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M.Sc. THESIS IN CIVIL ENGINEERING

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**UNIVERSITY OF GAZIANTEP
GRADUATE SCHOOL OF
NATURAL AND APPLIED SCIENCES**

**FRESH PROPERTIES OF SELF-COMPACTING CONCRETES
CONTAINING WASTE COARSE RUBBER AGGREGATES**

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**By
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coarse rubber aggregates**

**M.Sc. Thesis
in
Civil Engineering
University of Gaziantep**

**Supervisor
Assoc. Prof. Dr. Mehmet GESOĞLU**

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June 2015**

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Lamyaa Abed H.JAFER

ABSTRACT

FRESH PROPERTIES OF SELF-COMPACTING CONCRETES CONTAINING WASTE COARSE RUBBER AGGREGATES

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When the plastic materials used in daily life complete their lifetime or lost their necessary, they are continuously added to the waste materials in the landfills all over the world and their disposal needs a viable and environmental friendly solution. Recycled plastic materials is a promising material in the construction industry due to its light weight, elasticity, energy absorption, sound and heat insulating properties. Recycled plastic materials, which are produced from waste plastic materials and used for raw material in industry, have been used in this study to replace the coarse aggregate by weight using different percentages. The paper presented herein was carried out to investigate the workability and rheological properties of self-compacting concretes rubberized concretes with fly ash, with and without silica fume. At a water/binder (w/b) ratio of 0.32, the self-compacting concretes (SCC) were produced by replacing the coarse aggregate with four designated waste rubber contents of 0%, 10%, 20%, 30% and 40% by coarse aggregate volume. Moreover, the SCC with silica fume was produced in second series of mixes by partial substitution of cement with silica fume at varying amounts of 10% and this addition was examined with the relationship of the rubber content. Totally, 10 concrete mixtures were produced and tested for workability related properties such as passing ability, filling ability and rheology. The measured properties of concrete fresh behavior were concrete flow and passing-ability by slump flow, L-box and V-funnel tests. For the rheological testing of fresh SCCs, ICAR rheometer was used to find the rheological parameters.

Key words: waste rubber, rheology, self-compacting concrete, silica fume, workability.

ÖZET

KABA ATIK PLASTIC AGREGASI İÇEREN KENDİLİĞİNDEN YERLEŞEN BETONLARIN TAZE ÖZELLİKLERİ

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Gündelik yaşamda kullanılan plastikten üretilen malzemeler kullanım ömrünü veya gerekliliklerini doldurduğunda atık olarak tüm dünyada çöplüklere atık olarak eklenmektedir ve bunların yok edilmesi için uygulanabilir ve çevre dostu bir çözüm ihtiyacı vardır. Atık plastiklerinin geridönüşümü olan plastik parçaları yapı endüstrisinde hafif olması, elastikiyeti, enerji absorbe özelliği, ses ve ısı ızalasyon özellikleri sayesinde kullanılabilecek bir malzeme olarak görülmektedir. Atık plastiklerin geridönüşümü ile üretilen ve endüstriyel hammadde olarak kullanılan plastik parçaları bu çalışmada iri agregalar ile değişik oranlarda hacimce yer değiştirilerek kullanılmıştır. Tezde atık plastik ile üretilen uçucu kül ile silis dumanı eklentisi bulunan ve bulunmayan karışımlardan 0.32 su-çimento oranı ile üretilmiş kendinden yerleşen betonların, iri agregalar ile ağırlıkça 0%, 10%, 20%, 30% ve 40% oranlarında atık plastikler ile yer değiştirilmesinin bu tip betonlarda reolojik ve işlenebilirlik özelliklerinin değişimine etkisini inceleme amacı taşımaktadır. Ayrıca, kendiliğinden yerleşen betona ait karışımların bir serisinde bağlayıcı madde miktarının ağırlıkça %10 u silis dumanı olacak şekilde kullanılarak bu değişimin etkileride atık plastik oranına bağlı olarak incelendi. Toplamda 10 adet beton karışım üretildi ve bu on karışım geçme yeteneği, doldurma yeteneği ve reoloji özellikleri açısından incelenmiştir. Kendiliğinden yerleşen betonun akma ve geçme yeteneği yayılma, L-kutusu ve V-hunisi testleri ile gerçekleştirilmiştir. Kendiliğinden yerleşen betonun reoloji özellikleri ICAR Rheometer cihazı ile ölçülmüştür.

Anahtar kelimeler: atık plastik, reoloji, kendiliğinden yerleşen beton, silis dumanı, işlenebilirlik.

To my family they should receive my greatest appreciation for their enormous love.
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LIST OF CONTENTS

ABSTRACT	v
ÖZET.....	vi
ACKNOWLEDGMENT	viii
LIST OF TABLES	xii
LIST OF FIGURES	xiii
CHAPTER 1	1
INTRODUCTION.....	1
1.1 General	1
1.2 Research Objectives	2
1.3 Importance of the thesis:	3
1.4 Outline of the Thesis	3
CHAPTER 2	4
LITERATURE REVIEW.....	4
2.1 Self-compacting concrete	4
2.1.1 Advantages of SCC	6
2.1.2 Disadvantages of SCC.....	7
2.2 Properties of self-compacting.....	8
2.2.1 Workability.....	8
2.2.2 Filling ability	8
2.2.3 Passing ability	8
2.2.4 Segregation resistance	8

2.3 Rheology of fresh concrete	11
2.4 Rubber and waste tires	15
2.4.1 Classification of scrap-tires	16
2.4.2 Typical compositions of waste tires	19
2.4.3 Classification of recycled waste tire particles	20
2.4.4 Basic material properties of tire rubber	20
2.5 Fresh concrete properties of concrete made with rubber tire particles	21
2.5.1 Unit Weight	21
2.5.2 Slump	21
2.5.3 Air Content	22
2.6 Admixtures for SCC:-	22
2.6.1 Mineral Admixtures	23
2.6.2 Chemical Admixtures	28
2.7 Test methods for workability of self-compacting concrete	30
2.7.1 Slump flow and T500 time	31
2.7.2 L-box test	34
L-box test is used	34
2.7.3 V-funnel test	35
2.7.4 J-ring (ASTM C 1621)	38
2.7.5 The U-box	39
CHAPTER 3	41
EXPERIMENTAL PROGRAM AND METHODOLOGY	41
3.1 Introduction	41
3.2 Materials	41
3.2.1 Cement	41
3.2.2 Mineral admixtures	41
3.2.3 Waste coarse Rubber	42

3.2.4 Aggregates.....	43
3.2.5 Superplasticizer	44
3.3 Concrete Mixtures	45
3.4 Concrete casting, test specimens, and curing	45
3.5 Tests for Fresh Properties.....	47
3.5.1 Slump flow	47
3.5.2 V-funnel flow time	48
3.5.3 L-box test.....	48
3.5.4 Rheology test.....	50
3.5.5 Compressive strength	52
CHAPTER 4	53
TEST RESULTS AND EVALUATION	53
4.1 Fresh concrete properties	53
4.1.1 Slump flow diameter and slump flow time	53
4.1.2 V-funnel flow time	53
4.1.3 L-box height ratio, T_{200} and T_{400} times	57
4.1.4 Rheology	59
4.2 Compressive strength	64
CHAPTER 5	66
CONCLUSIONS	66
REFERENCES.....	67

LIST OF TABLES

	Page
Table 2.1 SCC Workability (Koehler and Fowler, 2007)	10
Table 2.2 Typical composition of manufactured tires by (Rubber Manufacturer's Association (2000)	17
Table 2.3 ASTM D-6270 Terminology for Recycled Waste Tire Particles	20
Table 2.4 Basic engineering properties of tire rubber compared with mineral aggregates	21
Table 2.5 Physico-chemical properties of fly ash. (A.A.Elsayed, 2012)	25
Table 2.6 Chemical Analysis and Physical Properties of the Silica Fume. (A.A.Elsayed, 2012)	27
Table 2.7 Experimental Results Comparing Properties of Mixes with and without Superplasticizer (Yang, 2004)	30
Table 2.8 Testing methods and limiting test values for SCC (Ahmad and Khadirnaikar, 2014)	38
Table 3.1 Physical properties and chemical compositions of Portland cement, fly ash and silica fume	42
Table 3.2 Properties of superplasticizer	44
Table 3.3 Mix proportions for self-compacting concrete (kg/m ³)	46
Table 3.4 Slump flow, viscosity, and passing ability classes according to (EFNARC 2005)	50
Table 4.1 Slump flow, L-box and V-funnel properties of SCCs at w/b of 0.32	54

LIST OF FIGURES

Figure 2.1 Necessity of Self-Compacting Concrete (Kochi and Nagaoka, 2000)	6
Figure 2.2 The Bingham Model for Concrete Rheology (Koehler and Fowler, 2007).....	11
Figure 2.3 Constitutive Relationships for Fresh Concrete Plotted on a Flow Curve. (Eric and David, 2007).....	13
Figure 2.4 Typical Geometrical Configurations for Concrete Rheometers. (Eric and David, 2007).....	15
Figure 2.5 The existing huge amount of Scrap tyres in the world (Turer, 2012)	17
Figure 2.6 Photographic view of tire chips a) 1.27cm and b) 1.9cm (Liu, 2013).	18
Figure 2.7 Tire rubber waste: a) ground and b) crushed (Pacheco-Torgal et al., 2012).....	18
Figure 2.8: a) Shredded Rubber and b) Crumb Rubber (Deshpande et al., 2012)	19
Figure 2.9 Effects of superplasticizer (Okamura, 1997)	29
Figure 2.10 Optimum combination of superplasticizer and w/c ratio (Okamura, 1997)	30
Figure 2.11 Base plate and Abrams cone (Schutter, 2005).....	32
Figure 2.12 Example of dimensions of a weight ring	32
Figure 2.13 L-Box testing apparatus (Domone, 2009)	35

Figure 2.14 Dimensions of the V-funnel (Domone, 2009)	37
Figure 2.15 J-ring test (Hadiwidodo and Mohd, 2008).....	39
Figure 2.16 Schematic representation of U- box test (Elhassan, 2014).....	40
Figure 3.1 The photographic views of waste coarse rubber.....	43
Figure 3.2 Sieve analysis of aggregates	44
Figure 3.3 Measurement of slump flow diameter for SCCs (Control mixture).....	47
Figure 3.4 Photographic view of V-funnel flow time measurement.....	48
Figure 3.5 Photographic view of L-box apparatus and testing procedure	49
Figure 3.6 Views of a) Rheometer and b) detailed schematic representati.....	51
Figure 3.7 Photographic view of compressive strength machine	52
Figure 4.1 Variation of slump flow diameter and slump classes of SCC with different rubber contents at 0% and 10% silica fume	55
Figure 4.2 Variation of T_{50} slump flow time of SCC with different rubber contents at 0% and 10% silica fume	55
Figure 4.3 Variation of V-funnel flow time and viscosity classes of SCC with different rubber contents at 0% and 10% silica fume	56
Figure 4.4 T_{50} slump flow time versus V-funnel flow time for SCC.....	56
Figure 4.5 Variation of L-box height ratio and passing ability classes of SCC with different rubber contents at 0% and 10% silica fume.....	57
Figure 4.6 Variation of a) T_{200} and b) T_{400} L-box flow time of SCC with different rubber contents at 0% and 10% silica fume	58
Figure 4.7 Torque versus rotational speed obtained from the Rheometer for rubberized SCC with: a) 0% and b) 10% silica fume contents.	60

Figure 4.8 Application of the Herschel-Bulkley model on the rheological data for rubberized SCC with: a) 0% and b) 10% silica fume contents.....	61
Figure 4.9 Variation in exponent 'n' values (Herschel-Bulkley) for SCCs with different silica fume and rubber contents.....	61
Figure 4.10 Application of the modified Bingham model on the rheological data for rubberized SCC with: a) 0% and b) 10% silica fume contents	63
Figure 4.11 Variations in c/μ values (modified Bingham) for SCCs with different silica fume and rubber contents.....	63
Figure 4.12 Variation in c/μ values (modified Bingham) for SCCs with 0% and 10% silica fume at different rubber contents	64
Figure 4.13 Variation in the compressive strength of SCC versus replacement level of rubber.....	65

LIST OF SYMBOLS

τ	Shear stress
τ_0	Yield stress
μ	Viscosity
ASTM	American Society for Testing and Materials
EFNARC	European Federation of National Trade Association
FA	Fly Ash
PC	Portland cement
SCC	Self Compacting Concrete
SF	Silica Fume
SP	Superplasticizer
W/B	Water/binder ratio
W/C	Water/cement ratio
WCR	Waste coarse rubber aggregate
WR	Waste rubber
α	Constant coefficient
$\dot{\gamma}$	Shear strain rate

CHAPTER 1

INTRODUCTION

1.1 General

Self-Compacting Concrete (SCC), which does not demand any outer vibration for compaction and flows beneath its weight, has revolutionized the construction industry. It was primarily improved and developed in Japan during late 1980's (Okamura and Ouchi, 1999). For SCC the fluidity and segregation resistance ensures a high grade of homogeneity, lower concrete voids and regular concrete strength, supplying the potential for a superior grade of finish and durability to the structure. Various approaches have been used to develop and improve the SCC (Okamura and Ozawa K, 1995). Suggested an ordinary (normal) mixture proportioning system using limited coarse aggregate, superplasticizer and low water cement ratio providing the potential for high early strength and earlier de-moulding. SCC of high fluidity and segregation resistance is achieved by employing a high Portland cement content, superplasticizer and viscosity modifying additives (VMA) (Khayat and Guizani, 1997). While, the cost of these concretes noticeably increased related with the use of high volume of Portland cement and chemical admixtures. Wastes and by-products have been known to substitute the cement content and hence reducing the cost (Elinwa. et al., 2008).

In recent times, this concrete has gained wide use in many countries for different applications and structural configurations. Adoption of SCC offers substantial benefits in enhancing construction productivity, reducing overall cost, and improving work environment. It is used when there is a shortage of labour, and also helps in achieving better surface finish (Khayat, 1999). Such innovative concrete demand and need high slump which can be enquired by addition of super-plasticizer. To avoid segregation on superplasticizer addition, the sand content is increased by 4% to 5%.

When the coarse aggregate volume in the concrete is excessive, the opportunity of contact between coarse aggregate particles increases greatly, causing interlocking

and the possibility of blockage on passing through spaces between steel bars is also increased. Therefore, the first point to be considered when designing SCC is to restrict the volume of the coarse aggregate. This reduction leads the use of higher volume of cement which increases the cost, besides resulting in undesirable temperature rise. So cement should be replaced by other mineral admixtures like Blast Furnace Slag, Fly Ash, Silica Fume, etc (Pai et al., 2014).

As per EFNARC (Guidelines, 2005) for SCC mix design, one of the most significant differences between SCC and conventional concrete is the combination of mineral admixtures. Thus, many researches on the mineral admixtures effecting on properties of SCC have conducted. In these studies, it shows the advantage of mineral admixture usage in SCC, such as improved workability with decreased cement content. Since the most expensive component of concrete is cement and reducing decreasing cement content is an economical solution for this problem. Besides, the particle packing and decrease the permeability of concrete can be improved by mineral admixtures. Thus, the concrete durability is also increased (Assie et al., 2007). Limestone powder, fly ash and granulated blast furnace slag which are industrial byproducts or waste materials are generally used as mineral admixtures in SCC (Felekoglu et al., 2006; Unal et al., 2006). Thereby, the workability of SCC is improved and the used rate of by-products or waste materials can be increased. From economical benefits, such uses of byproducts or waste materials in concrete reduce environmental pollution (Bosiljkov, 2003).

There are three properties that characterize a concrete as self-compacting concrete which are: flowing ability, the ability to totally fill every areas and corners of the formwork in which it is placed, the ability to pass through overcrowded reinforcement without separation of the constituents, segregation resistance - the ability to retain the coarse components of the mix in suspension in order to preserve a homogeneous material (Mahesh, 2014).

1.2 Research Objectives

The primary objectives of this research study are:

- Investigate experimentally the effect of waste coarse rubber aggregate on the fresh properties of self- compacting concrete.

- Examine the effects of increasing the coarse aggregate replacement percentage with recycled waste tire on concrete fresh properties; workability, unit weight, air content.
- To provide recommendations for using the recycled waste tires coarse aggregate in a concrete mixture designed for field implementation.

1.3 Importance of the thesis:

Contribution of the study to education, economy, society, health of people, environment, etc is as follows: The coarse rubber aggregate is disposal material. Although it is non-hazardous waste materials, it can be hazardous in the case of firing. To decrease the damage of this waste material to environment, it will be used in the self-compacting concrete production.

1.4 Outline of the Thesis

Chapter 1 Introduction: Aim and objectives of the thesis were introduced.

Chapter 2 Literature Review: A literature review was conducted on the properties of SCCs. The previous studies on the use of waste rubber, fly ash and silica fume for producing self-compacting concrete were provided.

Chapter 3 covers the experimental program conducted throughout this study. Properties of cement, waste rubber, aggregates, mineral and chemical admixtures used in the concrete production as well as the tests on fresh properties of SCCs are included.

Chapter 4 Test result and Discussions: Indication, evaluation, and discussion of test result were presented.

Chapter 5 Conclusions: Conclusion of the thesis was given.

CHAPTER 2

LITERATURE REVIEW

2.1 Self-compacting concrete

Self-Consolidating Concrete (SCC) is strongly flowable, non-segregating concrete which can spread into place also fill the formwork and enclose the reinforcement without any mechanical consolidation (ACI Committee 237R-07, 2008). SCC mixtures designed for pre-cast, pre-stressed applications which should be strongly workable to flow, restricted spacing and completely encapsulate reinforcements without any mechanical vibration (Precast/Pre-stressed Concrete Institute, 2003).

