000).

2.1.6 Segregation Resistance

The Segregation resistance belongs to the ability to retain the coarse components of the mixture and the fibers in suspension in order to keep up a homogeneous material. The stability depends actually on the viscosity of the concrete cohesiveness and mixture. In addition, the reduction of the free water content and the increase of the amount of fines might lead to the increase of segregation (Khayat et al., 1999).

Providing a high viscosity is capable of preventing a concrete mixture from bleeding and segregation, this because segregation resistance can be controlled by viscosity. The special case of segregation is bleeding in which water moves upwards by separates from the mixture and capillary action.

There are two main approaches that are capable of ensuring acceptable stability. Approach one is based on the Japanese technique. Its main idea lies under the use of a super-plasticizer, high powder content, low W/C percentage, low aggregate content and mineral admixtures (Bonen, 2004). However, approach two is based on low powder content, super plasticizer and integrating a viscosity-modifying admixture (Bonen, 2004).

2.1.7 Differences between SCC and Vibrated Concrete (VC)

The components of self-consolidating concrete are somehow equivalent to the components of VC, those components cement, aggregates, water and admixtures. However, there are some causes that lead to what is called self-compactibility. The low W/C ratio, large quantity of fine aggregates, the integration of admixtures, and the reduction of coarse aggregates are the four main causes that contribute to the self-compactibility. Figure 4 shows a general comparison between mix proportions of self-consolidating concrete (SCC) and vibrated concrete (VC) (Ouchi and Okamura, 2003).

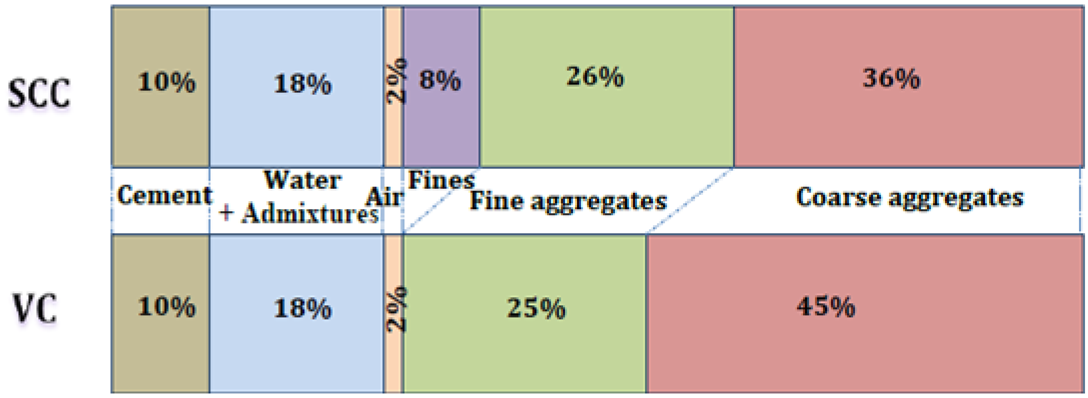

Figure 4: Differences among VC and SCC mixtures

The uniqueness of SCC lies under the fact of air bubbles migration into the surface without need of the vibration, which is predominantly because of different reasons, such as the material characteristics, mix proportion and dense matrix. The passing-ability of smoothly in the filling-ability and reinforcement bars of all the formwork without any bleeding or segregation are noticeable, no matter how narrow the structural elements are, or even the complicated shapes and heavy reinforcement they do have, and that's mainly because of the moderate viscosity and high fluidity. These fresh properties would be more than enough to provide a durable and high strength concrete in the hardened properties. Moreover, the performance becomes even higher by adding steel fibers (Ouchi and Okamura, 2003).

2.1.8 Mechanisms of Achieving Self-Consolidating Concrete

In the fresh state, and in order to prevent any segregation that might occur due to the formwork that passes between heavy reinforcement, SCC should attain both, rheological stability in addition to high flow ability, since that SCC is required to be as fluent as possible to completely fill under its own load.

Figure 5 explains the effect of each rule on the accomplishing of mechanisms and the three basic rules of fulfilling self-compact-ability (Ouchi and Okamura, 2003).

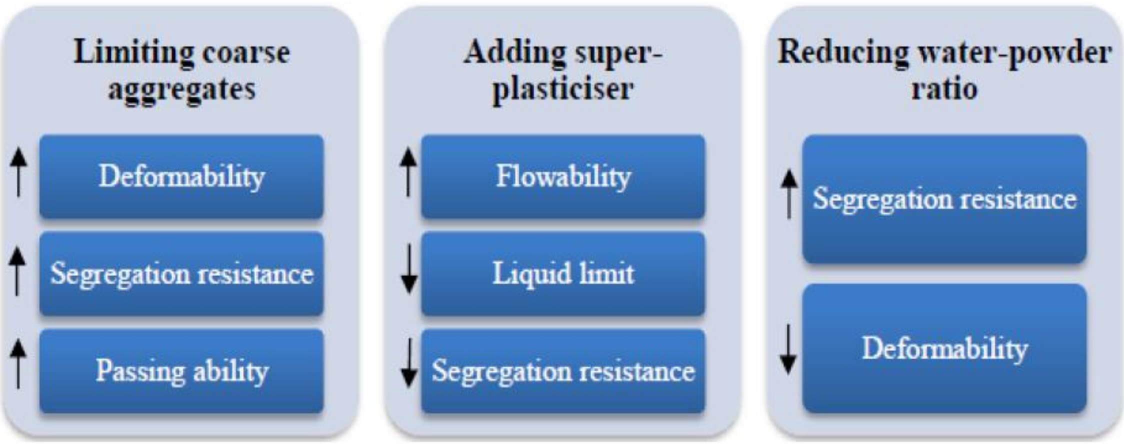

Figure 5: Accomplishing of Mechanisms (SCC) ↑ increases, ↓ decreases

Limiting aggregate content: The spreading of self-compacting concrete and its filling ability are limited by the contact between the aggregates. consequently by the replacing of crushed aggregates with the round aggregates, and reducing the volume of coarse aggregates the self-consolidating concrete passing ability will be increased, which would result to the improvement of the workability and the optimization of the packing density of skeleton (Kwan and Ng, 2010).

High super plasticizer quantity: Attaining a highly flow able mixture that conflict with staying the uniformity on the adequate level. The achievement of mechanism is due to the reducing of attractive forces among super-plasticizer and the particles of cement flocculated through dispersion the effects of plasticizer on the particles. The challenge is the ability to obtain an optimum amount since that a high quantity on one hand effect the segregation, on the other hand, the fluidity is settled by low quantity. Hence attaining a great degree of cohesiveness be able to warranty a substantial development in the whole presentation (Ng and Kwan, 2010).

High volume paste: Maintaining aggregate separation can be accomplished through a high volume of paste found in SCC (Tviksta, 2000) and (Okamura and Ouchi, 2003).

While increasing the fine quantity particles, consequently increases the cohesiveness and workability. Nevertheless, such an increase in the fine particles leads to simultaneous reduction of the intertwining of the coarse particles which could effect on the behavior of blocking (Khayat, 2000).

This inclusion of the large fines quantity requirement lies under the fact that there should exist cementitious replacement ingredients (such as; silica fumes, fly ash, GGBS, etc...) and that’s in order to avoid excessive heat generation.

Keeping in mind that SCC with the appropriate use of VMA can attain better flow-ability and greater slump without segregation. Moreover, SCC is capable of preventing sulfate attack and salt penetration (Nowak et al 2005; Massicotte et al 2000).

2.1.9 Self-Consolidating Concrete SCC Mixture Proportionings

A simple mix design was suggested by Okamura and Ozawa (1995), which focuses mostly on fixing the coarse aggregate content by 50 % of solid volume whereas the fine aggregate content by 40 % of mortar volume. However, the water to powder ratio ranges between 0.9-1 according to the properties of mortar because self-consolidating concrete is very sensitive to itself. Therefor the ability of self-consolidated concrete is reached by adjusting of the water/powder percentage and the amount of SP. This is not correlated to the grouping of sand and gravel, grades in a comparatively of high paste content. The first step for the growth of self-consolidating concrete has been instigated by Japanese method in several European countries (Radix and Brouwers, 2005).

The design of SCC has passed by several methods that are generally divided into steps. The first stage corresponds to the endless including admixtures, water, filling material and cement with lower than 0.1mm particles size, while the following stage is casing both the fine and coarse aggregates (Gaimster and Dixon, 2003).

No specific or standard mix is normalized for achieving SCC. The water to binder ratios should be not more than half and the trials should contain greater paste and lesser coarse-aggregate contents relating with normal concrete. Silica fume and fly ash are main admixtures that can improve both segregation resistance and workability.