Filling-ability (also known as deformability or unconfined flowability) describes the ability of the concrete to undergo through changes in shape and flow around obstacles completely enclose the reinforcement and fill the formwork under its own weight without having mechanical consolidation. Passingability known as the ability of the concrete to pass among different obstacles and narrow spacing in the formwork without blockage with having mechanical vibration. Filling capacity (also known as restricted deformability) is refers to the ability of the concrete to totally fill intricate formwork or formwork containing closely spaced obstacles, such as reinforcement. The resistance to segregation (stability) describes the ability of the concrete to maintain homogeneous distribution of its various constituents (ACI Committee 237R-07, 2008).

Workability refers to the ease of mixing, placement, consolidation and finishing of concrete (Khayat, 1999). The required workability for casting concrete depends on the sort of construction, chosen placement and consolidation methods, the complex shape of the formwork and structural design details which affect the degree of congestion of the reinforcement. SCC should display high filling ability, suitable passing ability and proper segregation resistance. These properties are affected by the selection and proportioning of materials, admixtures as well as application type. In the selection of material constituents and mixture proportioning of SCC for pre-cast

and pre-stressed structural elements, it is important that the concrete must be self-consolidating, i.e. it might flow into place and enclose the pre-stressing strands and reinforcing bars without any segregation or any blockage (Wu-Jian Long et al., 2012).

The SCC concept was first introduced in to scientific world in Japan in 1986 by Professor Hajime Okamura from Tokyo University. The first proto type was developed in 1988 by Ozawa from Tokyo University as a response to the growing and developing problems linked with durability of concrete and high demand for expertise workers. In Europe most probably used in civil works for transportation networks in Sweden, in the middle of 1990's. The EC sponsored a multi-national, industry lead project SCC 1997-2000 since then increasing seen by using SCC in all European countries. SCC was first developed so that the concrete durability structures might be improved. Since then, various investigations and researches have been carried out and the concrete has been used in most practical structures in Japan and Europe, generally by large construction companies. Researches for establishing a rational mix design method and ability of self-compact testing methods have been accomplished from the view point of making it a standard concrete (ACI Committee 237R-07, 2008).

To make concrete structures more durable and sufficient compaction skilled workers are required. However, the progressive reduction in the number of skilled workers in the construction industry has led to a similar and comparable reduction in the quality of construction work. One solution for the getting a durable concrete structures and independency of quality of construction work, is the use of the SCC, which might be compacted into every corner of formwork, by means of its own weight and without the need of vibrating compaction (Fig. 2.1) (Kochi and Nagaoka, 2000).

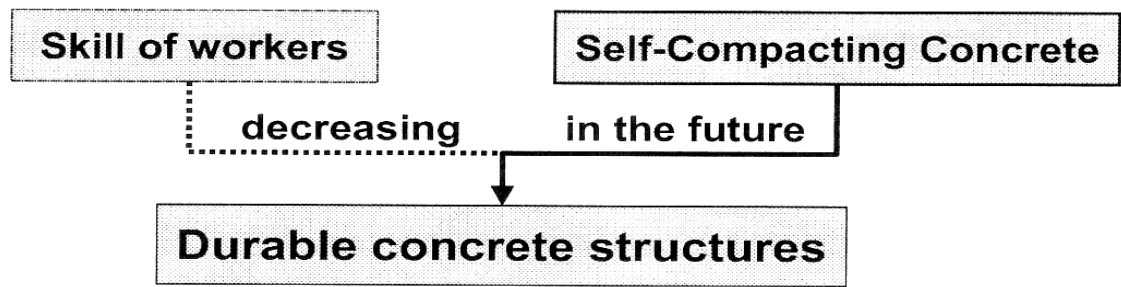


Figure 2.1 Necessity of Self-Compacting Concrete (Kochi and Nagaoka, 2000)

2.1.1 Advantages of SCC

1. Improving the Quality of Concrete:

- SCC yields homogeneous concrete in places in which the castings are difficult because of having congested reinforcement and difficult access etc.
- SCC displays a good filling ability especially around reinforcement.
- SCC is extremely well suited for specific and technically demanding structures such as tunnel linings, in which the possibility of the compacting concrete is limited in the closed space between rock and formwork.
- Displays narrow variation in properties on site.
- Mostly it is suitable for technology of Concrete Filled Tubes (CFT) construction for high rise buildings.
- It assures better quality of in-situ pile foundation.

2. Environmental and Human Health Protection:

- Decreases noise and sound at site, the pre-cast factory and neighborhood, as well as it is a silent concrete.
- Eliminates and removes problems with blood circulation in which it leads to “white fingers” which caused by compacting equipment, hence called a healthy concrete.
- SCC gives protection of noise in pre-cast industry by having no restrictive measures like ear protection, marked areas, safety instructions are necessary.
- Shortens and abbreviates the construction time by making construction process more accelerated, especially in pre-cast industry.

3. Time Reducing and Economy:

- Placement easiness improves the productivity and the saving cost through reducing the labor equipment.
 - Reduction in wearing and tearing of forms, therefore it extends the service life of forms.
 - Decreasing in the number of workers. Normally one cum requires 1.5 man-hours; with SCC this is reduced to 0.35 man-hours.
 - It decreases the consumption of resources and cost, even considering a larger price per cubic meter. Okamura has reported that it is possible to decrease the overall bridge cost by 5- 15 % (Shah et al., 2008).
 - Because of having high fluidity, this type of concrete does not need any vibrations so that it can save energy and ensuring a suitable cost in place.
 - Reduction of expenses and manpower needed for patching finished precast elements.
 - It enables the concrete supplier for providing a better consistency in transferring concrete, which reduces the interventions at the plants.
4. Construction with SCC is not affected by the skill of the workers, and shape and arrangement of reinforcing bars of the structures.
 5. SCC use in construction sites decreases the chance of accident by decreasing number of cables needed for the compacting equipment operations, hence, decreases the workers compensation premiums.
 6. It affords wide range opportunity for the use of high-volumes of byproducts materials. (Yahia et al. 1999, Bouzoubaa and Lachemi 2001, Persson 2002, Naik and Kumar 2003) since a higher volume of powder material is required for enhancing the cohesiveness and reducing the amount of superplasticizer and viscosity modifying agents (Shah et al., 2008).

2.1.2 Disadvantages of SCC

- Increased costs of material, especially for cementations materials and admixtures.
- Increased costs of formwork due to likely higher formwork pressures.
- Increased technical expertise required to develop and control mixtures.
- Increased variability in properties, especially workability.

- Increased quality control requirements.
- Decreased hardened properties-possibly including modulus of elasticity and dimensional stability-due to factors such as high paste volumes or low coarse aggregate contents.
- Delayed setting time in some situations due to the usage of admixtures.
- Increased risk and uncertainty associated with the use of a new product (Koehler and Fowler, 2007).

2.2 Properties of self-compacting

2.2.1 Workability

The workability of SCC is defined in terms of three properties: passing ability, filling ability, and segregation resistance (Table 2.1).

2.2.2 Filling ability

Describes the ability of concrete to flow under its own mass and completely fill formwork. It is important because concrete would not consolidate adequately without it.

2.2.3 Passing ability

Describe the ability of concrete to flow through confined conditions, such as the narrow openings between reinforcing bars. Although increasing the filling ability regularly increases passing ability and a high grade of filling ability do not assure passing ability.

2.2.4 Segregation resistance

Describe the ability of concrete to remain uniform in composition during placement and until setting. Segregation resistance includes both dynamic and static stability. Dynamic stability describes resistance segregation with concrete is not at rest - such as during mixing and placing. Static stability describes resistance segregation when concrete is at rest.

Each of these three workability properties should be managed and evaluated independently. Also the SCC must exhibit filling ability, passing ability, and

segregation resistance can vary exceedingly depending on the application. In target workability property selection, it is more important to design only for what is needed, with proper tolerances for anticipated construction variations. Increasing the levels of filling ability, passing ability and segregation resistance will often result in increased costs. Further, the susceptibility to segregation typically increases as the filling ability is increased.

Factors influence workability of concrete are:

- The duration and method of transportation.
- Characteristics and Quantity of cementations materials.
- Concrete consistency (slump).
- Grading shape and surface texture of fine and coarse aggregates.
- Entrained air.
- Water content.
- Concrete and ambient air temperatures.
- Admixtures.

A uniformly distribution of aggregate particles and the presence of entrained air significantly help to control segregation and improve workability (Abdulaziz, 2008).

Table 2.1 Workability of SCC (Koehler and Fowler, 2007)

	Definition	Application Requirements
Filling Ability	The ability of concrete to flow under its own mass and completely fill formwork.	Members with tight spaces—such as with narrow widths or congested reinforcement—and applications where concrete must flow long horizontal distances may require greater filling ability. High placement energy—such as that generated by pumping or by gravity acting on a large mass of concrete—may allow reduced filling ability requirements.
Passing Ability	The ability of concrete to flow through confined conditions, such as the narrow openings between reinforcement bars.	Applications may range from unreinforced or lightly reinforced sections with no passing ability requirements to narrow sections containing highly congested reinforcement with strict passing ability requirements.
Segregation Resistance	The ability of the concrete to remain uniform in composition during placement and until	All mixtures must exhibit segregation resistance. Requirements for dynamic stability may be higher for sections with highly congested reinforcement, conditions Where concrete subjected to vibration, or applications were concrete is dropped from vertical heights or required to flow long horizontal distances.

SCC workability also can be described in place of rheology, which is known as the scientific study of flow. In the context of concrete, rheology provides a scientific description of workability. The rheology of concrete is quantified in terms of plastic viscosity and the yield stress. The yield stress is described as the amount of stress

needed to maintain flow. Plastic viscosity is the resistance to flow once the yield stress is exceeded.

For SCC, the yield stress must be almost near zero to assure that the concrete can consolidate and flow under its own mass. The viscosity of plastic should not be too low, which lead to poor stability or too high, which lead the concrete that is sticky and difficult to place. Rheology is measured with a Rheometer. Specially designed Rheometers are available for measuring concrete. Rheometers determine and show the shear stress needed for concrete to flow at various shear rates. The greater the speed at which a fluid flows (higher shear rate), the more stress that is required and needed (higher shear stress). The relation between shear stress and shear rate is used to compute the yield stress and plastic viscosity, as shown in Figure 2.2. The Bingham model is used to represent this relationship.

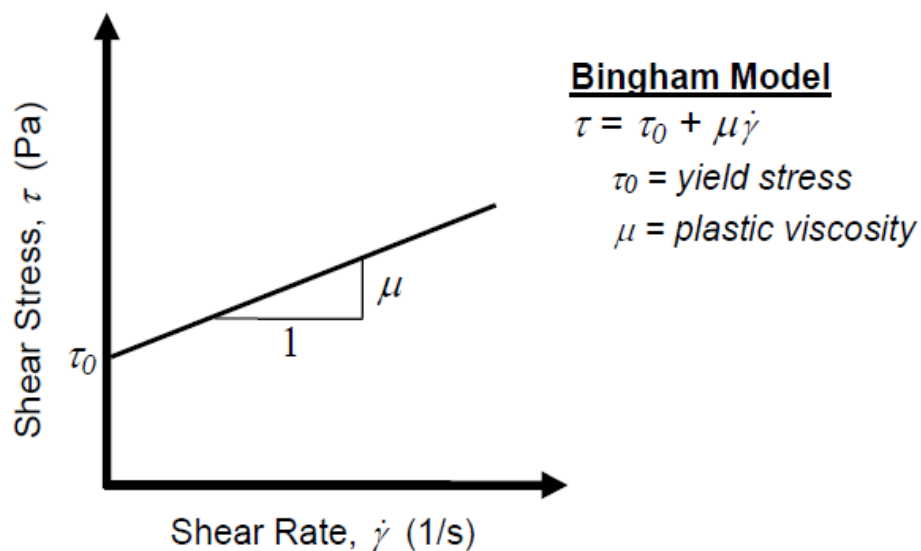


Figure 2.2 The Bingham Model for Concrete Rheology (Koehler and Fowler, 2007)

2.3 Rheology of fresh concrete

Rheology is the science that deals with the flow of materials and includes the deformation of hardened concrete, handling and placing of freshly mixed concrete, and the behavior of slurries and pastes. For discussion purposes only fresh concrete rheology properties are considered. In concrete work, it is usually desirable to produce the highest practical and economical density. Toward this goal, it is necessary to compare the vibrator characteristics with those of the concrete mixture.

This requires a thorough understanding of the properties of fresh concrete under vibration. Investigations on rheology of fresh concrete by a number of investigators attempt to describe the parameters involved (Lassalle, 1980). These parameters are reviewed on the basis of recent research and from the standpoint of application to the consolidation of fresh concrete.

Current standard test methods for determining concrete workability yield results of limited scope because they measure only one parameter. Examples of these tests are the slump, compacting factor, Vibe penetration, and other remolding and deforming tests. These tests, interpretation of their results, and rheology of fresh concrete are discussed by (Popovics, 1982) (Lane et al., 1998).

Rheology or the scientific research of deformation of matter and the flow provides an immediate approach to characterizing the SCC flow properties (Koehler, 2004). The purpose of using rheology is to provide and build a consistent, repeatable, and scientific description of concrete flow properties. Fundamental rheological parameters are inherent to a material, in theory it should be independent of the test device which is used. These rheological parameters can be compared with the workability of different mixtures to proportion new concrete mixtures also to simulate concrete flow in computer models. It is endurable to specify concrete mixtures in terms of rheological parameters. However Rheological parameters may not capture all relevant phases of workability. For example, passing ability depends primarily on aggregate characteristics and paste volume which cannot be fully predicted from rheological parameters. The characterization of concrete rheology is based on the hypothesis that concrete can be considered a fluid. Freshly-mixed concrete is fundamentally a concentrated suspension of aggregate particles in cement paste. In contrast to an elastic solid, which undergoes a recoverable deformation for the application of load, a fluid deforms and changes continuously under a constant shear stress and experiences there is no recovery of this deformation upon removing the load. Therefore, in characterizing the fundamental flow properties of a material, the relationship between shear stress, τ and shear rate, $\dot{\gamma}$, is considered. This relationship is shown graphically with a flow curve. The behavior of a fluid material may be idealized with a constitutive relationship. Six relation equations are shown in Figure 2.3 (Hackley and Ferraris, 2001).

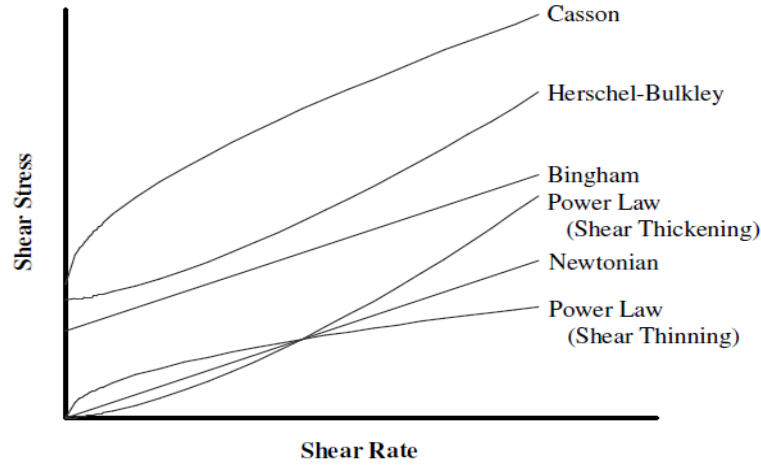


Figure 2.3 Constitutive Relationships for Fresh Concrete Plotted on a Flow Curve.
(Eric and David, 2007)

The Bingham model is the most excessively used constitutive relationship for concrete because of its simplicity and its ability to show concrete flow accurately (Ferraris, 1999). The Bingham model needs the determination of only two parameters-yield stress, τ_0 , and plastic viscosity, μ -as shown in Equation (2.1):

$$\tau = \tau_0 + \mu\dot{\gamma} \quad (2.1)$$

In practical terms, yield stress describes the amount of stress to maintain flow while plastic viscosity represents the resistance to flow once the yield stress has been exceeded. Increased plastic viscosity results in greater resistance to flow. The apparent viscosity is equal to the shear stress divided by the shear rate at any given shear rate. Thus, for a Bingham material, the apparent viscosity decreases with increasing shear rate. Fluidity is defined as the inverse of viscosity. For some concrete mixtures, the linear relationship between shear stress and shear rate is an oversimplification. The Herschel-Bulkley model incorporates two empirical constants, a and b , to represent non-linearity, as shown in Equation (2.2):

$$\tau = \tau_0 + \alpha\dot{\gamma}^b \quad (2.2)$$

If the yield stress is set to zero, the Herschel-Bulkley model describes a shear thinning or shear thickening power law fluid. Because some SCC mixtures can

exhibit shear-thinning behavior (Khayat, 2000) the variation in viscosity over a range of shear rates may need to be determined. In terms of the Bingham parameters, SCC must exhibit a proper combination of yield, stress and plastic viscosity in order to flow under its own mass and resist segregation. The yield stress is typically near zero to ensure that SCC will flow readily under its own mass; however, segregation might occur when the yield stress is too low. Plastic viscosity must be sufficiently high to prevent segregation, while not being too high that it restricts the speed of flow excessively.

Rheological parameters are commonly measured with rotational Rheometers. The use of Rheometers is well established in many fields (Barnes et al., 1989; Whorlow1992). Concrete Rheometers are typically rate-controlled devices, such that a range of various shear rates are applied and shear stresses are measured. Typical geometrical configurations for concrete Rheometers are shown in Figure 2.4. In a coaxial cylinders Rheometer, one cylinder rotates proportional to another, producing in shear through the fluid between the walls of the inner and outer cylinders. The rotation of a parallel plate Rheometer results in shear applied to the fluid due to a vertically and horizontally varying velocity distribution within the fluid. An impeller Rheometer collect some average shear rate in the surrounding fluid that can be used in conjunction with available calibration methods to compute rheological parameters. Thixotropy is another important rheological property, which is described as the reversible, time-dependent reduction in viscosity that happens when a material is faced to constant shear (Hackley and Ferraris, 2001). Beside thixotropy might be beneficial to SCC, its existence can complicate rheological measurements. Thixotropy has specific implications for lateral formwork pressures (Khayat and Mesbah, 2003), stability (Khayat, 1999), and pumpability (Barnes, 1997).