A review focused mostly about the trials mechanism and quantities from laboratory and in situ has shown that many differences exist in design; various features were similar to most of trials as shown in Table (1) (RILEM 174-SCC, 2000; Gaimster and Dixon, 2003). Table (2) provides the proposed slump flow diameter with the desired powder content (ACI 237, 2007, p.18).

Table 1: Mutual elements for SCC design

Property	**Comments**
Water content	150-200kg/m^3
Admixtures	Super plasticizer and Viscosity modifiers: key role is to improve workability and or affect directly segregation with achieving higher water/binder ratios.
Binders	Ranges between 450-600 kgandm3. Ground granulated blast furnace slag and Fly Ash are typically parameters to increase cohesion.
Fine Aggregate	Density ranges:710 to 900 kg/m^3
Aggregates	Density ranges: 750 to 920 kg/m^3. The sizes for crushed rock and gravels that are commonly used are up to 20mm.
Workability measurement	Several trials evaluate fresh properties (refer to section 2.1.4)

Table 2: Recommended powder content ranges

	Slump flow of < 550mm	**Slump flow of 550 mm to 650 mm**	**Slump flow of >650mm**
Powder-content Kg/m^3	355-385	385-445	>445

2.1.10 Effect of super-plasticizer on SCC

Super-plasticizers help for the reaching of lesser porosity and denser packing in concrete with improving the flow-ability and increasing the hydration over better dispersion in particle of cement (see figure 6), therefore is supporting to creating self-consolidating concrete mixes with good durability & strength (Deeb. R., 2013).

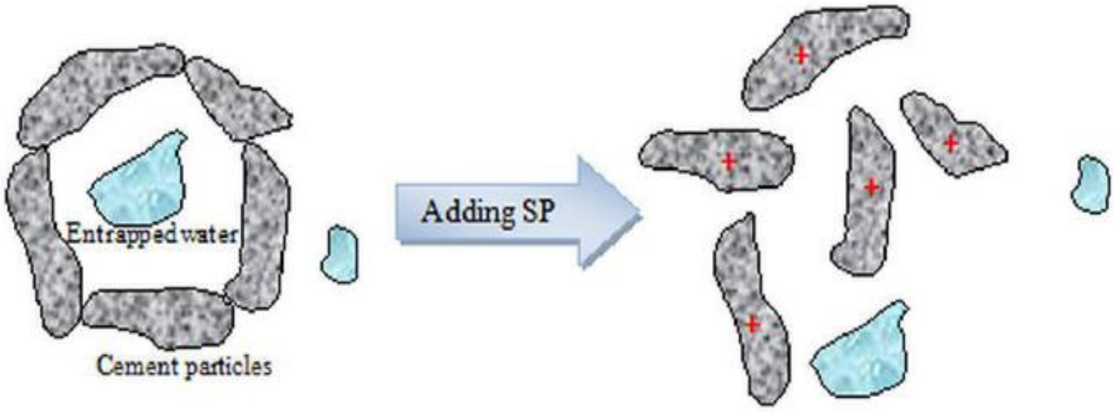

Figure 6: Dispersion of cement and water liberation due to the addition of SP

2.1.11 Placing and Production of Self-consolidating Concrete

Aggregates: The aggregates must contribute within similar origin without any need for modifications.

Mixing: In general, the period of mixing is more than the usual VC for all suitable mixers (Shetty, 2005).

Formwork: In self-consolidating concrete the formwork is designed in various shapes & sizes (ACI 237, 2007). It should be grout tight & water tight in the placing of self-consolidating concrete, exclusively in the low viscosity mixtures (ACI 237, 2007). Also, the pressure of formwork will be more for SCC than the usual VC, since SCC is highly flow-able mainly in the high casting rate (ACI 237, 2007).

Placing: To reduce the segregation danger while pouring SCC the following instructions should be trailed (Shetty, 2005, p.577):

- ❖ The vertical free fall distance must be no more than 5m.
- ❖ The height of pour lifts (layers) must be no more than 500mm.
- ❖ From the point of placing both the SCC and horizontal flow should not exceed10m.

Curing: self-consolidating concrete displays high cracking of plastic shrinkage and fast drying, then the first curing must be taking place early (Shetty, 2005). On the other hand, self-consolidating concrete should be fruitfully enveloped with the sheet of polyethylene.

2.1.12 Environmental Characteristics of Self-Consolidating Concrete

2.1.12.1 Environmental Effect and Sustainability

There are many factors that reduce the environmental impact over construction when SCC is used, like noise reduction due to non-vibration systems, lower concrete volume due to the reduction of cement quantity, and less energy consumption (RILEM 174, 2000).

2.1.12.2 Economical Characteristics of self-consolidating concrete

The self-consolidating concrete cost is more than the original concrete or reinforced one. It has declared that the self-consolidating concrete price is more by 10-15%.

Through taking in consideration the prices of finishing, labors and compaction, consequently self-consolidating concrete is absolutely not a pricy concrete for the same strength (Shetty, 2005).

2.2 Recycled Aggregates

2.2.1 Overview of recycled aggregates

RA are obtained when screening the demolished concretes. When concrete is mixed with totally or with a certain percentage of these recycled aggregates, it will be called Recycled Concrete (RC) (R. El Dalati, 2008).

The approach of recycling concrete is pointed to protect the environment as it helps to reduce the production of normal aggregates from quarries. Also, the mountains and the water shall be sustainably preserved (R. El Dalati., 2011).

The concept of sustainable construction development is becoming nowadays a widely discussed subject. It is also turning to become a challenge for the construction industry due to the increasing scarcity of natural resources and the ever increasing demolition and construction waste and also the increase in population and urbanization (Wai et al 2012). The essence of sustainable construction development can be given out as the possibility of meeting current needs taking into account the needs of future generations (Valeria et al 2009).

According to Mehta (2002) the global concrete industry consumes close to 10 billion tons of aggregates, and produces over 1 billion tons of construction and demolition waste annually. Aggregates constitute approximately 70% of concrete volume, thus the ability to utilize their waste and reuse them in the production of recycled concrete would have a huge positive impact on the environment.

However, one of the reasons that this utilization is not widely common is the misconception that is related to aggregates as they are seen as inferior aggregates (ICJ editorial, 2009). This misconception has been addressed by many researchers and it has been shown that, recycled aggregates have multiple uses across various concrete activities. The problem associated with the recycled aggregates is the adhered mortar at the surface of the recycled coarse aggregate. It is a porous material, having lower density in the bulk, saturated dry surface density and low specific gravity, with high tendency to absorb water (Hansen et al, 1993 & Ravindrajah1985 & Buck 1997). Soroushian and Tavakoli (1996) establish that the absorption of water capacity in RA reflects on the quantity of paste cement adhering to the particles of aggregates surface. The broad use of RCA is limited by the high absorption of water, thus increasingly shrinking the product of RCA. These downsides are as a result of the old mortar over cement paste adhered to the recycled aggregates surface such as in Figure 7.

At the other hand, reusing of destroyed concrete as aggregates in fresh one compositions in same situation will decrease the construction cost. This is due to the reduction in costs for the demolition waste management and for the transportation (R. El Dalati., 2011).

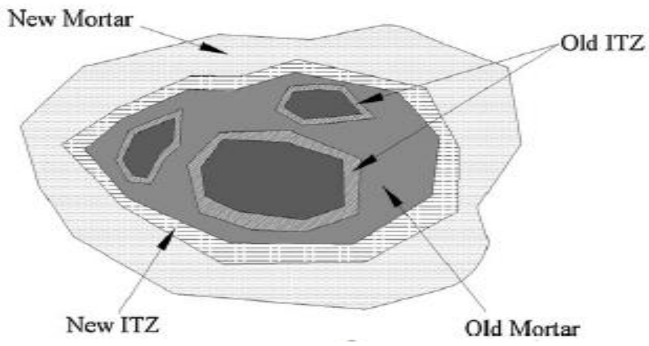

Figure 7: Structure of recycled aggregate

2.2.2 Types of Recycled aggregate

The recycled aggregates are aggregates formed from the inorganic materials previously used through building structures. RA in concrete can be used referring to the Standards of European for concrete. However, national specifications should be taken into consideration when using Recycled Aggregates (H. Kuosa, 2012).

The wastes of construction demolition, mortar, concrete, masonry, tiles and bricks, are the main components of RA (H. Kuosa, 2012). The resulting Recycled Concrete RC is affected by the types and dimensions of the incorporated RA (R. El Dalati, 2007). The types of RA are classified according to their origin from mountains as siliceous or calcareous or others. And the dimensions are classified according to grain size. Typical recycled coarse aggregates are > 5 mm, and typical recycled fine aggregates are < 5 mm).

By sorting and processing construction and demolition waste it is possible for high quality RA to be produced to subsequently produce concrete. According to European and other national specifications there are different classification techniques. In brief, the most important factor to achieve quality and to improve using RA is the accurate specifications (H. Kuosa, 2012).