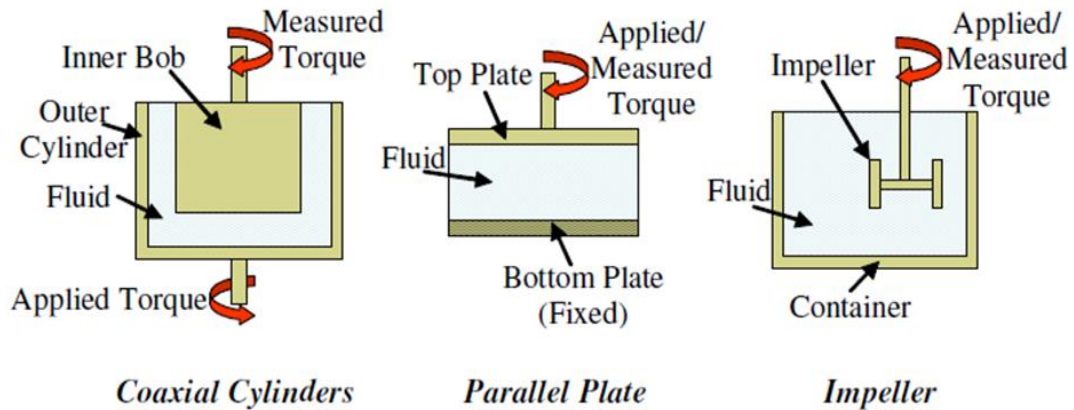


Figure 2.4 Typical Geometrical Configurations for Concrete Rheometers. (Eric and David, 2007)

2.4 Rubber and waste tires

Huge amounts of used rubber tires accumulate in the world each year 275 million in the United States (Papakonstantinou and Tobolski, 2006) and about 180 million in European Union (Silvestravičiūtė and Budrienė, 2002). One of the most widespread methods is to pile used tires in landfills, as due to low density and poor degradation they cannot be buried in landfills (Figure 2.5) (Segre and Joekes, 2000). These tires also can be placed in a dump or piled in a big hole in the ground. However these dumps serve as a great breeding medium for mosquitoes and due to the reality that mosquitoes are responsible for spreading many diseases, this turns to be a dangerous health hazard (Shuaib et al., 1997). In industry area larger amounts of rubber tire waste can be utilized as pigment soot, fuel, in bitumen pastes, roof and floor covers and for paving industry (Silvestravičiūtė and Budrienė, 2002; Kerševičius, 2002; Olivares et al., 2002). Concrete could be made cheaper by replacing some of its fine aggregate with granulated rubber crumbs from waste rubber tires. These granulated rubber crumbs are enquired through a process called continuous shredding, which is important to create crumbs small enough to replace an aggregate as fine as sand. These types of concrete are used in manufacturing reinforced pavement and bridge structures have better resistance to. (Kerševičius, 2002; Skripkiūnas and Grinys, 2005; Skripkiūnas and Grinys, 2005). The replacement of granulated rubber waste with aggregates deteriorates concrete mechanical properties (Eldin and Senouci, 1993; Lee et al., 1993). The reduce of compressive strength of concrete after some modification with rubber waste is explained by the more elastic and softer rubber

particles compared to the sand particles (Papakonstantinou and Tobolski, 2006; Eldin and Senouci, 1993 ; Lee et al.,1993).

The other reason for concrete compressive strength reduction is lower compressive strength of the crumbed rubber particles related to the strength of concrete aggregates (Eldin and Senouci, 1996; Sheikin et al., 1979). Deterioration of the mechanical properties of concrete with rubber additives is also explained by low adhesion among the rubber particles and cement matrix. (Silvestravičiūtė and Budrienė, 2002; Li et al., 2004). Using rubber waste in concrete, smaller concrete module of elasticity is gained. (Papakonstantinou and Tobolski, 2006; Olivares et al., 2002; Güneyisi et al., 2004; Bignozzi and Sandrolini, 2006). Therefore modulus of elasticity has relation with concrete compressive strength and the elastic properties of aggregates have substantial effect on the modulus of elasticity of concrete. The larger amount of rubber additives is added to concrete, the less modulus of elasticity is obtained (Papakonstantinou and Tobolski, 2006; Güneyisi et al., 2004).

2.4.1 Classification of scrap-tires

2.4.1.1 Scrap-tires

Scrap tires can be managed as a whole tire, as slit tire, as shredded or chopped tire, as ground rubber or as a crumb rubber product. A typical automobile tire weighs 9.07 kg, where a truck tire weighs about 45.36 kg. Table 2.2 gives the major materials used to manufacture tires by percentage of total weight of the finished tire that each material shows.

2.4.1.2 Slit-tires

These are product of tire cutting machines. These machines can slit the tire into two halves or can separate the side walls from the thread of the tires (Figure 2.5).



Figure 2.5 The existing huge amount of Scrap tyres in the world (Turer, 2012)

Table 2.2 Typical composition of manufactured tires by (Rubber Manufacturer's Association, 2000)

Composition (wt%)	Automobile tire	Truck tire
Natural rubber	14	27
Synthetic rubber	27	14
Carbon black	28	28
Steel	14-15	14-15
Fabric, filler, accelerators and antiozonants	16-17	16-17

2.4.1.3 Shredded/chipped tires

Tire shreds or chips imply primary, secondary or both shredding operations. The size of the tire shreds produced in the primary shredding process can vary from as large as 300 to 460 mm (12–18 in.) long by 100–230 mm (4–9 in.) wide, down to as small as 100–150 mm (4–6 in.) in length, depending on the manufacturer's shredder model and the condition of the cutting edges. Production of tire chips, normally sized from 76 (3 in.) to 13 mm (0.5 in.), needs both primary and secondary shredding to achieve sufficient volume (quantity) reduction (Read et al., 1991). (Figure 2.6)

2.4.1.4 Ground rubber

Ground rubber for applications of commercial may be nominally sized as large as 19 mm (or 3/4 in.) to as small as 0.15 mm (No. 100 sieve). It depends on the kind of size reduction equipment and intended applications. The processed used tires in ground rubber applications are subjected to two stages of magnetic separation and to screening. Various size fractions of rubber are recovered (Heitzman, 1992). Some processes/markets term 30 mesh rubber as crumb rubber Figure 2.7.

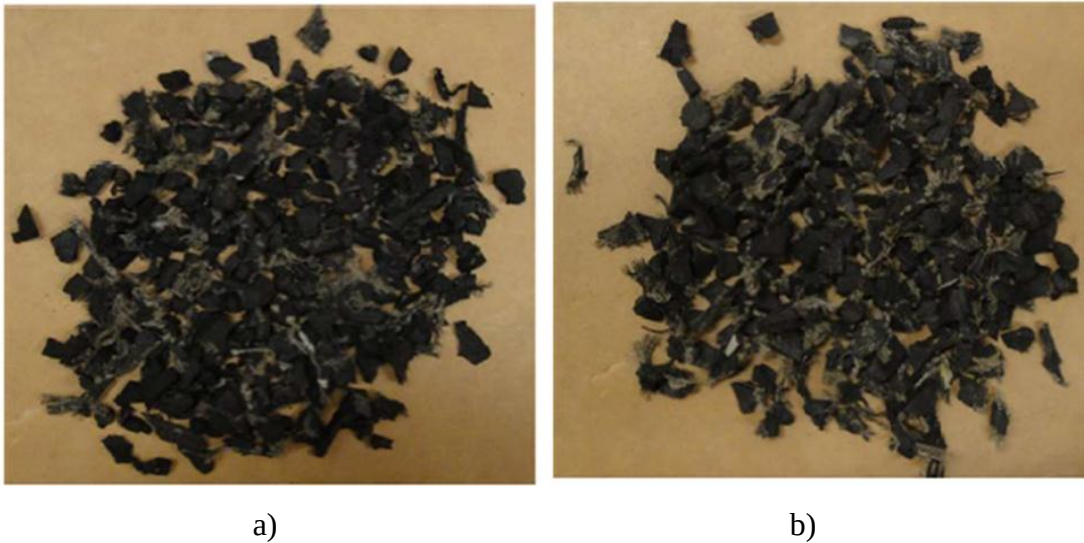


Figure 2.6 Photographic view of tire chips a) 1.27cm and b) 1.9cm (Liu, 2013).

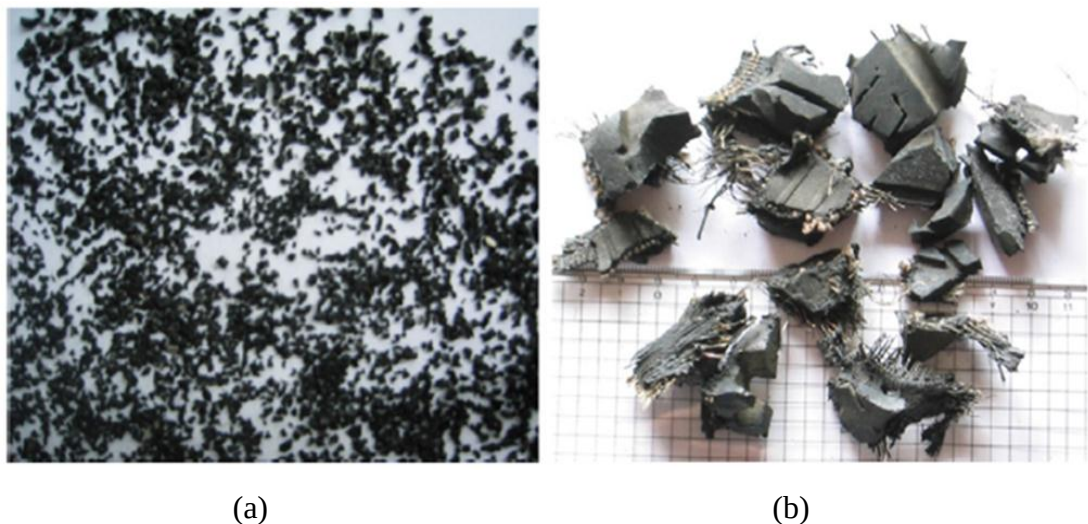


Figure 2.7 Tire rubber waste: a) ground and b) crushed (Pacheco-Torgal et al., 2012)

2.4.1.5 Crumb rubber

Crumb rubber consists of particle sizes from 4.75 (No. 4 Sieve) to less than 0.075 mm (No. 200 Sieve). (Figure 2.8) Generally, the following methods are used to change scrap-tires into crumb rubber. These methods are: (i) cracker mill process, (ii) granular process and (iii) micro-mill process. The cracker mill process tears apart or decreases the size of tire rubber by passing the material between rotating corrugated steel drums. This process produces an irregularly shaped particles having big surface area. The size of these particles varies from 5 to 0.5 mm (No. 4–No. 40 Sieve) and is commonly known as crumb rubber. Granular process shears apart the rubber with revolving steel plates, producing granulated crumb rubber particles, ranging in size from 9.5 (3/8 in.) to 0.5 mm (No. 40 Sieve) (Heitzman, 1992).

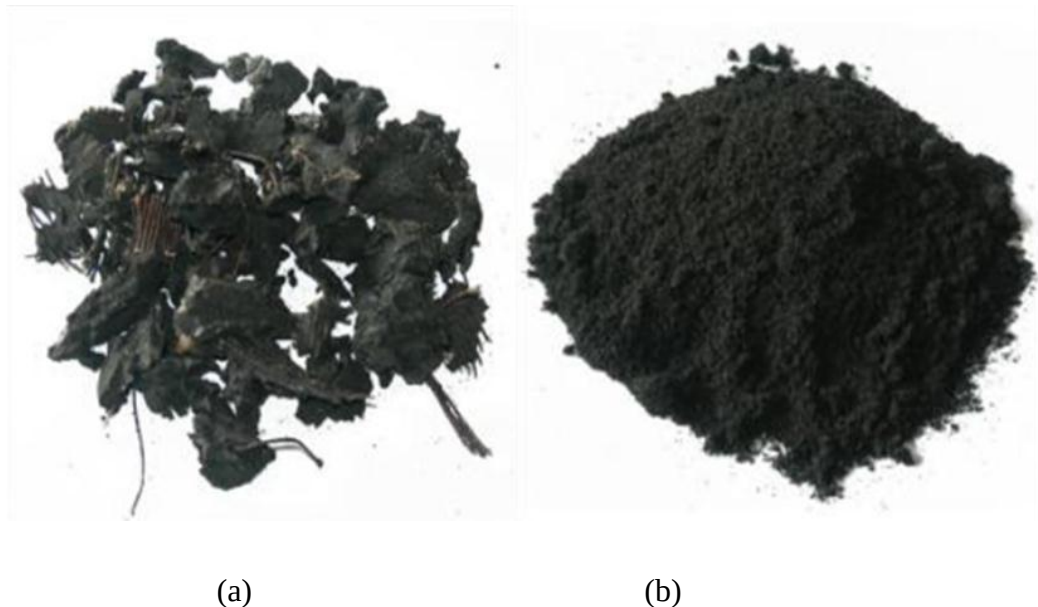


Figure 2.8: a) Shredded Rubber and b) Crumb Rubber (Deshpande et al., 2012)

2.4.2 Typical compositions of waste tires

Waste tires are the tires removed from automobiles and trucks. The typical weights of an automobile tire and a truck tire are 20 lbs. and 100 lbs. respectively. The main materials used for manufacturing tires include natural & synthetic rubber (41%), carbon black (28%), steel (14-15%), fabric, filler, accelerators and antiozonants (16-17%), (Siddique and Naik, 2004).

2.4.3 Classification of recycled waste tire particles

Table 2-3 includes the terminology for recycled waste tire particles defined by ASTM D-6270

Table 2.3 ASTM D-6270 Terminology for Recycled Waste Tire Particles

Classification	Lower Limit, (mm)	Upper Limit, (mm)
Chopped Tire	Unspecified dimensions	
Rough Shred	50*50*50	762*50*100
Tire Derived Aggregate	12	305
Tire Shreds	50	305
Tire Chips	12	50
Granulated Rubber	0.425	12
Ground Rubber	-	<0.425
Powered Rubber	-	<0.425

Chopped tires are the production of tire cutting machines. Those machines cut waste tires in to relatively large pieces. The primary shredding process can produce scrap tires with a size as large as 12-18 in. long by 4-9 in. wide (Siddique and Naik, 2004). Rough shreds; tire derived aggregates, tire shreds and tire chips are produced from the secondary shredding, which cut the tires down to 0.5–3 in. Granulated rubbers, ground rubbers and powered rubbers are manufactured by cracker mill process, granular process or micro-mill process, (Siddique and Naik, 2004; Heitzman, 1992). The commonly known crumb rubber consists of tire particles passing through No. 4 Sieve.

2.4.4 Basic material properties of tire rubber

This section presents the engineering properties necessary for design of scrap tires in applications of civil engineering, e.g. specific gravity, modulus of elasticity (MOE), etc. As discussed above, tires are consists of natural and synthetic rubber elastomers derived from oil, gas, and metallic intrusions. Other compositions e.g. carbon black, polymers, steel, and additives are incorporated to enhance performance of tires. The basic tire properties are summarized in Table 2-4 and compared with the mineral aggregates properties.

Table 2.4 Basic engineering properties of tire rubber compared with mineral aggregates

Properties References	Tire Rubber	Mineral Aggregates
Specific Gravity (Humphrey and Manion, 1992; Ahmed, 1993)	1.02-1.27	2.6-2.8
Modulus of Elasticity (Beatty, 1981; Kulhawy and Mayne, 1990)	180 – 750 psi	6,000-12,000 psi
Possion's Ratio (Beatty, 1981; Kulhawy and Mayne, 1990)	0.5	0.15-0.45
Dense, drained sand		

2.5 Fresh concrete properties of concrete made with rubber tire particles

2.5.1 Unit Weight

The specific gravity of rubber tire particles is much less than that of typical normal weight aggregates used in concrete. Sukontasukkul in his study of crumb rubber used in precast panels stated that the average bulk specific gravity of the crumb rubber was 0.96 compared to that of 2.43 for fine aggregate and 2.68 for coarse aggregate used in his research. This difference in the specific gravity causes mixtures with crumb rubber to have a lower unit weight than normal mixtures. Another factor that decreases the unit weight of mixtures with rubber tire particles is that they tend to have higher air contents (Sukontasukkul, 2009). Khatib and Bayomy found that the unit weight decreases as the amount of rubber added increases. A mixture with no rubber particles weighed 2.4 kg/m^3 while a mixture with 50% replacement of total aggregate volume weighed 1.8 kg/m^3 (Khatib and Bayomy, 1999).

2.5.2 Slump

In examining the concrete workability mixtures with rubber tire particles, Khatib and Bayomy found that the slump of the concrete decreased as the amount of rubber particles increased. They investigated three categories of mixtures with various

amounts of rubber tire particle replacement rates. The first category was made with crumb rubber to replace a portion of the fine aggregate. The second category contained rubber chips to replace a portion of the coarse aggregate and the third was a combination of crumb rubber and chips to replace both fine and coarse aggregates. Their findings showed that when rubber particles were used to replace 40% of the total aggregate volume content, the slump for the mixtures with rubber chips was near zero and the mixture could not be worked by hand mixing. The mixture with only crumb rubber was much more workable than the other two mixtures (Khatib and Bayomy, 1999).