2.2.3 Limitations for Recycled Aggregates Use

For instance, there can be limits for the composition of RA due to dangerous and risky ingredients like sulphates, chloride, bituminous material, and organic materials and also due to its low mass to volume ratio and more absorption of water. The least acceptable level for the density for RC is usually ranges from 2000 to 2200 kg/m3 and the most acceptable water absorption level ranges from 7% to 10%.

The most accepted values for chlorides and sulfates contents are typically specified in the normative documents. If the value is zero, a case-by-case analysis is considered through an identified reference. The maximum allowed sulfates content range between 0.8 % and 1.0 % of aggregates (by mass). However, the range of chlorides content is greater and vary depending on the demand level even within the same standard. In the construction domain, the most likely values are between 0.03 % and 0.05 %. Consequently, necessities which are based also on climatic factors and the level of exposure to those factors, must be different between countries due to different climates, and also due to the aforementioned national policies and safety levels (H. Kuosa, 2012).

The German guideline based on the code DIN has limited the amount of RA in the composition of RC to 30%. This limit could not be generalized as shown by (R. El Dalati and Matar, 2011) due to different reasons. The first is that the type of the original aggregate has an effect on the behavior of the concrete. The second is that the results obtained for different types and dimensions and even ages of the RA have shown differences in the strength compression and durability when limiting the amount of RA to 30%. Meanwhile, approximately the same results have been obtained for 20% of

RA whatever is the age of the original demolished concrete or the types and dimensions of the original aggregates. Finally, most of the specifications recommend to fix the amount of RA to 20% of the total quantity of aggregates when the RC is required to be structural. For landfill, all 100%RA can be used. Other limits are given according to the use of RA as in masonry construction or tiles (P. Matar and R. El Dalati, 2011).

2.2.4 Fresh Recycled Concrete Properties

In the recycled concrete the workability of constant water content ratio w/c is lesser than that for normal concrete as stated by many researchers (Topcu and Sengel,2004), (Oliveira et al.., 1996; Poon et al., 2004), (Rao, 2005), (R. El Dalati and Matar, 2001). This defect may be corrected by adding water or plasticizer or super-plasticizer or air entraining. Each admixture has its advantages and disadvantages. In fact, the addition of water will decrease the strength of concrete. The plasticizer or super plasticizer should be added carefully not to corrupt the mix. The addition of air entraining has been shown recently to be favorable for strength but no limitations are defined yet.

2.2.5 Properties of Hardened Recycled Concrete

2.2.5.1 Compressive Strength

All researchers have stated a decrease in compression strength for recycled concrete without any addition (Crentsil et al., 2001; Ajdukiewicz and Kliszczewicz, 2002). Many trials have been done to recapitulate the original value of the compression strength such as addition of the admixtures cited in the previous paragraph, or by adding more cement without exceeding the limit of 10%... It is important to note the recommendation given by (R. El Dalati and Matar, 2011) to wash the RA before the new mix. In fact, the powder surrounding the RA will cause a brittle behavior after crushing the concrete.

2.2.5.2 Flexural and Tensile Strength

The percentage of the flexural and the splitting strengths to the compressive strength ranges between two intervals (16 to 23%) and (9 to 13%), correspondingly (Katz, 2003). The above principles are less than the recommended by ACI 363R by 10% to 15%.

Referring to other research, and after measuring the direct tensile strength, it has been noticed the change between the recycled aggregates and plain concrete tensile strength was lower than 10% after 28 days. In addition, Researches have presented that the use of supplementary cementitious admixtures, for instance silica-fume, aids to develop the recycled aggregates properties (Ajdukiewicz. &.Kliszczewicz, 2002).

2.2.5.3 Durability

Some researchers have demonstrated that recycled concrete is significantly more permeable than normal concrete and so the durability of the RC is lower than for plain concrete. Moreover, the properties of durability be able to improve via some admixture such as fly-ash and silica-fume (Kumar N. Jha, 2006).

2.2.6 International use of RC and RA

The demand of RC and RA in construction is due to the high use in building industry all over the world (de Vries, P.,1996). For example, Holland has used 78,000 tons of RA since 90's such as, the international institute confessed that 20% of using the coarse RA achieve without any change in the mix properties for hardened & fresh concrete (de Vries., P.1996). A recent Federal Highway Administration report set a reference "Table 3" as the experience from European data on the subject of concrete and asphalt pavement recycling (US Department of Transportation, 2000).

Table 3: European data of asphalt pavement and concrete recycling

Country	Data Year	Material	Million Metric Tons (produced)	Million Metric Tons (used)
Sweden	1999	Old asphalt pavement	0.8	0.76
Denmark	1997	Demolition	1.5-2.0	Small quantities
		Old concrete	1.06	0.90
		Old asphalt pavement	0.82	0.82
		Old ceramic materials (brick)	0.48	0.33
Germany	1999	Old asphalt pavement	12.0	6.0
		Other road materials	20.0	11.0
		Demolition waste	23.0	4.0
		Old asphalt pavement	10.7	10.7
		BDW	9.2	9.2

The increasing demand in developing the concept of use of RA for the production of new concrete has also produced a concrete of high strength performance (Limbachiya MC.; Leelawat T.; Dhir RK, 2000).

2.2.7 Specifications of RC and RA

Three types are specified by (RILEM, 1994):

- Type I which consists primarily from masonry rubble.
- Type II which consists primarily from concrete rubble.

- Type III which consists of a blend of recycled aggregates (max. 20%) and natural aggregates (min. 80%).

Concerning that old concrete quality data is vague (ratio of water to cement, quality and quantity of additives, aggregates shape and size), and also the properties variation through time , the trials of RC must be related to 4 classes for complete comprehension of the behavior of the new mix (Nik. D. Oikonomou., 2004):

1. Historical data: related to old structures constituents.
2. Mechanical characteristic: such as, amount of soft granules, and the checking of resistance by los Angelo's apparatus.
3. Physical characteristic: such as, the absorption of water, sulfate & chloride ratios, and specific gravity.
4. Environmental features: such as, when ''leachates'' may be created

Chapter 3

EXPERIMENTAL STUDIES

3.1 General

This chapter presents a full description of the experimental strategy and tests that have been made in order to achieve the goal of the research. The rheological and mechanical tests for fresh and hardened SCC and RA-SCC are described and analyzed herein.

Based on the review of previous studies on SCC mixtures with and without RA, different mixes have been considered: one mix for normal SCC without RA, and six mixtures for RA-SCC corresponding to the amount of the incorporated RA. These amounts are for 30, 50, 70 & 100% both fine and coarse recycled aggregates, and 100% for coarse RA and 100% for fine RA.

According to the criteria described in Chapter 2, SCC in its fresh state should satisfy simultaneously the filling ability and passing ability.

The strength tests, namely the Compressive Strength and the Flexural Strength Tests have been carried out in this study. The slump flow test has been also done to determine the characteristics of the SCC providing the most fundamental information regarding the flow-ability. The durability test has also been carried out for all the considered mixes.

A slump flow diameter of 450 mm has been adopted as a minimum requirement for SCC; otherwise the test had to be repeated. Visual inspection was used to observe if segregation occurs.

No significant problems were observed in passing, filling and flowing ability for self-consolidating concrete and RA-SCC.

The compression strength has been determined by crushing the cast in laboratory specimens of cylinders 15 cm of diameter and 30 cm of height. The flexural strength has been carried out on beams of 100 ×100 ×400 mm.

The durability has been determined for 10 small specimens of total weight ranged between 450 and 550 g, and where each specimen has a weight ranging between 40 and 60 g.

3.2 Ingredients

3.2.1 Cement

The cement used in this research is the Portland Cement NL53:99 identified as ALSABEH CEMENT that is produced in Lebanon. The cement complies with all requirements according to NL53:99 for Portland Cement PA-L42.5 as shown in tables 4 and 5:

Table 4: Physical properties for Portland Cement PA-L42.5

Test	Requirements	Results
Initial Set (min)	Min 75 min	154
Final Set (min)		
False Set %		
Air Content %		
Autoclave Expansion		
Sulfate Expansion (14 days)		
Water Expansion (14days)		
Soundness "Le Chatelier" (mm)	Max 10.00	1.50
Blaine (cm^2/g)	Min 3000	3954
Water Demand		27.00

Table 5: Portland cement characteristics

Compressive Strength (N/mm^2)	Requirements	Results
1 day		
2 days	Min 12.50	19.40
3 days		
7 days		33.25
28 days	42.5-62.5	52.54
Heat of Hydration (J/g)		

3.2.2 Aggregates

The used aggregates are classified as coarse, medium and fine aggregates described as following:

- Crushed and Recycled Coarse Aggregates: the size is in the range (10-19mm).
- Crushed and Recycled Medium Aggregates: the size is in the range (5-9.5mm).
- Crushed and Recycled Fine Aggregates: the size is in the range (0-4.75mm).
- Sand: the size less than 2mm.

Figures 8, 9, 10,11,12,13 and 14 show all types of used aggregates and sand:

Figure 8: Crushed coarse aggregates

Figure 9: Crushed medium aggregates

Figure 10: Crushed fine aggregates

Figure 11: The sand

Figure 12: Recycled coarse aggregates

Figure 13: Recycled medium aggregates

Figure 14: Recycled fine aggregates

3.2.3 Used Water

For all the SCC and RA-SCC mixtures pure water should be used and it has also been used for the curing of samples.

3.2.4 Super-plasticizer

An ultra-high water reducer range (super-plasticizer) commercially known as “ARACO SP10” that complies with ‘ASTM C-494 F’ was used because it is Ideal for producing Self Consolidating Concrete (SCC), free flowing concrete and substantial water-reducing agent for promotion high quality strength concrete.

The tables 6 and 7 summarize the technical and product data of “ARACO SP10”:

Table 6: The technical data of ARACO SP10 Source, 2012

Test	Value	Standard
Density	1.19±0.015	ASTM C494
Chloride Content	Nil	BS EN 480 P10
Dosage	0.4 to 3 kg/100 kg of cement	Carry out trail mixes to obtain the correct dosage

Table 7: The product data of ARACO SP10 Source, 2012

Type : Sulphonated naphthalene based polymer
Form : Brown liquid
Packing : 1000 lt. flow bins Bulk supply in tanker trucks is possible on demand
Storage Condition: Store in a dry area between 5°C and 35°C, protect from direct sunlight.
Shelf life: 12 months minimum from production date if stored properly in original unopened packaging.

3.3 Mix Details

The considered mixes are entitled as presented in table 8:

Table 8: Concrete mixes used in this research

Mix 1	Plain SCC
Mix 2	30% RA-SCC
Mix 3	50% RA-SCC
Mix 4	70% RA-SCC
Mix 5	100% RA-SCC
Mix 6	100% coarse RA-SCC
Mix 7	100% fine RA-SCC

The water cement ratio has been fixed for all the mixes to 0.4. The concrete mix proportions have been designed in accordance with ACI 318- 11mix design research. The same mix design proportioning has been used for the seven mixes in order to produce 3 cylinders of 15 cm of diameter and 30 cm of height (Volume=0.018m^3). The difference between the mixes is the amount of the incorporated recycled aggregates RA where they correspond to 30%, 50%, 70%, or 100% of the total aggregates, and also to 100% coarse RA, and 100% fine RA. These proportions are listed in Table 9:

Table 9: SCC mix design in accordance with ACI 318- 11

Materials	**Content reference (Kg/m3)**	**Mix Dosage (Kg)**
Cement	450	8.1
Water	180	3.24
Sand	850	15.3
Fine aggregates (0-4.75mm)	180	3.24
Medium aggregates (5-9.5mm)	625	11.25
Coarse aggregates (10-19mm)	135	2.43
Super plasticizer	8	0.144

3.4 Mixing Procedure

After measuring all the materials according to the proportions as mentioned in Table 9, they have been mixed together until insuring the homogeneity of the concrete.

While the mix is still fresh, the slump flow test has been done and then the concrete immediately casted into the cylinders as indicated by the norm BS EN 12390-3 (2009).

No vibrating table was needed in the laboratory due to the ability of the self-consolidated concrete to fill up the cylinders under the use of its own weight only.

Figure 15 shows the used mixer.

Figure 15: Concrete Mixer

3.5 Self-Consolidating Concrete and RA-SCC Samples

3.5.1 Compressive Strength Testing Cylinder Samples Casting

The standard cylinders mold size used for compressive strength test for both self-consolidating concrete and recycled aggregates self-consolidating concrete is 15×30cm. Three cylinders were casted for each mix referring to BS EN 12390-3 (2009) standards.

3.5.2 Curing Procedure

All the specimens that need to be tested for the hardened properties were kept in their molds in the laboratory for the day after casting. After one day molding, the samples took away from the molds and putted in water tank for 28days referring to BS EN 12390-2 (2000) standards such as displayed in Figure 16:

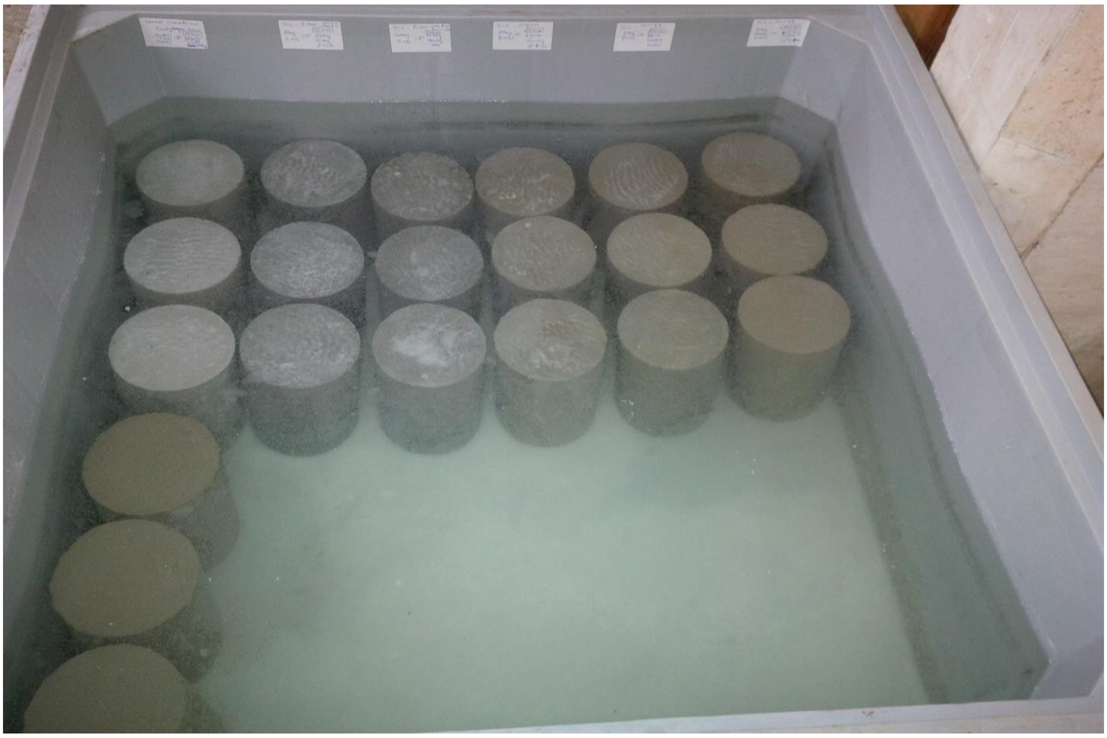

Figure 16: Test specimens in the curing tank

3.6 Fresh properties for self-consolidating concrete and RA-SCC

The fresh properties for all mixtures were tested to ensure the flow-ability. Slump flow test was the only fresh properties test used in this study as shown in Figure 17 according to ASTM C1611 (2012).

In general, the higher, slump flow, and better concrete's ability to fill formworks. Since the slump test gives good indication of filling capacity and flow-ability, it was selected in this project as the standard test to evaluate the rheological behavior of fresh SCC and RA-SCC.

Figure 17: Slump test for SCC Mix

3.7 Hardened Properties for Self-Consolidating Concrete and RA-SCC

3.7.1 Compressive Strength testing

All tests have been carried out after 28 days of the casting on the cylinders as referred to the standards (BS EN 12390-3, 2009) with a speed rate of 3KN/s. The compressive strength has been obtained by the using of compression apparatus test, as displayed in Figure 18:

Compressive strength test have been carried out on the cylindrical specimens at 28 days according to BS EN 12390-3 (2009). The pace rate used is 3KN/S.

Figure 18: compression test apparatus

The compressive strength of concrete is directly given by the equipment in MPa according to the diameter dimension of the cylinder.

3.7.2 Flexural Strength Test

In order to perform the flexural strength test the considered specimens were chosen to be beams of 100x100x400 mm dimensions for all types of SCC and RA-SCC. The test was based on a fourth point bending on the beam at a fix level of deformation (1 mm per minutes) referring to BS 14488-3 (2006) standards. The span length was measured to be 300 mm. The arrangement of the flexural strength is shown in figures 19, 20 and 21.