2.5.3 Air Content

Several researchers have found that the addition of rubber tire particles to concrete results in higher air content. Khatib and Bayomy found that as the amount of rubber tire particles increase the air content of the mixture increased (Khatib and Bayomy, 1999). Conclusions of the study have been confirmed by Fedroff et al. who found higher air contents in mixtures containing crumb rubber than the control mixtures even without the use of an air entraining admixture. The researchers thought that the higher rubber contents may be due entrapped air on the surface of the rubber particles due to their texture and non-polar nature (Federoff et al., 1996).

2.6 Admixtures for SCC

Admixtures, described as materials added in very small amounts to modify or change the properties of the cement-water-aggregate system, this have been used for many years before (Ramachandran, 1996; Edmeades and Hewlett, 1998). In recent years, many investigators have found that the use of supplementary cementitious materials (SCMs) like fly ash, blast furnace slag, silica fume, metakaolin and rice husk ash etc. can not only improve the different properties of concrete both in its fresh and hardened states, but also can contribute to economy in construction costs.

However the strength and durability characteristics of concrete mixes with such SCMs have to be assured before using them in large infrastructural projects. Permeability of concrete is considered to be the most important characteristic of concrete that affects its durability (Aitcin, 1998; Baykel, 2000). Poor impermeability of concrete might lead to the ingress of Chloride ions into concrete resulting in the

corrosion of the steel rebar embedded in it. Once this occurs, the structure will no longer gain its structural integrity; the lifespan is reduced and the general safety of the public amenity is severely degraded. It is apparent that for many reinforced concrete members, the ability of the concrete to resist chloride penetration is an essential factor in determining its successful performance over an extended period.

At micro-level, the chloride permeability of a concrete mix has relation with the pore structure of the cement-paste matrix. When pore volume increases, the apparent chloride diffusion coefficients increase (Savas, 1999; ACI 211-1-91, 1993) (Pore-structure of concrete differs with age and depth from the exposed surface (Saricimen et al., 200; Stanish et al., 1997). The resistance to chloride penetration of concrete is significantly increased with the incorporation of finer fly ash particles (P. Chindaprasirtet al., 2007; Kalifa P et al., 2000). Such an increase in chloride-ion penetration results from the reduced water-to-binder ratio, the reduced average pore-size of the paste and the improved interfacial zone. The incorporation of fly ash may also enhance the workability of the mixes due to the smooth spherical surfaces of the fine fly ash particles. Hence the use of higher volumes of fly ash in concrete is advantageous in reducing the permeability of concrete due to their filler as well as pozzolanic effects (Sherman et al., 1996). In the present study, an attempt is made to investigate the chloride permeability resistance characteristics of a few candidate self-compacting, high-volume fly ash concrete mixes. Further, effect of blending other mineral admixtures like GGBFS silica fume, metakaolin and rice husk ash concrete mixes are also examined (Amrutha et al., 2011).

2.6.1 Mineral Admixtures

The most often used mineral admixture in the concrete industry is pozzolan. According to American Concrete Institute (ACI), a pozzolan is described as “siliceous or siliceous and aluminous materials which in themselves possesses little or no cementitious value but in finely divided form and the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties”. ACI 231 defines the chemical reaction between the siliceous and/or siliceous-alumina components in the pozzolan, calcium hydroxide and water as pozzolanic reaction. There are two types of pozzolan, namely natural pozzolan and man-made pozzolan. Natural pozzolans are

of volcanic origin (these were used by the early Romans and Greeks) such as trass, certain pumicites, perlite, and kaoline. Man-made pozzolans include industrial by-products such as fly ash, blast furnace slag, and silica fume (Güneyisi, 2004).

2.6.1.1 Fly ash

Fly ash is very much similar to volcanic ashes used in production of the earliest known hydraulic cements about 2,300 years ago. Those cements were made near the small Italian town of Pozzuoli which later gave its name to the term “pozzolan”. A pozzolan is a siliceous or siliceous aluminous material which when mixed with lime and water forms a cementitious compound. Fly ash is the best known and one of the most commonly used, pozzolans in the world. Fly ash is the notorious waste product of coal based electricity generating thermal power plants, known for its ill effects on agricultural land, surface and sub-surface water pollution, soil, air pollution and diseases to mankind. Researchers have proposed few ways of reusing fly ash for variety of application. One of the most common reuse of fly ash is in cement concrete. Fly ash particles are almost totally spherical in shape, allowing them to flow and blend freely in mixtures. That capability is one of the properties making fly ash a desirable admixture for concrete. These materials greatly improve the durability of concrete through control of high thermal gradients, pore refinement, depletion of cement alkalis, resistance to chloride and sulphate penetration, and continued micro structural development through a long-term hydration and pozzolanic reaction. The utilization of by-products as the partial replacement of cement has important economical, environmental and technical benefits such as the reduced amount of waste materials, cleaner environment, reduced energy requirement, durable service performance during service life and cost effective structures. In this experimental investigation, an attempt has been made to study the techno-economic analysis for the compressive strength of fly ash concrete. The fly ash is procured from Deep agar Thermal Power Plant. This plant is located near Bhusawal city in Jalgaon District in Maharashtra State. The plant is an establishment of 1968. It has a generation capacity of 480 MW. It consumes 7500-8500 MT/day of coal and produces 2550 to 2800 MT/day fly ash. Here, in our work a comparative study of the characteristics compressive strength between Ordinary Portland Cement concrete and Fly ash based concrete has been made. Fly ash is used in different proportions ranging from 10% to 50% by weight of cement in steps of 5%. Using the

experimental data, a column section is designed. The relative cost of column sectioned signed with OPC as well as various proportion of fly ash is estimated and compared. It is observed that fly ash can be safely and economically used. This also provides an environmental method of fly ash disposal.

Properties of fly ash:

Various tests were done to find out the physical and chemical properties of fly ash which is illustrated in table 2-5. It can be seen that all parameters are within permissible limits (Suman et al., 2012). The benefits for using fly ash in concrete include the following: (Klieger et al., 1994)

- Improved workability,
- Lower heat of hydration,
- Lower cost concrete,
- Improved resistance to sulfate attack,
- Improved resistance to alkali-silica reaction,
- Higher long-term strength,
- Opportunity for higher strength concrete,
- Equal or increased freeze thaw durability,
- Lower shrinkage characteristics, and
- Lower porosity and improved impermeability. (Elsayed, 2012)

Table 2.5 Physico-chemical properties of fly ash. (Elsayed, 2012)

Parameter	Observed value	Permissible value as per IS3812- 2003
Specific surface area	340-360m ² /kg	>250 m ² /kg
Particle retained on 45 micron sieve	28.9%	<35%
Compressive strength at 28 days	44-48 N/mm ²	>39-43 N/mm ²
Soundness	0.014 to 0.018%	<8%
Silica+alumina+iron oxide content	88-91%	>70%
Silica	58-60%	35%
sulfur as SO ₃	0.26-0.32%	<0.3%
Mgo	0.26-0.34%	<0.5%
Loss on ignition	0.9-1.05%	<1.5%
Available alkalies as Na ₂ O	0.16-0.02%	1.5%
Chlorides	0.16-0.02%	0.05%

2.6.1.2 Silica fume

The American Concrete Institute (ACI) defines silica fume as a “very fine non-crystalline silica produced in electric arc furnaces as a byproduct of production of elemental silicon or alloys containing silicon” (ACI 116R). It is usually a grey colored powder, somewhat similar to Portland cement or some fly ashes (Silica fume–user's manual, Federal Highway Administration (2005)).

Silica fume is also known as micro silica, volatilized silica or condensed silica fume. It is a by-product from silicon metal and ferrosilicon alloy production. The material is a very fine powder with spherical particles about 100 times smaller in size than Portland cement or fly ash. The diameters range from 0.02 to 0.5 μ m with an average of 0.1 μ m. Silica fume contains 85 to 95% non-crystalline silicon dioxide. The first application of silica fume in the United States was conducted in Kentucky in 1982 (Klieger et al., 1994). The use of silica fume will make concrete with the following properties: (Sobolev and Vladimir, 2007).

- Low heat of hydration,
- Retarded alkali-aggregate reaction,
- Reduced freeze-thaw damage and water erosion,
- High strength,
- Increased sulfate resistance,
- Reduced permeability

Silica fume is also known for creating problems in handling and cracking related to its small particle sizes and increased water requirement. The chemical analysis and physical properties of silica fume shown in Table 2.6 (Elsayed, 2012).

Table 2.6 Chemical Analysis and Physical Properties of the Silica Fume. (Elsayed, 2012)

Analysis and properties	Mass %
SiO ₂	90.2
Al ₂ O ₃	1.7
Fe ₂ O ₃	0.4
CaO	2.1
MgO	1.7
Na ₂ O	0.7
K ₂ O	0.7
SO ₃	0.5
Loss on ignition (LOI)	2.5
Specific Surface Area (cm ² /g)	200000
Specific gravity	2.21

i. Effect of silica fume on fresh properties of cement/mortar/concrete

Rheological properties of a fresh cement paste play an important role in determining the workability of concrete. The water requirement for flow, hydration behavior, and properties of the hardened state largely depends upon the degree of dispersion of cement in water. Properties such as fineness, particle size distribution, and mixing intensity are important in determining the rheological properties of cement paste. Due to the charges that develop on the surface, cement particles tend to agglomerate in the paste and form floc that trap some of the mixing water. Factors such as water content, early hydration, water reducing admixtures and mineral admixtures like silica fume determine the degree of flocculation in a cement paste. Fresh concrete containing silica fume is more cohesive and less prone to segregation than concrete without silica fume. Concrete containing silica fume shows substantial reduced bleeding. Additionally silica fume reduces bleeding by physically blocking the pores in the fresh concrete. Use of silica fume does not significantly change the unit weight of concrete. (Siddique and Khan, 2011)

2.6.2 Chemical Admixtures

In SCC there are two principles of chemical admixtures which are: a synthetic high-range water reducer (super-plasticizer) and a viscosity modifying admixture (VMA). These might be used by themselves but are more commonly used together (Nasvik, 2002).

2.6.2.1 Superplasticizers

Superplasticizers are a water-reducing admixture that causes a significant increase in flowability with little effect on viscosity. (Okamura, 1997) For example, the addition of 0.3 to 1.5 percent (by weight of cement) conventional superplasticizer to a concrete mix with 50-70 mm slump increases slump to 200-250 mm. (Mehta and Monteiro, 2001) (See Figure 2.9). Superplasticizers have been on the market for more than 30 years. However, these had the problem of retarding initial set and inhibiting complete hydration of cement particles. The new generation of superplasticizers is based on polycarboxylated ethers, which act as powerful cement dispersants that require less mix water to provide dramatic increase in flow. Some of these have also been engineered to set more rapidly and provide more complete cement hydration. Polycarboxylate based-superplasticizers are now available from about 50% of the producers of ready-mix concrete in the US, truly opening up the market for SCC (Nasvik, 2002). The primary negative effect when adding superplasticizer alone to concrete is that the mix may have a tendency to segregate and bleed. There are two paths to avoid this problem, involving modifying mix proportions and use of viscosity modifying admixtures. Segregation can also occur with a normally consolidating concrete if over vibrated (Khayat et al., 2001). Another limitation of superplasticizers is that the concrete will lose its high consistency in 30-60 minutes, reverting back to its original slump. Therefore, there is only this short window of time between mixing and placing. For precast concrete, this is usually not a complication. In fact, in precast, it is often desirable to have this short duration before regaining stiffness, especially for steam curing, which is a more rapid way to cure concrete (Mehta and Monteiro, 2001). On the other hand, the high slump loss characteristic that occurs with adding superplasticizer may pose a serious problem for ready-mix concrete. On the job site, many other factors may cause a time delay between mixing and pouring. Such unforeseen occasions could lead to

wasted concrete and labor, if not requiring more for repair. Researchers have discovered two methods of dealing with this problem (Mehta and Monteiro, 2001).

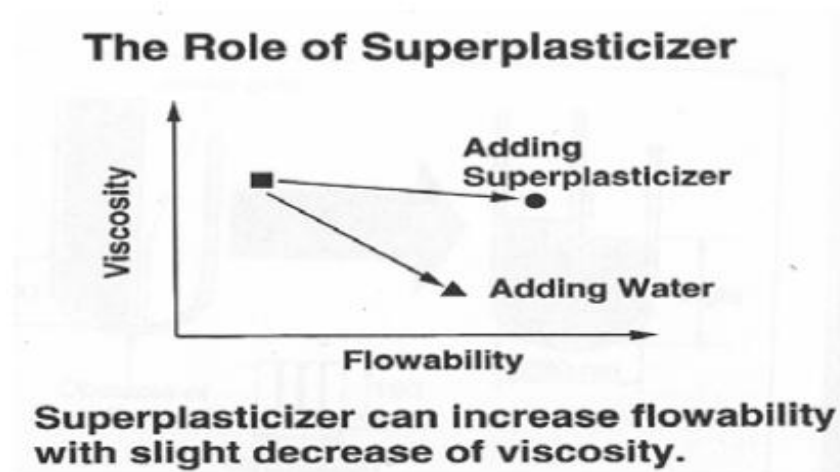


Figure 2.9 Effects of superplasticizer (Okamura, 1997)

The first is that superplasticizer after repeated doses of the slump damage, to maintain performance within a few hours. The second and third quantity, however, the concrete mix may be prone to segregation. The second strategy is to add back into the mix is a factor that may increase the slump to 2-3 hours maintain. Such admixtures with these retarding agents are termed low-slump-loss superplasticizers and have been used in hot-weather concrete where the high temperature induces quicker setting times. (Mehta and Monteiro, 2001) Several tests have been performed on superplasticized concrete vs. control mixes. The following table shows how several important properties of SCC achieved with superplasticizers compare to those of low-slump and high-slump control mixes:

Table 2.7 Experimental Results Comparing Properties of Mixes with and without Superplasticizer (Yang, 2004)

Properties of Mixes with Superplasticizer	Compared to high-slump (watery concrete)	Compared to low-slump (75 mm)
Slump Loss		Faster
Setting Time Retardation		Slight
Segregation & Bleeding	Slight	
Comp & Flex Strength		Not much difference
Freeze-Thaw Durability	Overall satisfactory	
Permeability	Overall satisfactory	
Drying Shrinkage	Less	No difference

The primary purpose behind using superplasticizers is in achieving highly flowable concrete while maintaining low water and high fines content. Low water-to-cement ratio is a principal factor enhancing strength, durability, permeability and shrinkage. See Figure 2.10. (Yang, 2004)

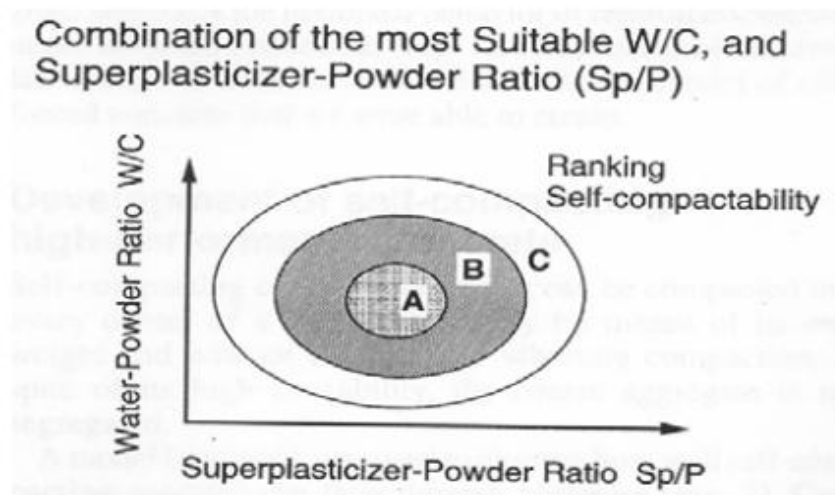


Figure 2.10 Optimum combination of superplasticizer and w/c ratio (Okamura, 1997)

2.7 Test methods for workability of self-compacting concrete

Basic requirements for self-compacting concrete are those in the fresh state: Flowability, viscosity (measure of the speed of flow), passing ability (flow without blocking) and segregation resistance. A concrete mix can only be classified as SCC if

the requirements for all characteristics are fulfilled. Each of them can be addressed by one or more test methods. The most repeated are:

2.7.1 Slump flow and T_{500} time

Slump flow is a test to assess the flowability and the flow rate of SCC in the absence of obstructions. It is based on the slump test described in EN 1235-2. The result is an indication of the filling ability of SCC and the T_{500} time is a measure of the speed of flow and hence the viscosity. The fresh concrete is poured into a cone. When the cone is upwards the time from commencing upward movement the cone to when the concrete has flowed to a diameter of 500 mm is measured; this is the T_{500} time. The largest diameter of the slow spread of the concrete and the diameter of the spread at right angles to it are then measured and the mean is the slump-flow, Figure 2.7 (Grdić et al., 2008).

Principle

The slump flow test aims at studying the filling ability of SCC. It measures two parameters: flow spread and flow time T_{50} (optional). The former shows the free, unrestricted deformability and the latter indicates the rate of deformation within a defined flow distance.

Equipment

- Base plate of size at least 900×900 mm, made of impermeable and rigid material (steel or plywood) with smooth and plane test surface (deviation of the flatness not exceed 3mm), and clearly marked with circles of $\varnothing 200$ mm and $\varnothing 500$ mm at the center, as shown in Figure 2.11.

NOTE The deviation of the flatness of the test surface is defined as the greatest difference in height between the highest and the lowest points on that surface, while disregarding any small single cavities in the surface.