Figure 19: Beam under 4-points loading flexural test (a)


Figure 20: Beam under 4-points loading flexural test (b)

Figure 21: Flexure test by four-Point loading

3.7.3 Durability Test

The durability parameter has been determined using the slake durability index after two drying and wetting cycles with abrasion (see Figure 22), which involves measuring the existing resistance through aggregates toward failing then breaking down while exposed to variations in the content of water ASTM D4644 (2008). Generally, the aggregates resulted from rocks, however, the durability is proposed evaluating whether the suggested aggregates are recycled or natural.

Figure 22: Slake Durability Device

Figure 23: Adding distilled water to the tank of the slake durability device

One sample from each mixture has been taken. To characterize a trial, “10” aggregates weighing each one 40g-60g, summing up an overall weight of 450g-550g, have been designated. The designated samples were sited in a drum then dry to a fixed weight at 60°C, thus A of the drum in addition to samples was recorded.

For each test, the drum is located in a reservoir of distillated water joined to an engine (see Figure 23). The rotation has been conducted for 10min at 20 rpm. Assembly drum and assembly with specimens were removed then dry to a fixed weight. Moreover, B and the retained portion have been recorded.

Lastly, the index of durability was determined referring to equation (1):

$$I_d = \frac{B-C}{A-C} \times 100 \quad (1)$$

“C” is the dry clean drum weight without samples.

3.8 Non Destructive Tests

3.8.1 Schmidt Hammer

The Schmidt hammer is a non-destructive test, it’s a method for helping to guess the compression strength of concrete as decided by the (International standard ASTM C805).

The Schmidt Hammer checks the Penetration Resistance and the Surface Hardness of concrete (see Figure 24). It works by assessing the rebound of the loaded hammer spring, once the concrete trail is impacting against the surface.

On the other hand, it has its limitations as it does not give a direct measurement of the strength of the material. It simply gives an indication based on surface properties.

The Schmidt hammer is very sensitive to the changes of a trail, thus there is a process to proceeds a group of estimations and determine the mean value of the readings. It can be conducted in vertical, horizontal and transitional angles. Nevertheless, in different angles the calibrations are necessary.

Schmidt hammer is only a test used for estimating the strength of concrete in structure. It can hardly be considered as a substitute for compressive strength test.

Figure 24: Schmidt Hammer Test

3.8.2 Pundit

The ultrasonic pulse velocity UPV or the pundit can be used to measure the speed of propagation of the ultrasonic pulse stress longitudinal waves.

The pundit or ultrasonic pulse velocity is useful to estimating the depth of fire damage and evaluating the uniformity of concrete, to estimating the severity of deterioration and locating the internal cracks & voids, to estimating the strength of early age, to identifying the anomalous regions for invasive sampling with the drilled cores and finally to evaluating the repairs crack effectiveness.

The Pundit test has been done for the beams of SCC and RA-SCC. More than 20KHZ stress longitudinal waves of ultrasonic pulse has been hosted in to one surface of concrete by the coupled of transducer to the surface with gel pairing.

As shown in Figures 25 and 26, the pulse inter in the concrete then on the opposite surface is received by the transducer similar coupled. The time of transit of the pulse is measured by the machine.

Pulse velocity was calculated as displayed in equation (2):

$$v = \frac{l}{t} \quad (2)$$

Where:

V = Velocity (m/second),

l = path length (m)

t = time (sec)

The ultrasonic pulse velocity is ruled by several international codes containing the (ASTM C597, 2009) standard.

According to (Shariati et al., 2010) the best-fit curve that represents the relation between ultrasonic pulse velocity (UPV) and compressive strength (Fc) has the following equation (3):

$$Fc = 15.533V - 34.358 \quad (3)$$

Where, V is the ultrasonic pulse velocity (UPV).

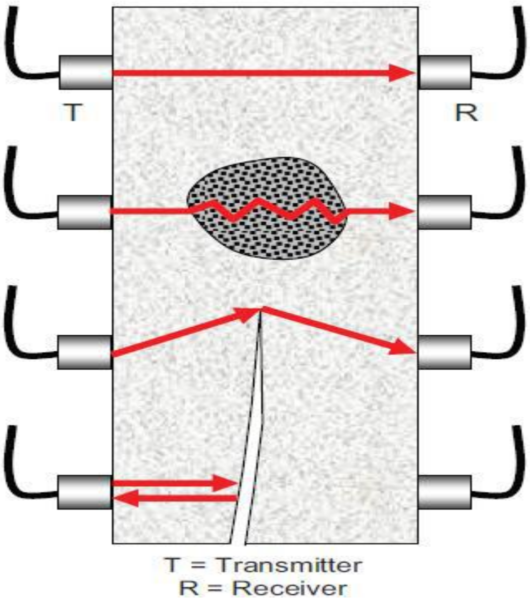

Figure 25: Pundit pulse travel through concrete

Figure 26: Pundit test

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The originality of this research figures in studying the effect of using local aggregates produced in Lebanon and the Middle East region which are known to be calcareous, and so they absorb higher quantity of water than the silico-calcareous aggregates which exist in general in Europe and other countries. Therefore, the norms used in Europe and USA and other countries should be adjusted according to the context of the region (R. El Dalati, Matar, 2007). Also, studying the effect of the variation in the sizes of RA on the mix of SCC between normal, coarse and fine, provides an originality.

It is essential to mention that according to the literature (R. EL Dalati, Matar, 2011), all recycled and natural aggregates were washed and dried before making the tests.

4.2 Workability and Flow-Ability for the SCC and RA-SCC Mixes

For the present research, the fresh properties such as flow-ability of self-consolidating concrete & RA-SCC mixtures were assessed by the slump flow test.

It's normal that using recycled aggregates with usual concrete will significantly decrease the workability. In this research, the consistency and workability were steadily modifying by the different amount of recycled aggregates added to the mixes.

The results, given in Table 10 shows that self-consolidating concrete & RA-SCC mixtures are conforming to the literature requirements.

Table 10: Fresh properties results of SCC and RA-SCC mixes

Mix number	RA amount	Slump flow
1	0% RA-SCC	670mm
2	30% RA-SCC	620mm
3	50% RA-SCC	590mm
4	70% RA-SCC	570mm
5	100% RA-SCC	560mm
6	100% coarse RA-SCC	570mm
7	100% fine RA-SCC	600mm

According to the (ASTM C1611) standards, to classify the concrete as self-consolidated the slump flow should exceed the diameter of 500 mm. This shows that the all mixes used in this study meet the requirements of SCC.

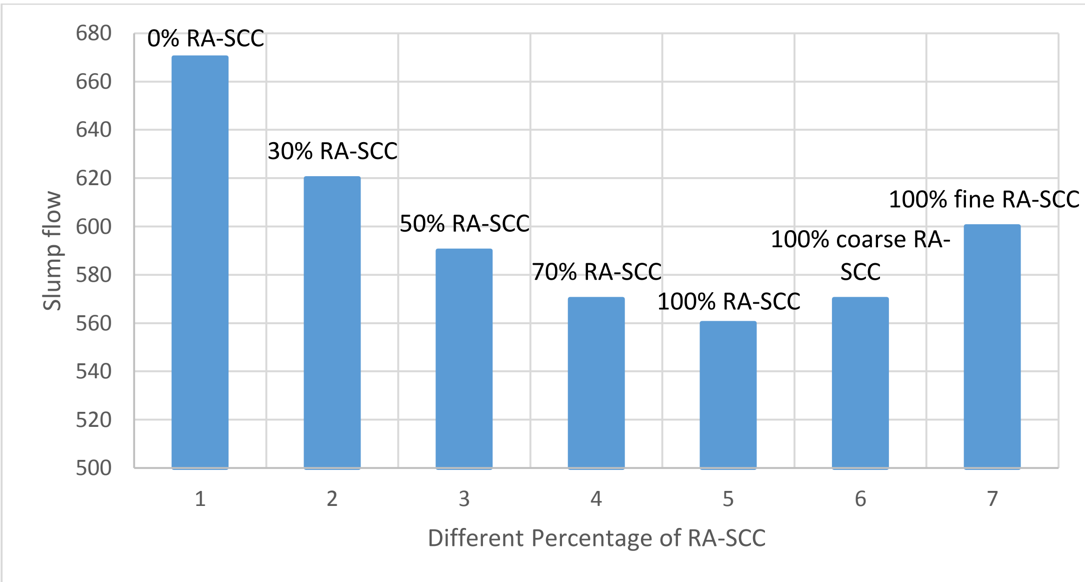

Figure 27: Slump flow for different RA-SCC

As it was expected, it is clearly shown from Figure 27 that the inclusion of recycled aggregates into the self-consolidated concrete will affect negatively its workability. This is shown in the flow spread where it was reaching 670mm in Mix1 which is free of any recycled aggregates, although this flow spread decreased after each inclusion of recycled aggregates until it reached 560mm in Mix5 which is the mix with the highest amount of both fine and coarse recycled aggregates. Moreover the slump flow of the RA-SCC mixtures increased with increasing the fine recycled aggregates, such as Mix7 (100% fine recycled aggregates) reached 600mm while Mix6 (100% coarse recycled aggregates) reached 570mm. This confirms the previous recommendations given by literature to use fine recycled aggregates in the mix of SCC.