- Abrams cone with the internal upper/lower diameter equal to 100/200 mm and the height of 300 mm, as shown in Figure 2.11.
- Weight ring (>9 kg) for keeping Abrams cone in place during sample filling. An example of its dimensions is given in Figure 2.12. Alternatively, a cast

iron cone may be used as long as the weight of the cone exceeds 10 kg. As a second alternative the cone may be kept in position by human force.

- Stopwatch with the accuracy of 0.1 second for recording the flow time T_{50} .
- Ruler (graduated in mm) for measuring the diameters of the flow spread.
- Bucket with a capacity of larger than 6 liters for sampling fresh concrete.
- Moist sponge or towel for wetting the inner surface of the cone and the test surface of the base plate.
- Rag for cleaning spilled concrete if any.

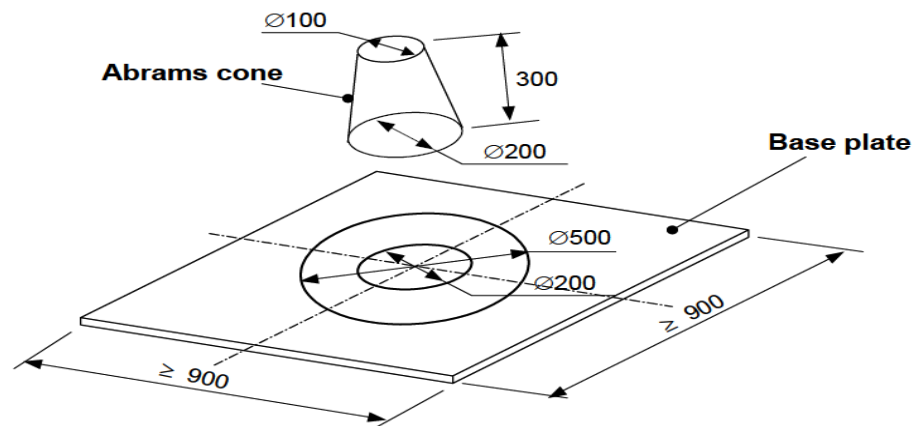


Figure 2.11 Base plate and Abrams cone (Schutter, 2005)

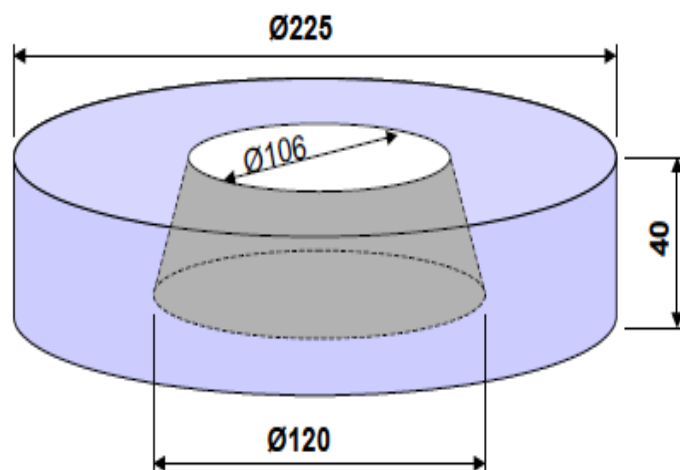


Figure 2.12 Example of dimensions of a weight ring (Schutter, 2005)

Test procedure

- Place the cleaned base plate in a stable and level position.
- Fill the bucket with 6~7 liters of representative fresh SCC and let the sample stand still for about 1 minute (± 10 seconds).
- During the 1 minute waiting period pre-wet the inner surface of the cone and the test surface of the base plate using the moist sponge or towel, and place the cone in the center on the 200 mm circle of the base plate and put the weight ring on the top of the cone to keep it in place. (If a heavy cone is used, or the cone is kept in position by hand no weight ring is needed).
- Fill the cone with the sample from the bucket without any external compacting action such as rodding or vibrating. The surplus concrete above the top of the cone should be struck off, and any concrete remaining on the base plate should be removed.
- Check and make sure that the test surface is neither too wet nor too dry. No dry area on the base plate is allowed and any surplus of the water should be removed – the moisture state of the plate has to be ‘just wet’.
- After a short rest (no more than 30 seconds for cleaning and checking the moist state of the test surface), lift the cone perpendicular to the base plate in a single movement, in such a manner that the concrete is allowed to flow out freely without obstruction from the cone, and start the stopwatch the moment the cone loses contact with the base plate.
- Stop the stopwatch when the front of the concrete first touches the circle of diameter 500 mm. The stopwatch reading is recorded as the T_{50} value. The test is completed when the concrete flow has ceased.

NOTE Do not touch the base plate or otherwise disturb the concrete until the measurement described below is completed.

- Measure the largest diameter of the flow spread, d_{max} , and the one perpendicular to it, d_{perp} , using the ruler (reading to nearest 5 mm). Care should be taken to prevent the ruler from bending.
- Clean the base plate and the cone after testing (Schutter, 2005).

2.7.2 L-box test

L-box test is used to assess the passing ability of SCC to flow through tight openings including spaces between reinforcing bars and other obstructions without segregation or blocking. L-box has arrangement and the dimensions as shown in Figure 2.13. Test procedure is to support the L-box on a level horizontal base and close the gate between the vertical and horizontal sections. Pour the concrete from the container into the filling hopper of the box and allow standing for (60 ± 10) s. When movement has ceased, measure the vertical distance, at the end of the horizontal section of the L-box, between the top of the concrete and the top of the horizontal section of the box at three points equally spaced across the width of the box. By difference with the height of the horizontal section of the box, these three measurements are used to calculate the mean depth of concrete as H_2 mm. The same procedure is used to calculate the depth of concrete immediately behind the gate as H_1 mm. The passing ability is calculated from the following equation: $PA = H_2/H_1$ (Grdić et al., 2008).

Principle

The method aims at investigating the passing ability of SCC. It measures the reached height of fresh SCC after passing through the specified gaps of steel bars and flowing within a defined flow distance. With this reached height, the passing or blocking behavior of SCC can be estimated.

Equipment

- L- Box, as shown in Figures 2.13. Two types of gates can be used, one with 3 smooth bars and one with 2 smooth bars. The gaps are 41 and 59 mm, respectively.
- Suitable tool for ensuring that the box is level i.e. a spirit level.
- Suitable buckets for taking concrete sample.

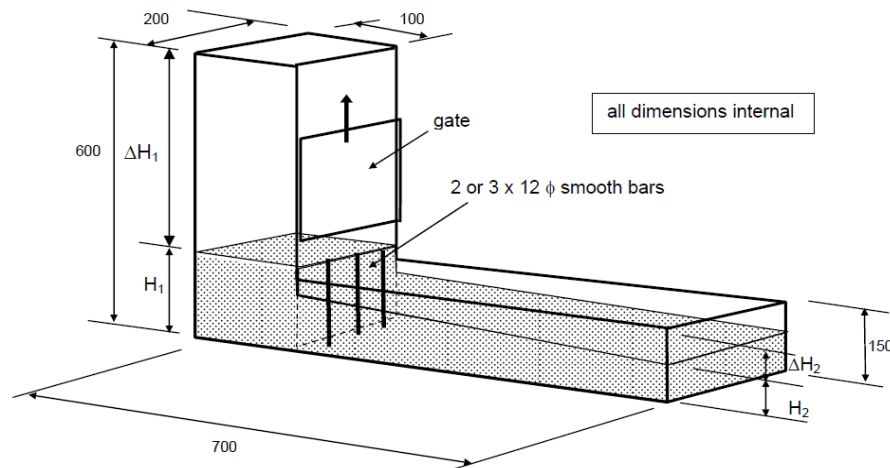


Figure 2.13 L-Box testing apparatus (Domone, 2009)

Test procedure

- Place the L-box in a stable and level position.
- Fill the vertical part of the L-box, with the extra adapter mounted, with 12.7 liters of representative fresh SCC.
- Let the concrete rest in the vertical part for one minute (± 10 seconds). During this time the concrete will display whether it is stable or not (segregation).
- Lift the sliding gate and let the concrete flow out of the vertical part into the horizontal part of the L-box.
- When the concrete has stopped moving, measure the average distance, noted as Δh (see Figure 2.13), between the top edge of the box and the concrete that reached the end of the box, at three positions, one at the center and two at each side (Schutte, 2005).

2.7.3 V-funnel test

The V-funnel test is used to assess the viscosity and filling ability of SCC. Procedure is to clean the funnel and bottom gate, then dampen all the inside surface including the gate. Close the gate and pour the sample of concrete into the funnel, without any agitation or rodding, then strike off the top with the straight edge so that the concrete is with the top of the funnel. Place the container under the funnel in order to retain the concrete to be passed. After a delay of (10 ± 2) s from filling the funnel, open the gate and measure the time t_v , to 0.1 s, from opening the gate to when is possible to

see vertically through funnel into the container below for the first time. t_v is the V-funnel flow time. V-funnel is shown in Figure 2.14 (Grdić et al., 2008).

Principle

The V-funnel flow-time is the time for a defined volume of SCC to flow through a narrow opening at the mouth of the funnel and gives an indication of the filling ability of SCC provided blocking and/or segregation do not take place; the flow-time of the V-funnel test is to some degree related to the plastic viscosity.

Equipment

Fig. 2.14 shows the dimensions of the V-funnel. The flow-time depends on the volume of SCC, the size of the opening gap and whether other key characteristics of SCC than filling ability affect the test response.

To measure the V-funnel flow-time the following equipment is required:

- V-funnel made of steel, with a flat, horizontal top and placed on vertical supports, and with a quickly releasable, watertight opening trapdoor.
- Straightedge to level concrete.
- Clean, wetted and squeezed towel or cloth.
- Stopwatch (accuracy: 0.1 s).
- Bucket with a capacity of 12 liters.

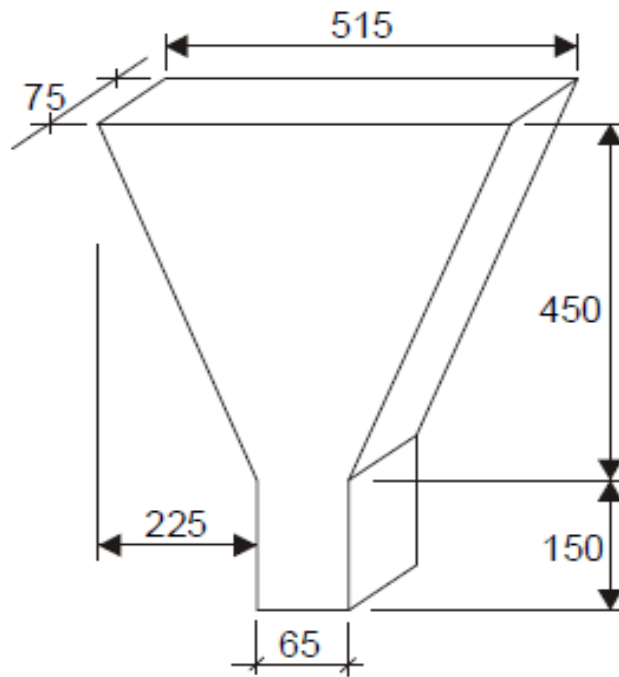


Figure 2.14 Dimensions of the V-funnel (Domone, 2009)

Preparation of the test:

1. Place the clean V-funnel vertically on a flat, firm ground, with the top opening horizontal.
2. wet the interior of the funnel with a moistened towel; surplus water must to be removed; the inside of the funnel has to be 'just wet'.
3. Close the trapdoor and position the bucket below it.
4. Fill the funnel completely with a representative sample of SCC without applying any compaction or rodding.
5. Strike off any surplus of concrete. Do not knock or move the V-funnel until it is empty.

Execution of the test and data processing:

1. 10 seconds after completing the filling, open the trapdoor.
2. Start the stopwatch at the same moment as the gate opens.

3. Look vertically inside the funnel, and stop the time at the instant that daylight can be seen through the opening. The above operation shall be carried out three times using the same sample and without any cleaning between tests. The flow-times from the second and the third running shall be recorded. The funnel should be cleaned after testing is complete.

Expression of results

Two results can be arrived from the V-funnel test: flow-time and visual observations.

Flow-time: The flow-time is the period from releasing the gate until first light enters the opening gap. Round the flow time is to the nearest 1/10 s.

Visual observations: Any temporary or complete stop of the flow might indicate instability of SCC (Domone, 2009).

Table 2.8 Testing methods and limiting test values for SCC (Ahmad and Khadirnaikar, 2014)

Property	Test method	Material	Recommended values
Flowability / Filling ability	Slump flow	Concrete	650 – 800 mm Average flow diameter
	V – funnel	Concrete	6 – 12 sec Time for emptying of funnel
Passing ability	L – box	Concrete	0.8 – 1.0 Ratio of heights at the beginning and end of flow
	J – ring	Concrete	0 – 10 mm Difference in heights at beginning and end of flow

2.7.4 J-ring (ASTM C 1621)

The test is used to determine the passing ability of SCC through reinforcement steel and obstacles. A sample of fresh SCC is placed in a standard slump cone with J-ring based, which contains steel bars. The mold is raised, the SCC passes through J-ring, and the J-ring patty diameter is measured (ASTM, 2009). The higher the J-ring slump flow value, the greater ability the SCC has to fill a steel reinforced form or mold, and the farther SCC can travel through a reinforcing bar from a discharge point

under its own weight (ACI, 2007). The difference between the unconfined slump flow and the J-ring slump flow is used to identify the restriction degree of SCC to pass through reinforcing bars. (See figure, 2.15). (Elfatih, 2014)



Figure 2.15 J-ring test (Hadiwidodo and Mohd, 2008)

2.7.5 The U-box

The U-box test is used to measure the filling ability of the mixes. The apparatus consists of a vessel that is divided by a middle wall into two compartments, as shown in Figure 2.11. As shown in Figure 2.11, an opening with a sliding gate is fitted between the two sections. Reinforcing bars with normal diameter of 13 mm are installed at the gate with center-to-center spacing of 50 mm. This creates a clear spacing of 35 mm between the bars. Concrete filled in the left hand box is allowed to pass through this obstacle and to fill the right hand box. More will be the height of filling in the right hand box more will be the filling ability of the SCC mix. In this test, the degree of compact ability can be indicated by the height that the concrete reaches after flowing through an obstacle. Concrete with the filling height of over 300 mm can be judged as self-compacting. (Hadiwidodo and Mohd, 2008).

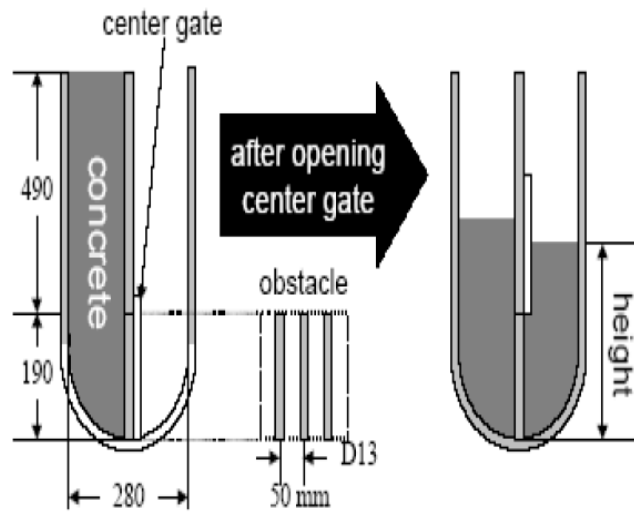


Figure 2.16 Schematic representation of U- box test (Elhassan, 2014)

CHAPTER 3

EXPERIMENTAL PROGRAM AND METHODOLOGY

3.1 Introduction

In this study an experimental program was conducted to investigate the effects of rubber aggregates on the fresh properties of self-compacting concretes. For this purpose two mineral admixtures, namely fly ash (FA) and silica fume (SF), and rubber coarse aggregate were used in the production of self-compacting concretes. The fresh properties of the self-compacting concretes produced were observed through slump flow diameter, slump flow time, V-funnel flow time, L-box height ratio and Rheology test for plastic viscosity.

3.2 Materials

3.2.1 Cement

The cement used in all SCC mixtures was a normal Portland cement of CEM I 42.5 R (PC) which corresponds to ASTM Type I grade. It had a specific gravity of 3.15 g/cm³ and specific surface area of 3260 cm²/g. Data showing the physical and chemical analysis reported by the cement manufacturer are given in Table 3.1.

3.2.2 Mineral admixtures

3.2.2.1 Fly ash

The fly ash (FA) used in this research was a class F type according to ASTM C 618 (2002) and obtained from Yumurtalik-Sugozu thermal power plant in the form of commercial grade. It had a specific gravity of 2.25 g/cm³ and the specific surface area of 379 m²/kg. The chemical analysis of FA is shown in Table 3.1.

3.2.2.2 Silica fume

A commercial grade silica fume (SF) obtained from Norway was utilized in this study. It had a specific gravity of 2.2 g/cm^3 and the specific surface area (Nitrogen BET Surface Area) of $21080 \text{ m}^2/\text{kg}$. In Table 3.1, both the chemical analysis and physical properties of SF is providing.