We conclude that the workability and flow-ability of RA-SCC decrease with the increasing of RA amount, this is because the RA absorb more water than the natural aggregates. These results agreed with the literature and what was expected to happen. Also, we conclude that the inclusion of 100% fine recycled aggregates into the mix of SCC has a negligible effect on its workability and flow.

4.3 Compressive Strength

As mentioned in Chapter 3, for the compression test three cylinders (d=15cm and h=30cm) were tested at 28 days of curing for all mixes.

The maximum compressive strength values obtained for the SCC and RA-SCC specimens are given in Table 11 and Figure 28:

Table 11: Compressive strength test results

Mix #	Concrete type	The average compression strength (MPa)
1	SCC Plain	34
2	30% RA-SCC	19
3	50% RA-SCC	21
4	70% RA-SCC	31
5	100% RA-SCC	38
6	100% coarse RA	20
7	100% fine RA	36

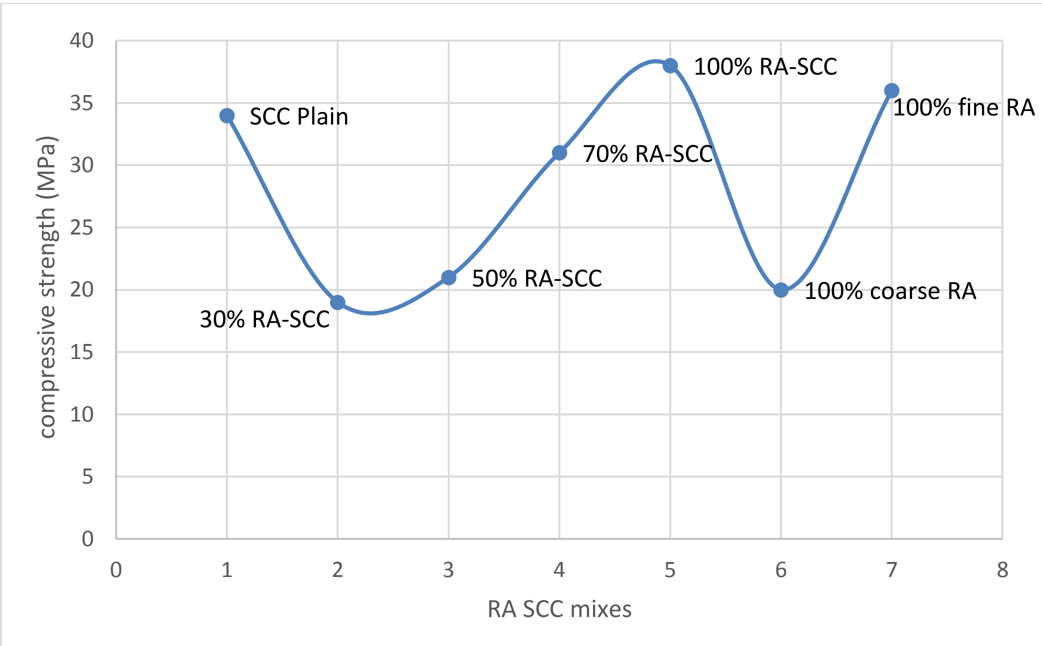

Figure 28: The average test results of 28 days compressive strength

The results show that:

- ❖ All SCC and RA-SCC mixes can be considered good as normal concrete need only a compressive strength between 20 and 35MPa.

- The norm given by ACI 544.1 (1996) is still valid for original calcareous aggregates, where it is clearly shown that the compressive strength is affected by the presence of recycled aggregates. Although, the addition of coarse and fine RA improves slightly the strength of the SCC until a better results for 100% RA-SCC of all sizes.
- The highest 28 days compressive strength obtained is 38MPa for 100% (fine and coarse) RA-SCC. For 100% only coarse aggregates the strength is 20 MPa which is a low value by comparison to the value obtained for the 100% fine RA-SCC which is 36 MPa.
- The fine and coarse recycled aggregates can be used for the self-consolidating concrete mixtures. But the fine recycled aggregates insure good strength.

Finally, this increase in compression strength is because of the presence of fine recycled aggregates in all the mixes except the 100% coarse RA-SCC.

4.4 Flexural Strength Test

The flexural strength was performed according to ASTM C 78 with fourth-point bending. The flexural strength or modulus of rupture was calculated by equation 4:

$$f_r = \frac{PL}{BD^2} \tag{4}$$

Where, f_r is the flexural strength or modulus of rupture in (MPa), P is the load in (N), L is the span length (300 mm), b is specimen average width (100 mm), and d is specimen average depth (100 mm).

The obtained flexural strength values for all mixes are given in table 12 and figure 29:

Table 12: Results of flexural strength or modulus of rupture

Mix #	Concrete Type	Flexural Test Results (MPa)
1	SCC plain	6.9
2	30% RA-SCC	3.75
3	50% RA-SCC	4.5
4	70% RA-SCC	5.1
5	100% RA-SCC	6.3
6	100% coarse RA-SCC	3
7	100% fine RA-SCC	6

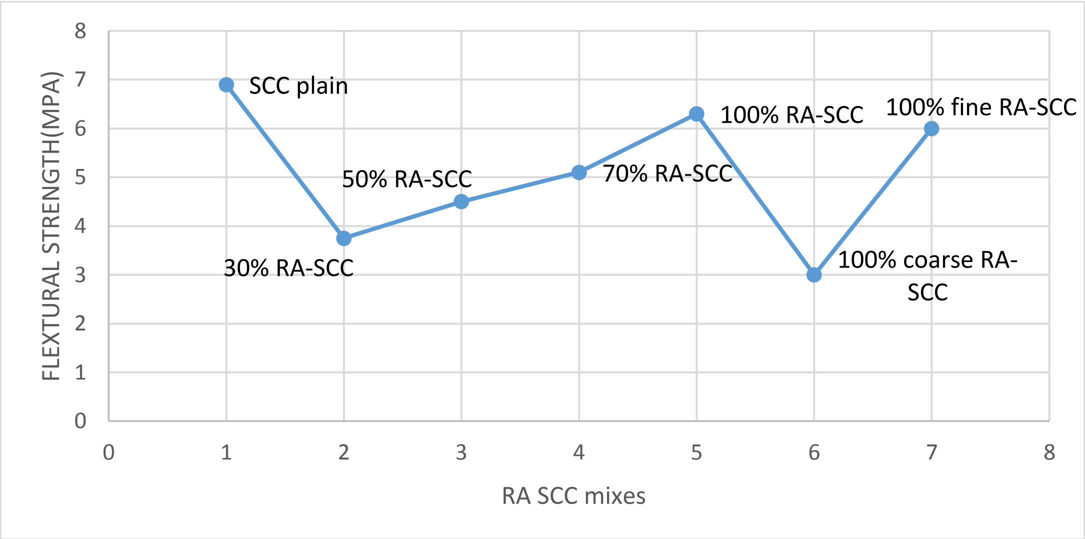

Figure 29: Test results of flexural strength

The results that can be concluded are:

1. The same tendency for the flexural strength as for the compressive strength to a slightly increase by increasing the percentage of recycled aggregates of all sizes coarse and fine. Meanwhile, the flexural strength of plain SCC is higher than the flexural strength of all RA-SCC.

2. The flexural strength for 100% fine RA-SCC has reached 6 MPa which is approximately the same as for all coarse and fine 100% RA-SCC which is 6.3 MPa. However, the flexural strength for only coarse recycled aggregates 100% RA-SCC is 3 MPa. This permits to recommend not to use only coarse aggregates in the mix of SCC.