Table 3.1 Physical properties and chemical compositions of Portland cement, fly ash and silica fume

Analysis Report (%)	Cement	Fly ash	Silica fume
CaO	62.33	4.24	0.45
SiO ₂	19.96	56.20	90.36
Al ₂ O ₃	4.98	20.17	0.71
Fe ₂ O ₃	3.32	6.69	1.31
MgO	2.78	1.92	-
SO ₃	2.88	0.49	0.41
K ₂ O	0.63	1.89	0.45
Na ₂ O	0.38	0.58	1.52
Loss on ignition	2.19	1.78	3.11
Specific gravity	3.15	2.25	2.20
Specific surface area (m ² /kg)	326	379	21080

3.2.3 Waste coarse Rubber

The waste rubber aggregates with a specific gravity of 0.95 partly replaced a volume fraction of the medium crushed-stone gravel (4–8mm), are shown in (Fig.3.1). Two control SCCs with silica fume but (without rubber aggregates) and eight series of SCC incorporating rubber aggregates were prepared. The different mixes are designated by their level of rubber aggregate content. The letter R refers to Rubber coarse aggregates and, for example, SCC10R designates the mix where the volumetric ratio of rubber aggregates to crushed aggregates is 10%. The five groups of concretes with rubber particle replacement at different proportions 0%, 10%, 20%, 30%, and 40% are shown in Table 3.3. For all the mixes, the water/binder ratio by

weight was kept constant at 0.32, the term binder including cement, fly ash and Silica fume. A series of tests were performed, notably by batching each additive in order to prevent prominent segregation and bleeding when rubber aggregates were used, and the concrete mix proportions in Table 1 were chosen after confirming that these proportions behaved like SCC in the fresh state.



Figure 3.1 The photographic views of waste coarse rubber

3.2.4 Aggregates

In this study, the coarse aggregate included two types of crushed-stone gravel with a nominal maximum size of 16 mm. Type one size of 8-16 mm size and type two size of 4-8 mm . As fine aggregate, a mixture of natural river sand was used with a maximum size of 4 mm. The coarse aggregate for type1 had a specific gravity of 2.64 and for type2 had a specific gravity of 2.66. The specific gravity of natural river sand were 2.39. The particle size gradation obtained through the sieve analysis and physical properties of the fine and coarse aggregates are presented in grading curves of fine and coarse aggregates associated with that of the control mixture are presented in Figure 3.2.

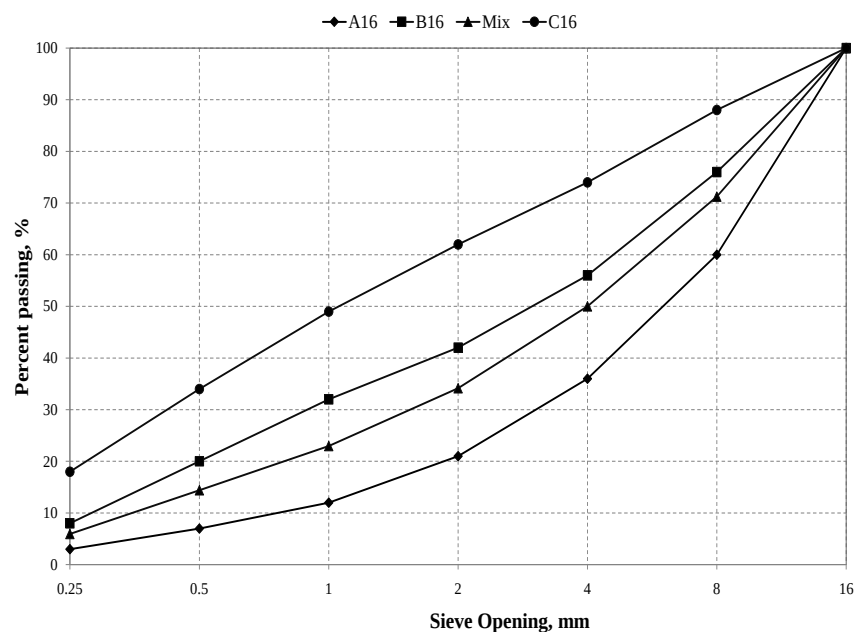


Figure 3.2 Sieve analysis of aggregates

3.2.5 Superplasticizer

A polycarboxylic-ether type super plasticizer (SP) with a specific gravity of 1.07 and PH of 5.7 was used in all mixtures. The properties of superplasticizer are given in Table 3.2 as reported by the local supplier.

Table 3.2 Properties of superplasticizer

Properties	Superplasticizer
Name	Glenium 51
Color tone	Dark brown
State	Liquid
Specific gravity (kg/l)	1.07
Chemical description	Polycarboxylic-ether
Recommended dosage	%1-2 (% binder content)

3.3 Concrete Mixtures

A total of 10 SCC mixtures were designed at 0.32 water/binder ratio (w/b). In the design of the concretes, enumerated from Mix ID given in Table 3.3, the w/b ratio was 0.32 and the total cementitious materials content was 550 kg/m³. In the production of such concretes the mineral admixtures used were FA and SF. The mixtures (M1 and M6) in Table 3.3 were designated as the control Mixtures without rubber particles while the remaining mixtures M2, M3, M4, M5 incorporated binary cementations blends and rubber, ternary (PC+FA+R), and M7, M8, M9, M10, quaternary (PC+FA+SF+R) cementations blends in which a proportion of Portland cement was replaced with the mineral admixtures and waste rubber. The replacement ratios for all FA 20% and rubber particle replacement at different proportions of 0%, 10%, 20%, 30%, and 40% While those of SF for five mixtures 0% and for five mixtures 10% by weight of the total cementations materials.

3.4 Concrete casting, test specimens, and curing

In the production of SCCs, the mixing sequence and duration are so important that a special procedure for batching and mixing proposed by (Khayat et al., 2000) was employed to supply the same homogeneity and uniformity in all mixtures. The batching sequence consisted of homogenizing the waste coarse rubber, fine, and coarse aggregates for 30 sec in a rotary planetary mixer, then adding about half of the mixing water into the mixer and continuing to mix for one more minute. Thereafter, the aggregates were left to absorb the water in the mixer for one minute. After the cement and mineral admixtures were added, the mixing was resumed for another minute. Finally, the SP with remaining water was introduced, and the concrete was mixed for 3 min and then left for 2 min to rest. Eventually, the concrete was mixed for additional two minutes to complete the mixing sequence. The concretes were designed to give a slump flow of 70±3 cm which was achieved by using the superplasticizer at varying amounts. For this, trial batches were produced for each mixture till the desired slump flow was obtained. After the mixing procedure had been completed, tests were conducted on the fresh concrete to determine slump flow time and diameter, V-funnel flow time, L-Box height ratio, initial and final setting times, and viscosity. Segregation and bleeding were also visually checked during the slump flow test.

Table 3.3 Mix proportions for self-compacting concrete (kg/m3)

Mix ID	(w/b)	Cement	Fly ash	Silica fume	Water	SP*	Coarse waste rubber	Natural sand	Coarse aggregate	
									No I	No II
SF0R0	0.32	440.0	110	0	176	7.42	0.00	783.50	391.75	391.75
SF0R10	0.32	440.0	110	0	176	7.43	13.99	783.49	352.57	391.75
SF0R20	0.32	440.0	110	0	176	6.60	28.02	784.47	313.79	392.23
SF0R30	0.32	440.0	110	0	176	7.44	41.97	783.48	274.22	391.74
SF0R40	0.32	440.0	110	0	176	6.88	56.01	784.15	235.24	392.07
SF10R0	0.32	385.0	110	55	176	8.80	0.00	773.11	386.55	386.55
SF10R10	0.32	385.0	110	55	176	8.69	13.81	773.24	347.96	386.62
SF10R20	0.32	385.0	110	55	176	8.47	27.62	773.49	309.40	386.75
SF10R30	0.32	385.0	110	55	176	8.36	41.44	773.63	270.77	386.81
SF10R40	0.32	385.0	110	55	176	8.42	55.25	773.56	232.07	386.78

3.5 Tests for Fresh Properties

3.5.1 Slump flow

The slump flow test specified by the Japan society of civil engineers evaluates the capacity of concrete to flow under its own weight without any restraint, except from the friction of surface and test based on the slump cone test, used for traditional concrete. To measure the slump flow, an ordinary slump flow cone is filled with SCC without any compaction and leveled. The cone is lifted and average diameter of the resulting concrete spread is measured as seen Figure 3.3. A slump flow value ranging from 650 mm to 800 mm for a concrete to be compacted according to EFNARC (2002). In this study, slump flow diameter of all the mixtures was kept constant at about 67 to 80 cm. In the slump flow test, the time (T_{50}) was also measured which determines the time taken for the concrete to reach the 500 mm spread circle. A lower time indicates greater flow ability. EFNARC suggests a T_{50} of 2 to 5 sec for a SCC.

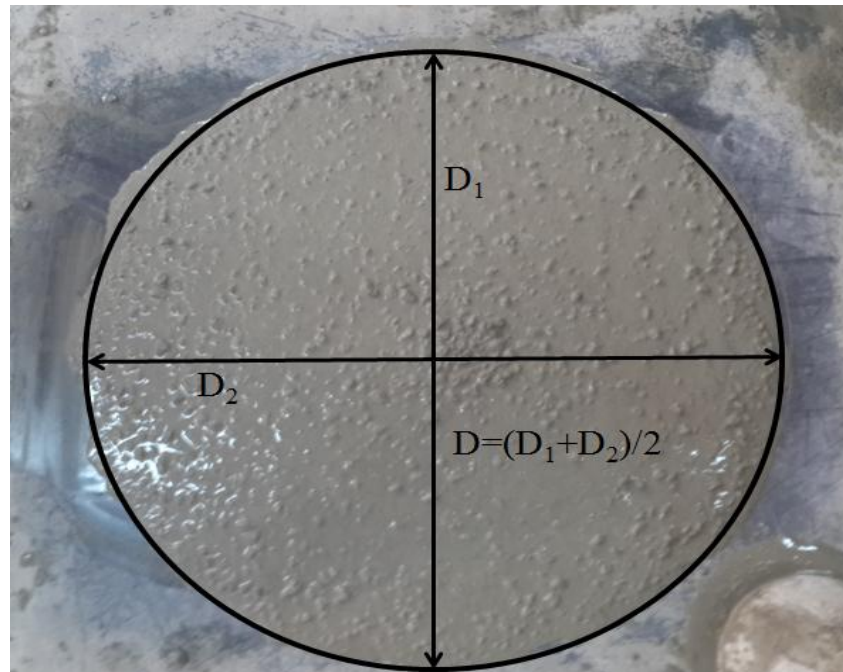


Figure 3.3 Measurement of slump flow diameter for SCCs (Control mixture)

3.5.2 V-funnel flow time

In evaluating the flowability and the viscosity of the mixtures the V-Funnel test was conducted (Figure 3.4). The flow time is determined using a simple procedure in which the funnel is completely filled with fresh concrete, and the flow time is measured as the time between the opening of the orifice and the complete emptying of the funnel. Good flowable and stable concrete would consume short time to flow out. According to Khayat et al. (1997), a funnel test flow time (t_{v-f}) less than 6 sec is recommended for a concrete to qualify for self-compacting. According to EFNARC, t_{v-f} ranging from 6 to 12 sec is considered adequate for a SCC.



Figure 3.4 Photographic view of V-funnel flow time measurement

3.5.3 L-box test

The L-box apparatus consists of a rectangular-section box in the shape of an 'L', with a vertical and horizontal section, separated by a moveable gate, in front of which vertical lengths of reinforcement bar are fitted (Figure 3.5). The vertical section is filled with concrete, and then the gate is lifted to let the concrete flow into the horizontal section.

When the flow has stopped, the height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section. It indicates the slope of the concrete when at rest. This is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted. The horizontal section of the box can be marked at 200mm and 400mm from the gate and the times taken to reach these points measured. These are known as the T_{200} and T_{400} times and are an indication for the filling ability. L-box test assesses filling and passing ability of SCCs, and serious lack of stability (Segregation) can be detected visually. Segregation may also be detected by subsequently sawing and inspecting sections of the concrete in the horizontal section. Typical acceptance values according to EFNARC are in the range of 0.8 to 1.0. If the concrete flows as freely as water, at rest it will be horizontal, so H_2/H_1 reaches 1. Therefore, the closer this test value so called 'the blocking ratio' is to unity, the better the flow of the concrete.



Figure 3.5 Photographic view of L-box apparatus and testing procedure

Table 3.4 Slump flow, viscosity, and passing ability classes according to (EFNARC 2005)

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

3.5.4 Rheology test

Characterization of rheology was achieved by International Center for Aggregates Research (ICAR) Rheometer as shown Figure 3.5. To this aim, the fresh SCC was poured into container of the Rheometer and filled up to a height of 305 mm. Four-bladed vane having 127 mm diameter and 127 mm height was immersed into the center of fresh concrete and rotated at a series of specific speeds. The gap distance is 89 mm above and below the vane. The ICAR Rheometer was utilized to monitor the flow curve which consists of the following inputs: breakdown speed and time, number of points, time per point, initial speed, and final speed for each of the fresh concrete mixtures. The first rotation speed is 0.5 rps for a breakdown period of 20 s. Torque measurements were then recorded for seven speeds ranging in descending order from 0.5 rps to 0.05 rps. For analyzing rheological parameters of the fresh concrete properties, Equation 3.1 was used for drawing the flow curves in relative units.

$$T=Y+VN \quad (3.1)$$

Where V is denoted as the slope of the line (Nm.s) related to plastic viscosity, Yintercept of the line with the torque axis (Nm) which is related to yield stress , N is denoted as

rotation speed (rps) and T is the torque axis (Koehler and Fowler, 2004). To determine the plastic viscosity analytically in fundamental units, the resultant data were evaluated based on the Bingham model Equation 3.2, where by a straight line was fitted to the plot of torque τ (Pa), versus rotation speed, (rad/s). The intercept, τ_0 (Pa), and the slope, μ (Pa.s), of this line were considered to be related to yield stress and plastic viscosity, correspondingly.

$$\tau = \tau_0 + \mu\dot{\gamma} \quad (3.2)$$

Where τ is shear stress (Pa), τ_0 is yield stress (Pa), μ is plastic viscosity (Pa s), and $\dot{\gamma}$ is shear rate (rotation speed) (1/s). Due to the thixotropic and loss of workability of the fresh concrete, the parameters in the Bingham equation, particularly yield stress and viscosity are not constant in time (Wallevik, 2003; Roussel, 2005; Roussel, 2006). Moreover, the apparent viscosity increases by increasing shear rate, which is due to the preferential orientation of the particles resulting in the more rapid increase of the shear stress than the shear rate (Roussel, 2006; Douglas, 2004).

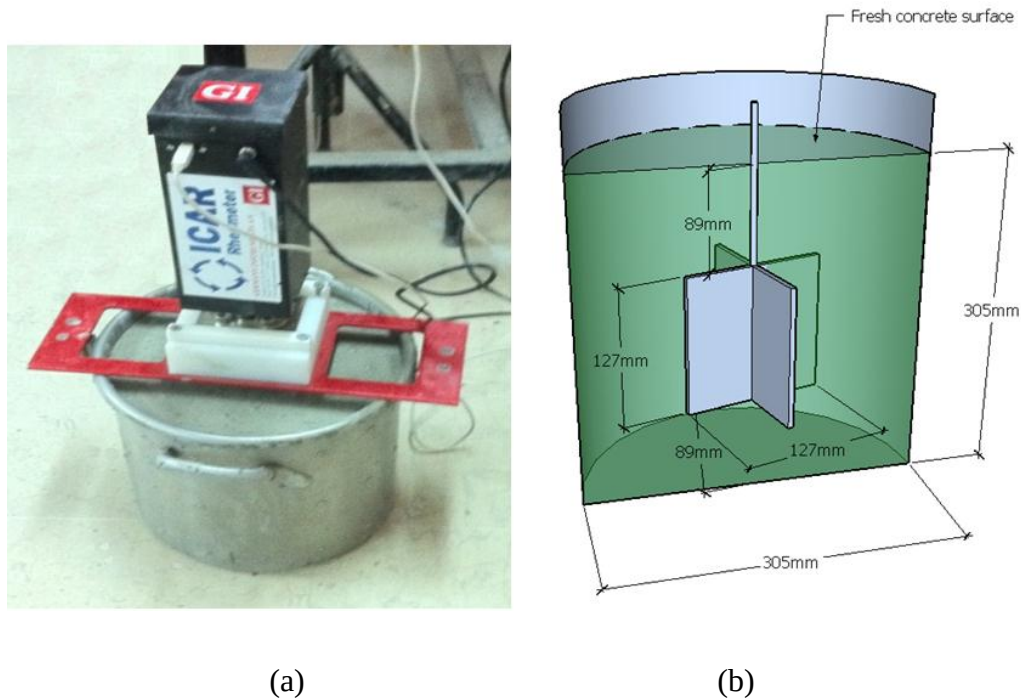


Figure 3.6 Views of a) Rheometer and b) detailed schematic representati

3.5.5 Compressive strength

Measurement of compressive strength was applied according to ASTM C 39 (2012) by means of a 2000 KN capacity testing machine. The test was conducted on three 150x150x150-mm cubes for each mixture at the ages of 28 and 90 days. The compressive strength was computed from average of three cylinders at each testing age.



Figure 3.7 Photographic view of compressive strength machine

CHAPTER 4

TEST RESULTS AND EVALUATION

4.1 Fresh concrete properties

4.1.1 Slump flow diameter and slump flow time

In this study, all of the concrete mixtures were designed to give a slump flow diameter of 67 to 80 cm which was realized by using superplasticizer at varying amounts. Therefore, as seen in Table 4.1 and Figure 4.1 showed the slump flow diameter of the concretes ranged from 67 to 80 cm conforming, EFNARC recommendations because the lower and upper acceptance limit of slump flow diameter according to EFNARC were 65 and 80 cm, respectively. Slump flow times (T_{50}) of all produced concretes were less than 5 sec. Table 4.1 and Figure 4.2 showed that concretes with quaternary blends of FA, SF and waste coarse rubber had generally lower slump flow time (T_{50}) than the control concrete at low w/b ($w/b = 0.32$) ratio concretes. The silica fume addition increased the demand for superplasticizer. The increasing in the slump flow diameter by SF addition was due to the increasing of the superplasticizer. Also, the slump flow time was decreased due to the same reason.