4.5 Durability

All results obtained for durability first and second cycle (according to equation 1 given in chapter 3) are presented in Table 13 and Figure 30:

Table 13: Durability indices for different percentage of RA-SCC

Type	SCC plain	30% RA-SCC	50% RA-SCC	70% RA-SCC	100% RA-SCC	100% coarse RA-SCC	100% fine RA-SCC
I_d (%) 1^{st}cycle	99.82	99.79	99.80	99.22	99.58	99.26	98.68
I_d (%) 2^{nd}cycle	99.82	97.97	97.89	99.02	99.58	99.25	98.44

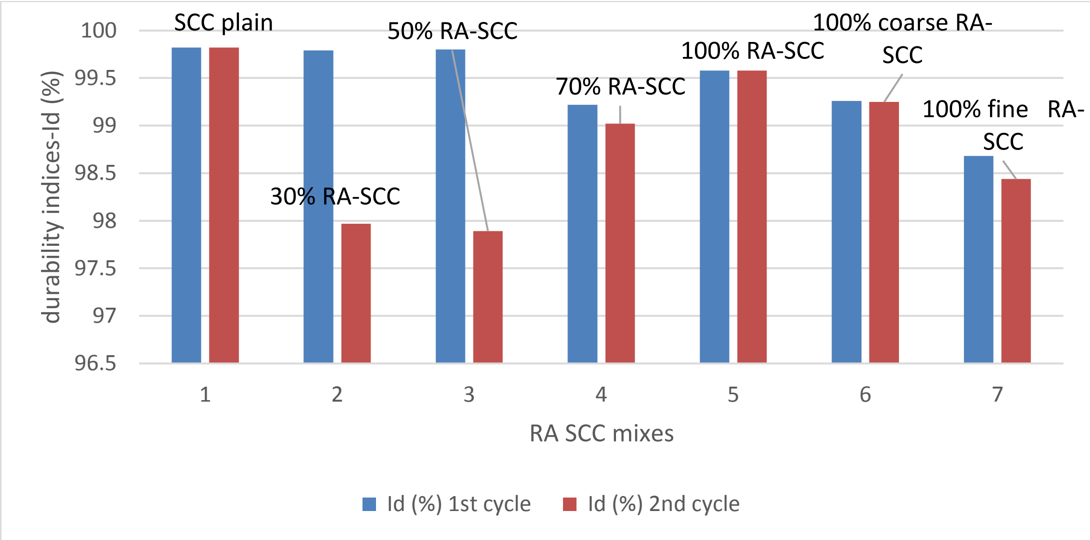

Figure 30: Durability indices for different percentage of RA-SCC

The results indicate the following:

1- All durability indices for the first cycle are above 98% and for the second cycle are above 97%. The lowest durability index (98.68) for the first cycle corresponds to the use of 100% fine RA. And the lowest durability index (97.89) for the second cycle corresponds to 50% coarse and fine RA.

2- The decrease in durability for the first cycle may attend $(99.82 - 98.68)/99.82 = 0.01142$ so 1.14%. And the decrease in durability for the second cycle may attend $^{(99.82 - 97.89)}/_{99.82} = 0.0193$ so 1.93%. Finally the decrease in durability when using RA in the mix of SCC is not significant.

3- The durability index for the plain SCC has not been influenced by the number of cycles. The same remark has been noted for the 100% coarse and fine RA and for the 100% coarse RA. Meanwhile for the 100% fine RA and the 70% coarse and fine RA the durability has been slightly affected by the number of cycles. But the most affected durability indices by the number of cycles have been noted for the 30% and 50% coarse and fine RA.

4- By comparing the values got for the 100% coarse and fine RA, the 100 % coarse RA and the 100% fine RA, we find that the best values for both cycles correspond to the 100% of all sizes coarse and fine, and the worst values correspond to only the fine 100% RA, while the value for the coarse 100% RA are ranged between them. We can conclude that the existence of coarse RA with fine RA improve the durability.

5- All the values for durability indices match with those obtained for compression and flexural strength.

4.6 Pundit test

The results of ultrasonic pulse velocity test and compressive strength (according to the equations 2 and 3 given in chapter 3) for all the mixes are given in Table 14, Figure 31 and Figure 32:

Table 14: The average of five sections results of Ultrasonic Pulse Velocity Test

Number	Concrete Type	Time (micro-sec)	Pulse Velocity (km/sec)	Compressive Strength (MPa)
1	SCC Plain	23.03	4.34	33.1
2	30% RA-SCC	23.66	4.22	31.3
3	50% RA-SCC	23.60	4.23	31.4
4	70% RA-SCC	23.58	4.24	31.5
5	100% RA-SCC	23.55	4.25	31.6
6	100% coarse RA-SCC	24.79	4.03	28.3
7	100% fine RA-SCC	23.76	4.20	31

The quality of concrete depending on the values of pulse velocity are given according to IS: 13311 (1992) by the Table 15.

Table 15:General guidelines for concrete quality based on UPV

PULSE VELOCITY	**CONCRETE QUALITY**
>4.0 km/s	Very good to excellent
3.5 – 4.0 km/s	Good to very good, slight porosity may exist
3.0 – 3.5 km/s	Satisfactory but loss of integrity is suspected
<3.0 km/s	Poor and los of integrity exist.

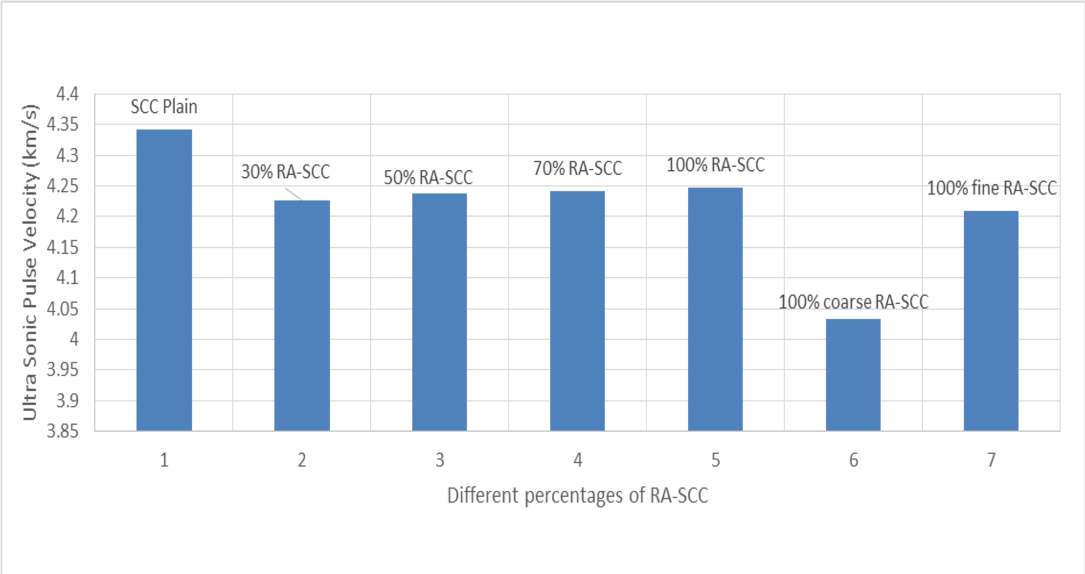

Figure 31: The average of five sections results of Ultrasonic Pulse Velocity

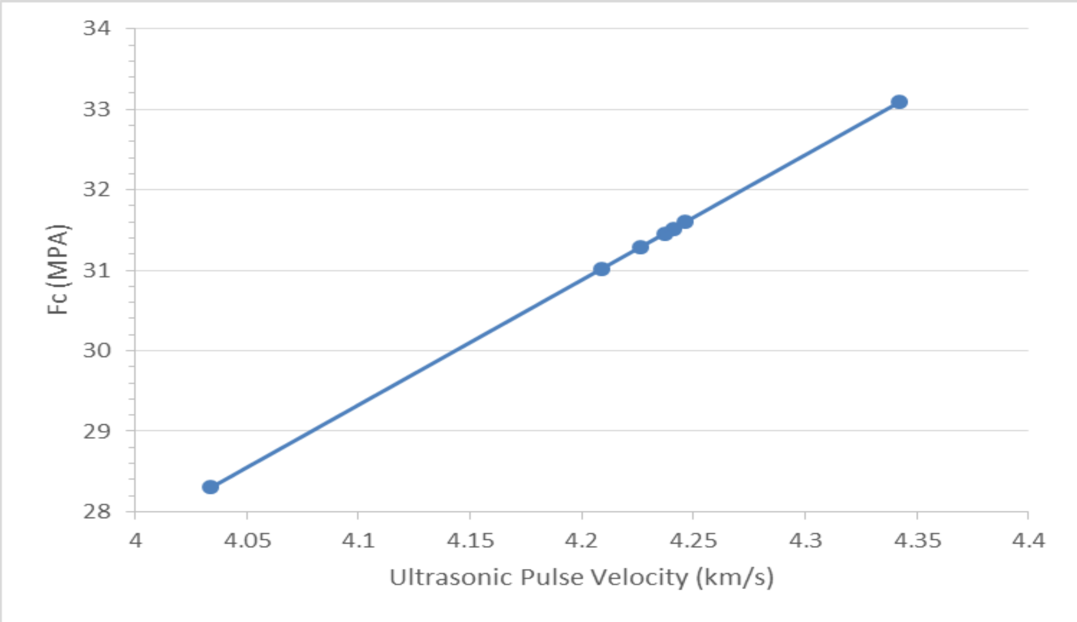

Figure 32: Ultrasonic Pulse velocity/compressive strength calibration curve

The examination of the results shows the following:

1- The maximum ultrasonic pulse velocity is 4.34 (km/s) is obtained from the SCC plain mix. Meanwhile all ultrasonic pulse velocities for RA-SCC are acceptable to have a good concrete.

2- Using recycled aggregates slightly decrease the UPV in self-consolidating concrete mixtures. This is because the voids availability in the recycled aggregates mixtures are higher than in the self-consolidating concrete plain mixtures, so the required time of ultrasonic waves to pass will decrease.

3- The ultrasonic pulse velocity sharply decreased in mix 6 when we used 100% only coarse recycled aggregates.

4- The calculated values for compression strength have the same tendency as for the obtained values by the compression test. While for the obtained strength by test for the plain SCC was 34 MPa, the calculated value was 33.1 MPa. So the difference is $(34 - 33.1)/34 = 0.026$ i.e. 2.6% which is not significant.

4.7 Schmidt Hammer test

An average of 10 readings applied on test cylinders are recorded for each mix. All the obtained results and the corresponding mean value are given in Table 16 and Figure 33:

Table 16: The strength results using Schmidt hammer

#	Concrete Type	1	2	3	4	5	6	7	8	9	10	Mean Strength
1	**SCC Plain**	31	28	29	36	28	27	32	31	29	28	**29.9**
2	**30% RA-SCC**	28	27	32	29	26	25	24	27	29	24	**27.1**
3	**50% RA-SCC**	29	30	27	30	29	25	25	32	27	30	**28.4**
4	**70% RA-SCC**	36	29	33	36	34	34	30	30	36	30	**32.8**
5	**100% RA-SCC**	34	33	34	35	31	31	30	33	32	36	**32.9**
6	**100% coarse RA-SCC**	23	25	29	25	19	27	26	27	25	27	**25.3**
7	**100% fine RA-SCC**	30	30	31	29	30	27	36	29	34	30	**30.6**

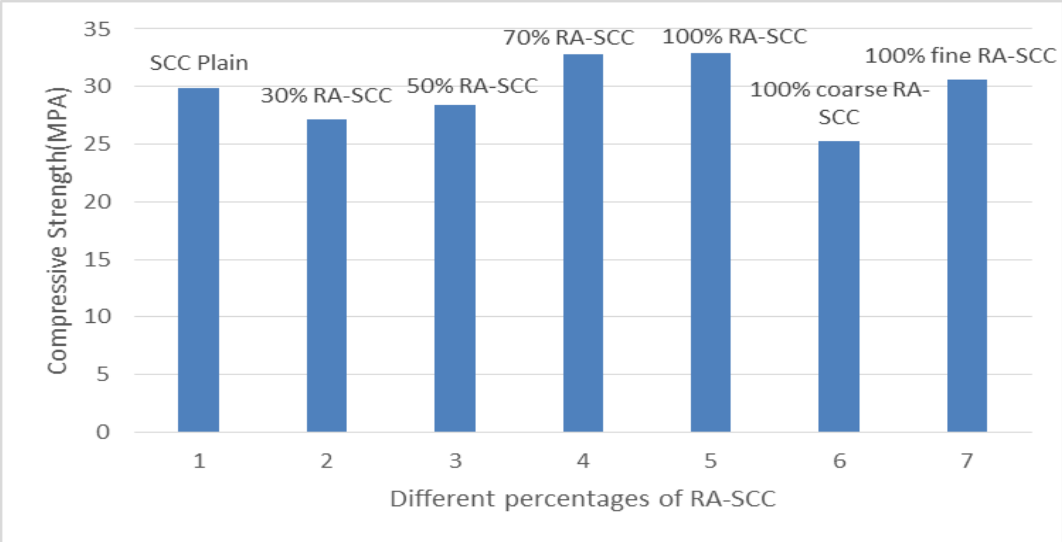

Figure 33: The mean strength test result by Schmidt hammer

The examination of the results indicates that:

1- The values for compression strength have approximately the same tendency as for the obtained values by compression test. Only the value for the SCC was slightly lower than the real value obtained by crushing.

2- The value for the 100% coarse RA is the worst as for all previous results. No big difference appears between the 70% and 100% coarse and fine RA where the compression strength is better. But both of them have better value than that for the 100% fine RA. Thus we may conclude that it will be better to combine coarse and fine RA in the SCC mix.

4.8 Summary

1- The workability of all tested mixes for SCC (with and without RA) was good regarding the required diameter flow which should be higher than 500mm according to ASTM C1611 (2012). This good workability is due in fact to the addition of super-plasticizer.

2- All the results obtained for compression strength by the non-destructive tests (Schmidt hummer and pundit) were adequate to those obtained by the destructive test.
3- All the flexural strengths obtained for the casted beams have shown the same tendency as for compression strengths. Meanwhile, the relationship should be determined by carrying out more tests.
4- The addition of RA decreases the workability of SCC but could provide better strength. This is the reason why the 100% RA-SCC was chosen for more comparison. This comparison has been directed toward the coarse and fine RA with the RA (fine and coarse).
5- The 100% RA-SCC for all sizes has shown the best performance regarding the strengths, workability and durability which still acceptable and constant for both the first and second cycle.
6- The 100% coarse RA-SCC is not recommended due to its worst strength.
7- The 100% fine RA-SCC can be used but not advised since it did not gave the same index for durability in the second cycle.

Chapter 5

CONCLUSIONS AND FUTURE RECOMMENDATIONS

5.1 Conclusions

In this study, different amounts of recycled aggregates were used to produce recycled aggregates self-consolidating concrete (RA-SCC). It aimed to study the effect of changing the amount of recycled aggregates on the fresh and hardened properties for instance slump flow test, compression and flexure strength (four point loading) and durability. Also the compressive strength was determined by some non-destructive tests such as Schmidt hammer and pundit.

The main objective of this experimental research was to inspect the interaction between RA-SCC composites and SCC. All the Recycled Aggregates (RA) were obtained when screening the demolished concretes. The mix proportions were kept the same for all the mixes (cement, water, aggregates and super-plasticizer). Also, the w/c ratio (0.4) was kept constant. The varying was only in the amount of recycled aggregates.

The behavior of the structural members might be affected by variables not intended for investigation in this study. However, the conclusions made herein would be an important asset to the future development of design guidelines for structural members casted by self-consolidating concrete based partially or totally on recycled aggregates.

The analysis of all results obtained in this research has led to the following conclusions:

1. The fine and coarse RA can be used for the production of self-consolidating concrete mixtures. However, 100% of recycled aggregates (RA) is the best amount, when respecting the recommendation given by literature to be washed and dried before use.
2. The flow diameter above 600 mm is achieved in the plain SCC mix. Otherwise, using recycled aggregates with different amounts in the SCC mix, has given acceptable workability and flow-ability as required for SCC mixes.
3. The addition of less than 100% of RA into the SCC mix decreases its compressive strength and flexural strength. This is due to the relative value of slump (workability) which is decreasing with the addition of RA and so increasing the strength.
4. The addition of 100% fine RA into the SCC mix gives less to equal value of the strength as for plain SCC but better than the addition of 100% coarse RA. This result is conform to the literature.
5. Even the literature recommends the use of fine RA in the composition of self-consolidating concrete, the present research has demonstrated that the mix between coarse and fine RA for the amount of 100% is the best considering all the examined properties herein. The use of 100% of only coarse RA is not recommended. But the use of 100% fine RA is acceptable regarding its workability, durability, compressive and flexural strength.
6. Finally, a strict mixing process was followed in this experimental research. In order to accomplish a good quality in fresh self-consolidating concrete (SCC) and recycled aggregates self-consolidating concrete (RA-SCC) mixtures, it is

necessary to follow the recommended mixing procedure. This procedure with the given mix proportions, has led to a good SCC that is durable, able to flow and fill the molds without any necessity of vibration, and that has good compressive and flexural strengths.

5.2 Future recommendations

The future recommendations help the researchers to add more beneficial work to this experimental study using the following ideas:

1. Carry on to further progress the proportion of RA into the SCC mixes to achieve greater flow-ability. Also, clarify how other parameters affect it.
2. Determine further necessary parameters in order to make a complete comprehension of the behavior of the RA-SCC, like modulus of elasticity, the relationship between tensile and compressive strength, the poison’s ratio, thermal expansion coefficient, permeability, porosity and fire resistance.
3. Complete further standard tests for SCC with recycled aggregates, which include the L-box, V-funnel, and column segregation tests. These tests would permit better estimation of the value of the mixtures for use in structural applications.
4. In order to see the influence of w/c percentage, on both hardened and fresh properties on SCC and RA-SCC, which it was fixed, various water cement percentages will be tried.
5. The addition of some materials such as fly ash, silica fume, limestone dust and slug with various replacement levels can also be investigated.

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