4.1.2 V-funnel flow time

The flowability and viscosity of SCCs was evaluated by means of V-funnel flow time. According to EFNARC (2002), the concrete having a V-funnel flow time within 6 to 12 sec may be highly resistant to possible segregation. The variation of V-funnel flow time of the produced SCCs is given in Tables 4.1 and (Fig.4.3). The time measured via the V-funnel flow was in the range of 13.8-25.5 sec depending mainly on the concrete composition. It was observed in Tables 4.1 that apart from the control (M1 and M6), some of the other concretes M2, M3, M4, M5, M7, M8, M9, M10, did not fulfill the EFNARC recommendation for V funnel flow time. Similar findings have been reported

in the literature such that the upper limit of V-funnel flow time extended to as high as 46 sec (Felekoglu et al., 2006). Figure 4.3 show the variation in the V-funnel flow time of the concretes made with quaternary blends of cementations 'materials for 0.32 w/b ratios, respectively. It was observed that increasing the replacement ratio of SF from 10% resulted in a gradual reduction in the V-funnel flow time of concrete for w/b ratios. The V-funnel flow time was decreased by increasing the superplasticizer content when 10% SF was incorporated.

Table 4.1 Slump flow, L-box and V-funnel properties of SCCs at w/b of 0.32

Mix No	Mix Description	Slump flow		L-box			V-funnel Flow time (sec)
		T ₅₀ (sec)	D(cm)	T ₂₀₀ (sec)	T ₄₀₀ (sec)	H2/H1	
M1	SF0R0	3.8	75	9	16.8	0.89	19
M2	SF0R10	4.2	73	11.5	19.1	0.91	19.5
M3	SF0R20	3.2	68.5	11	17.64	0.87	22
M4	SF0R30	3.3	72.5	9.6	14.9	0.9	23.5
M5	SF0R40	3.5	67	7.8	15	0.85	25.5
M6	SF10R0	3.3	79	8.4	11	0.92	13.8
M7	SF10R10	3.5	79.5	7.9	14.4	0.97	14.5
M8	SF10R20	3.1	76	7.2	14.1	0.88	15
M9	SF10R30	2.7	75.5	7.6	14.1	0.91	16
M10	SF10R40	2.5	77	7	12.35	0.88	14.5

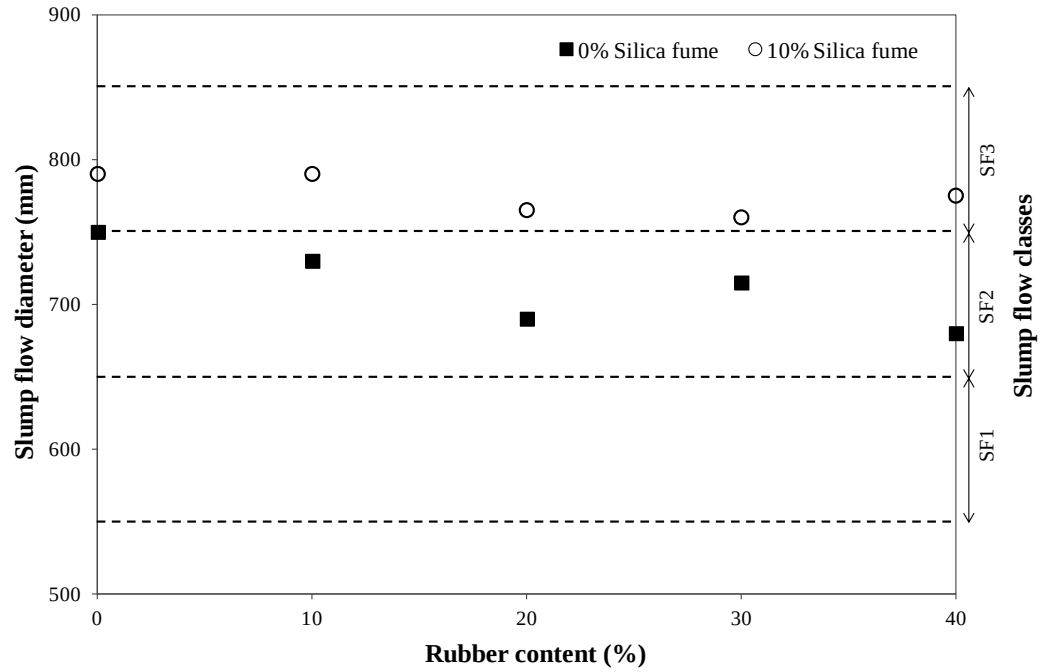


Figure 4.1 Variation of slump flow diameter and slump classes of SCC with different rubber contents at 0% and 10% silica fume

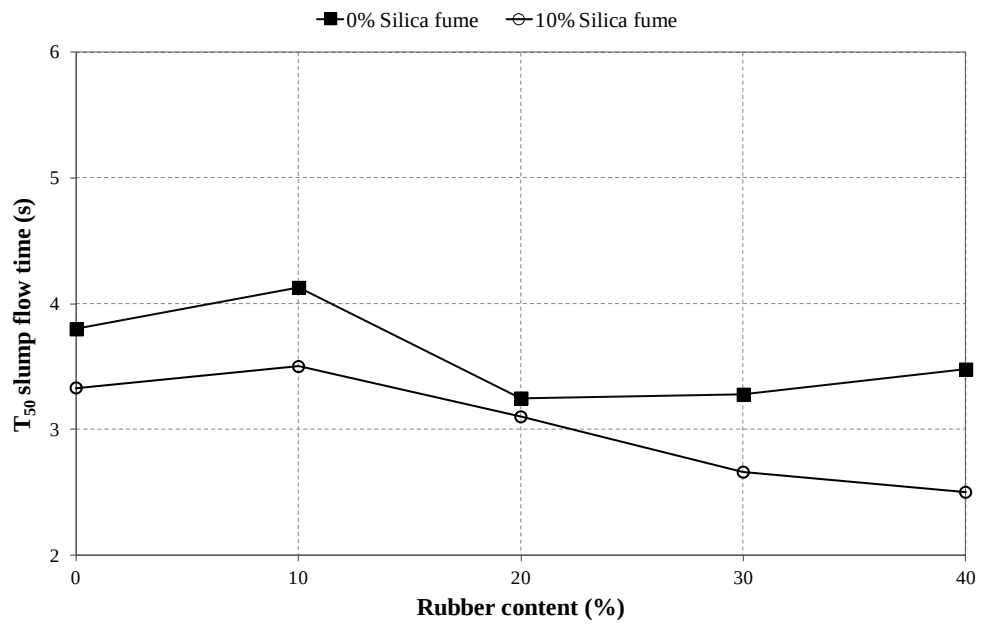


Figure 4.2 Variation of T_{50} slump flow time of SCC with different rubber contents at 0% and 10% silica fume

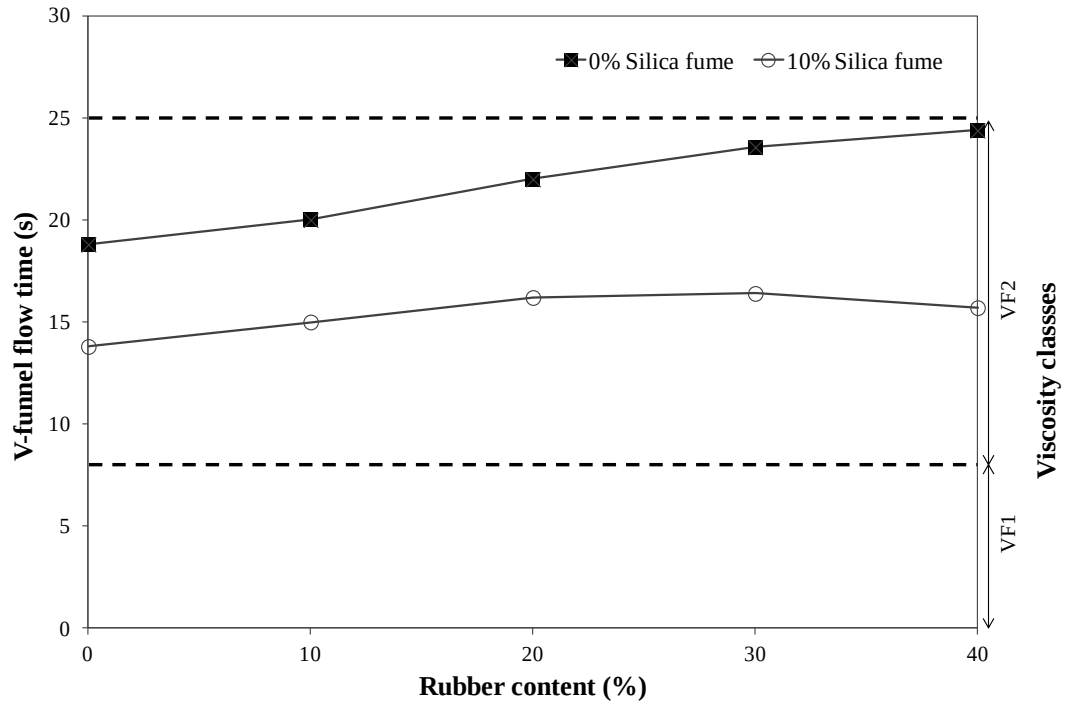


Figure 4.3 Variation of V-funnel flow time and viscosity classes of SCC with different rubber contents at 0% and 10% silica fume

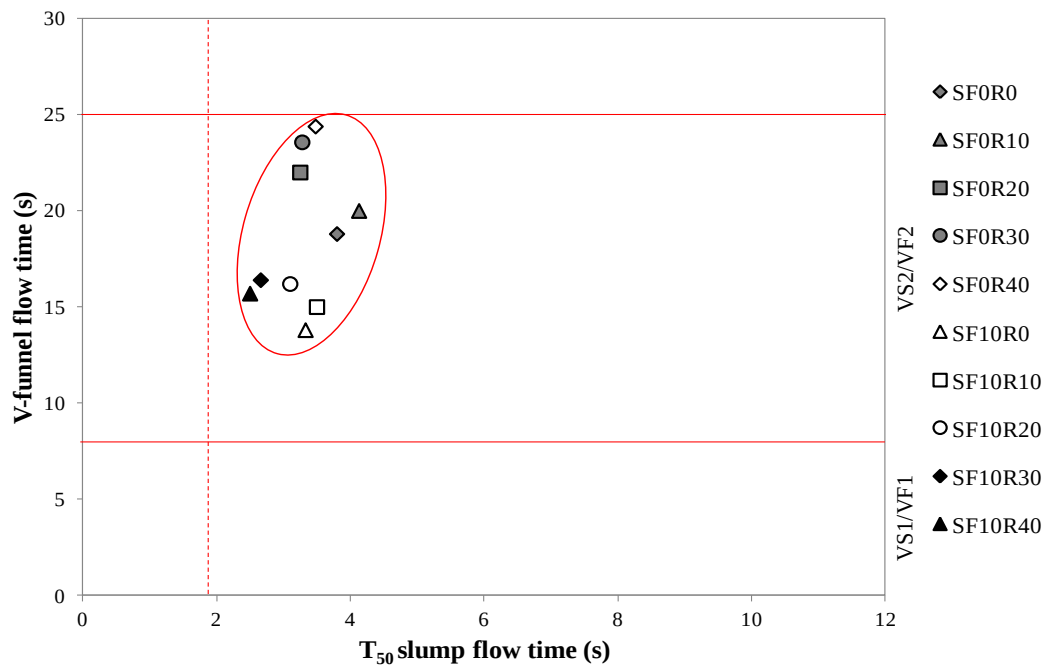


Figure 4.4 T_{50} slump flow time versus V-funnel flow time for SCC

4.1.3 L-box height ratio, T_{200} and T_{400} times

Passing ability of the self-compacting concretes was measured by means of the L-box test. The test provided H_2/H_1 ratio as a measure of the flow ability among reinforcing bars. The variation in the L-box height ratio (H_2/H_1) is presented in Tables 4.1 and Figure 4.5. All mixtures satisfied the EFNARC limitation given for the L-box height ratio. H_2/H_1 ratio value ranged from 0.85 to 0.97 depending mainly on the mineral admixture used in concrete and rubber content. The ratio of H_2/H_1 was in the range of 0.8 to 1.0 for all mixtures (Figures 4.5 and 4.6), thus generally satisfying the EFNARC recommendation for the passing ability in terms of L-box test. In all cases, with silica and without adding silica when the rubber aggregate ratio is 10% of the amount of H_2/H_1 is greatest. T_{200} and T_{400} times to be taken for the mixture to reach a distance of 200 and 400 mm along the horizontal section from the sliding door of the L-box were also given in Table 4.1. These results gave some indication about the easy flow of the concrete mixtures with the mineral admixtures compared to the control mixture. The T_{400} time of the control concrete was about 16.8 sec. the L-box height ratio was also affected by increasing the superplasticizer content when 10% SF was

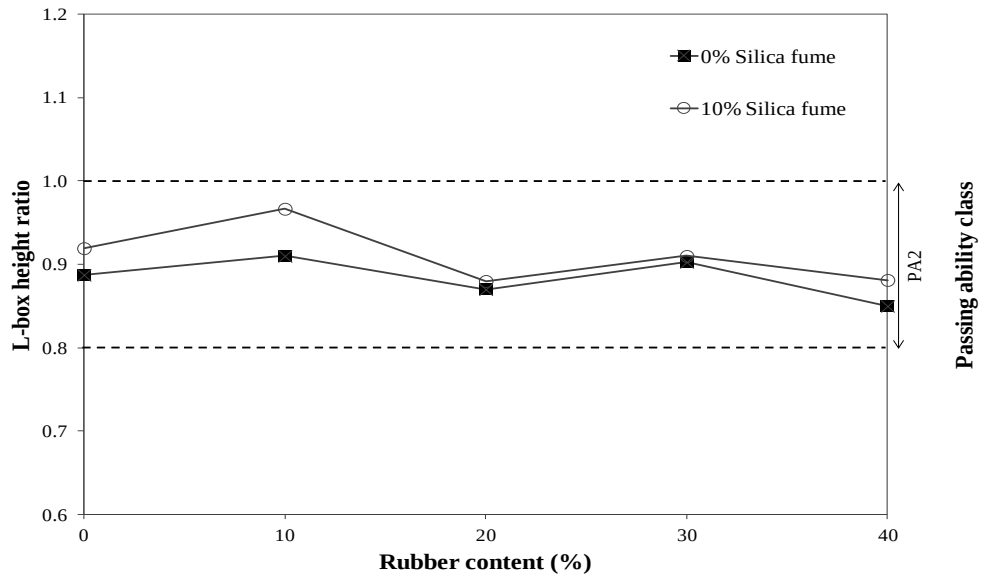
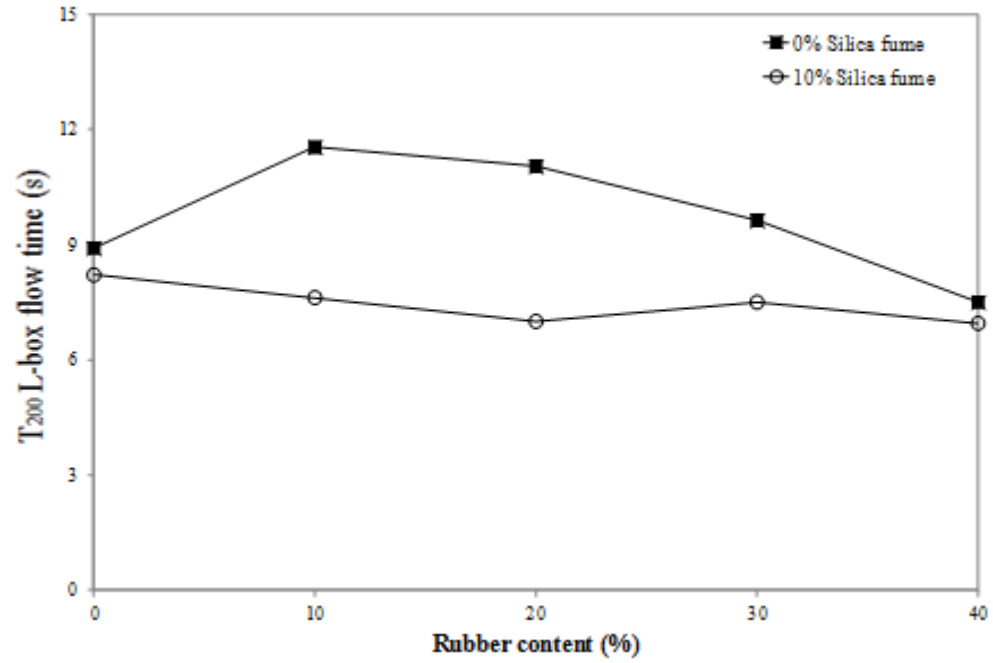
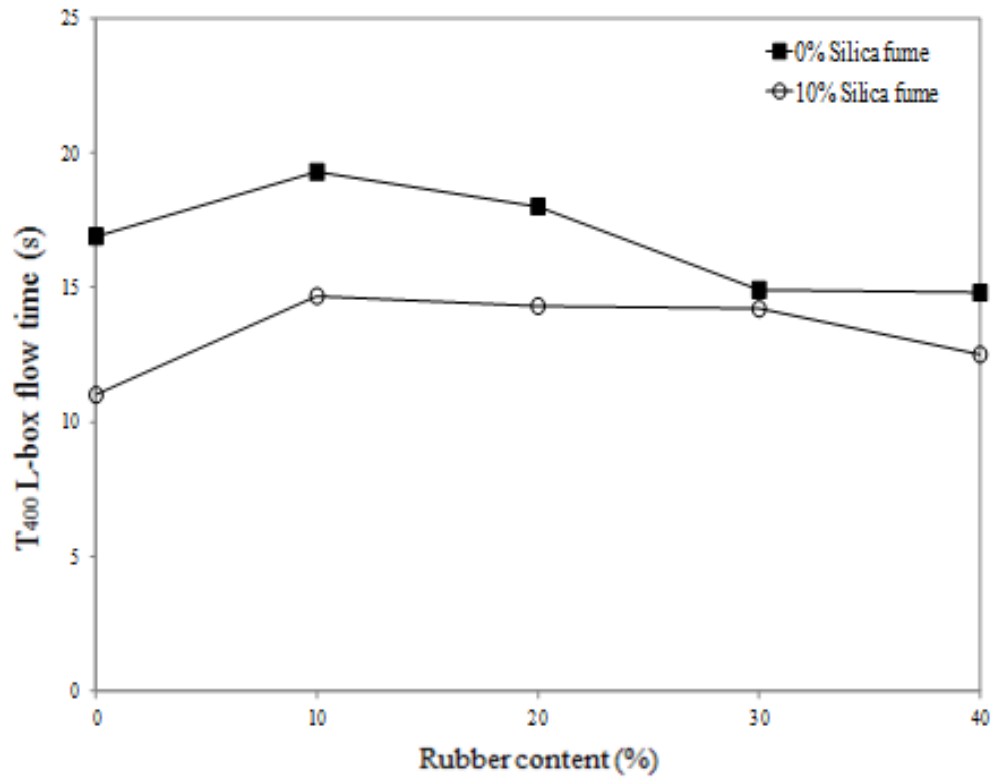


Figure 4.5 Variation of L-box height ratio and passing ability classes of SCC with different rubber contents at 0% and 10% silica fume



(a)

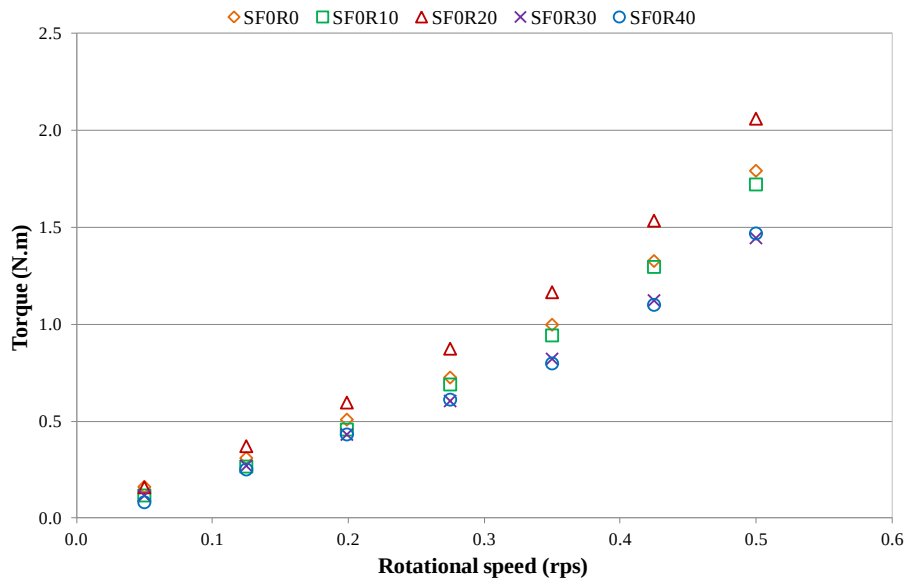


(b)

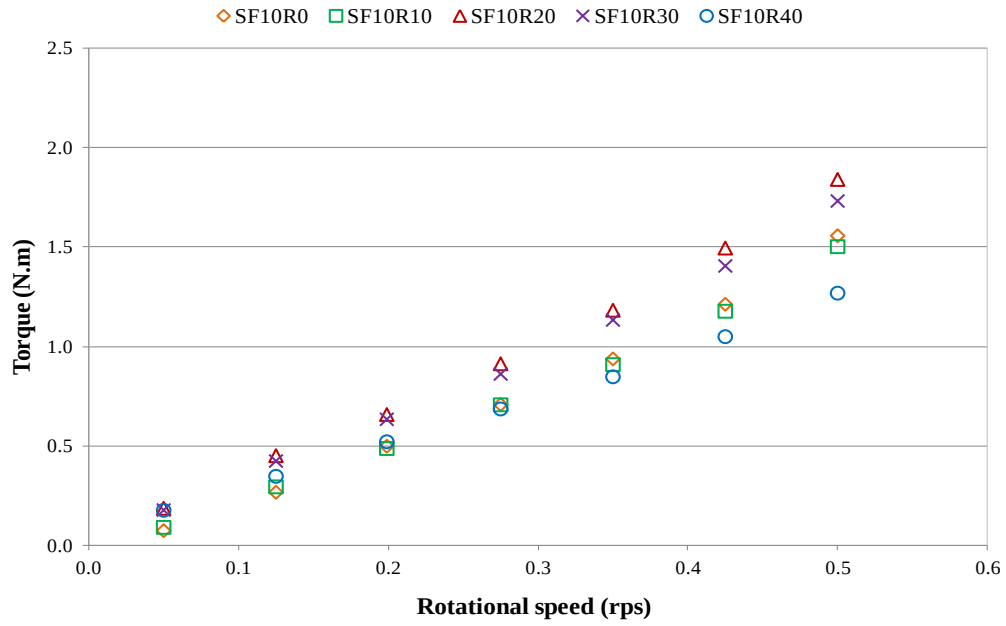
Figure 4.6 Variation of a) T_{200} and b) T_{400} L-box flow time of SCC with different rubber contents at 0% and 10% silica fume

4.1.4 Rheology

Yield stress and viscosity are the most critical rheological parameters for concretes, particularly for SCCs. In order to ensure a high flowing ability as well as a good cohesion of the SCC, a low yield stress and moderate viscosity are required (Koehler, 2009). Specifies that self-compacting concrete has far lower yield stress value than conventional concrete. Considerably lower yield (near to zero) stress allows concrete to flow freely. Moreover, having similar plastic viscosity to that of normal concrete, SCC gains segregation resistance. SCC mixture should be designed to have neither too low nor too high plastic viscosity. Because, when SCC has too low plastic viscosity there is risk of segregation, while in case plastic viscosity is too high concrete is sticky and difficult to pump and place (Koehler, 2009). The flow curves of SCCs are given in Figure 4.7. The data used for plotting the graphs were obtained from ICAR Rheometer in terms of rotational speed (V) in revolution-per-second and torque (T) in Newton-meter. V and T represent the shear strain rate and shear stress, respectively. It was found out that torque was almost more, when used 20% of coarse rubber aggregate for all mixtures.

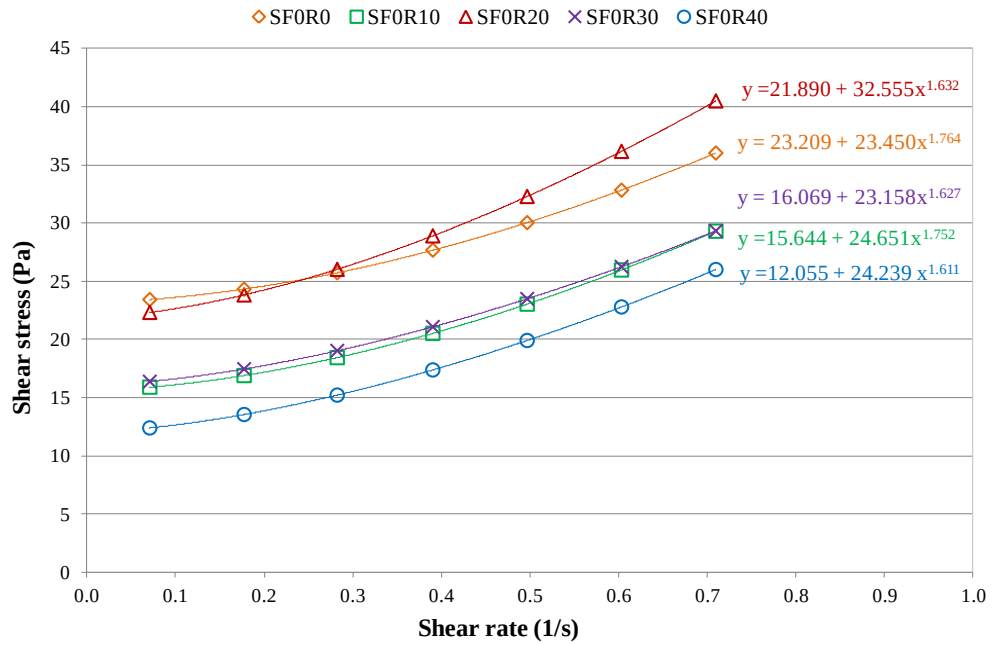


(a)

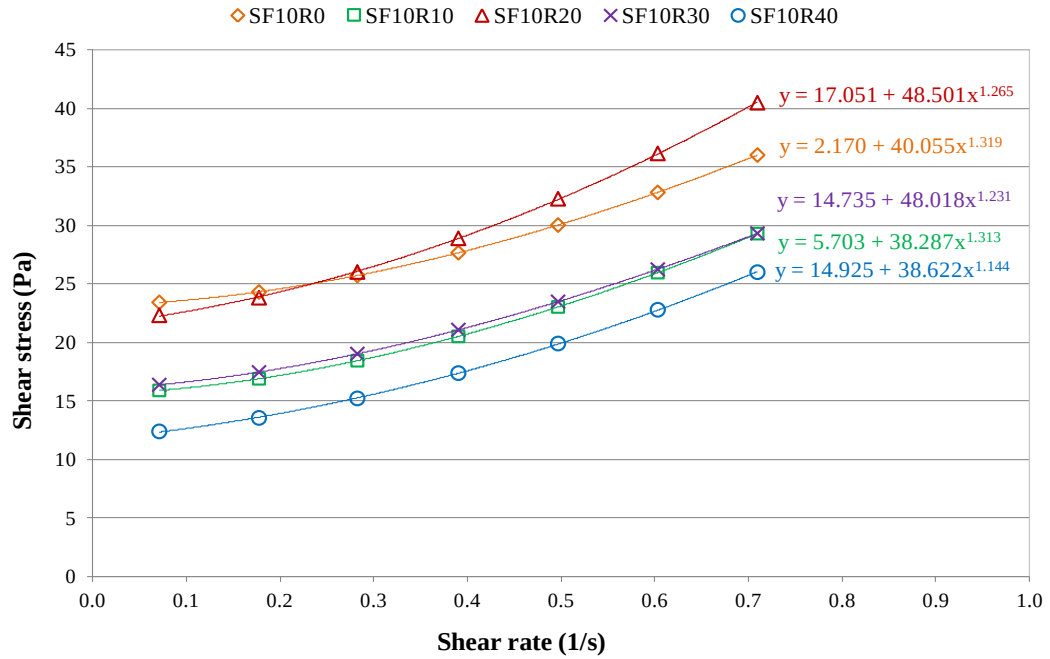


(b)

Figure 4.7 Torque versus rotational speed obtained from the Rheometer for rubberized SCC with: a) 0% and b) 10% silica fume contents.



(a)



(b)

Figure 4.8 Application of the Herschel-Bulkley model on the rheological data for rubberized SCC with: a) 0% and b) 10% silica fume contents

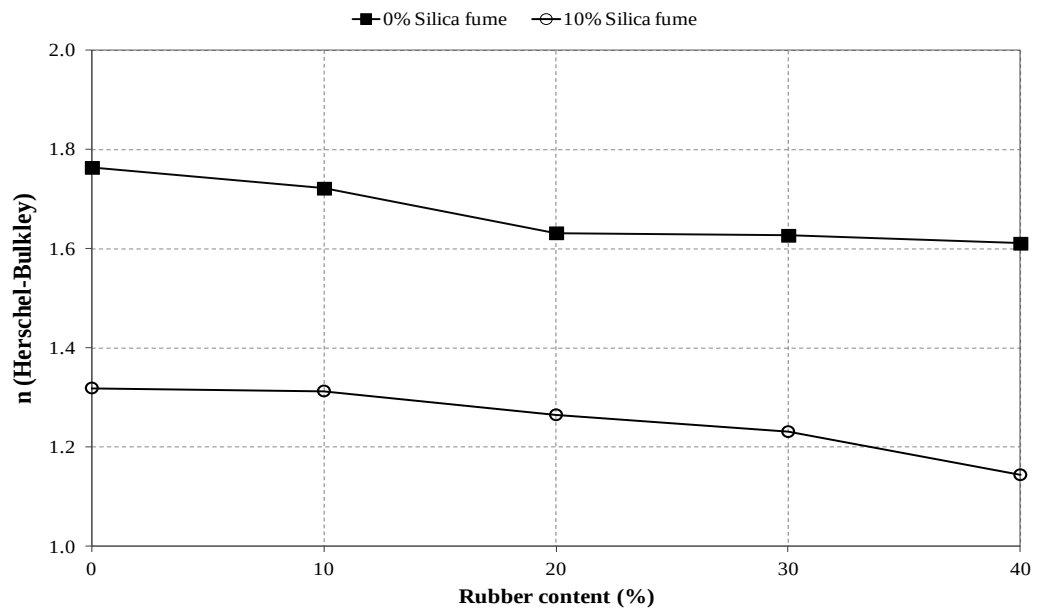
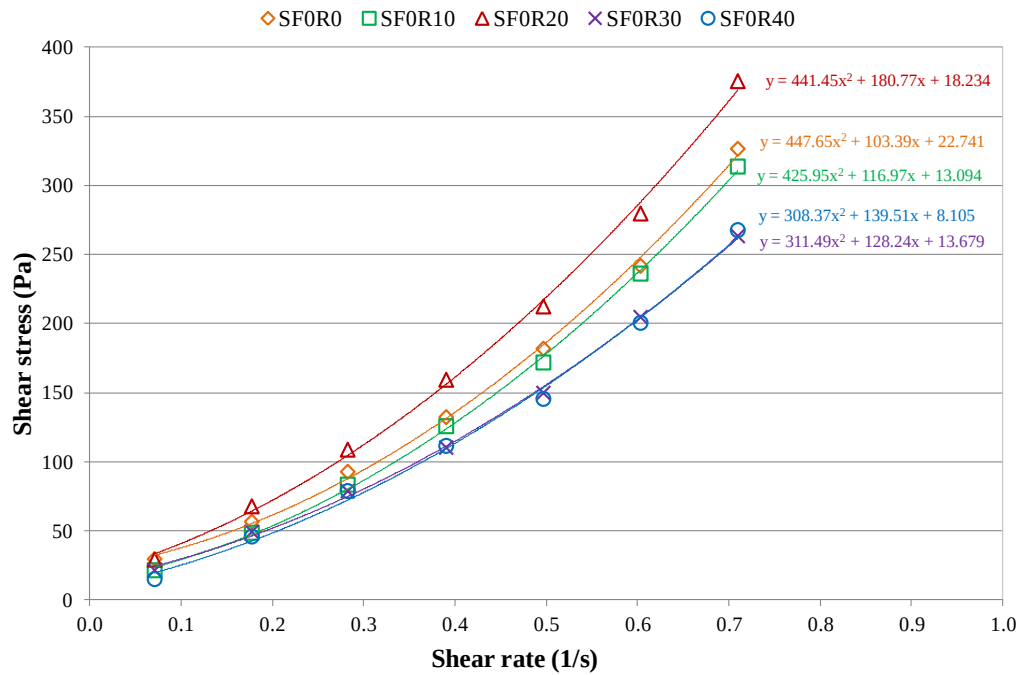
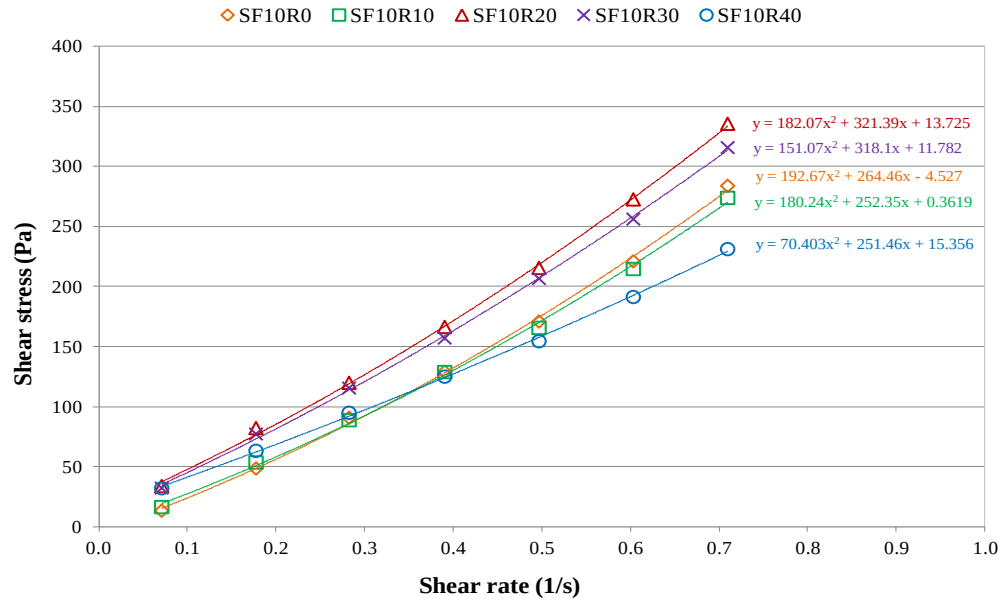


Figure 4.9 Variation in exponent 'n' values (Herschel-Bulkley) for SCCs with different silica fume and rubber contents

When T values are converted to shear stress (τ) and rotational speed is converted to shear rate ($\dot{\gamma}$), then the plastic viscosity can be calculated using Bingham model. The plastic viscosity values are demonstrated in Figure 4.10(a and b). As seen in Figure 4.10, increasing the replacement of mineral admixture resulted in increase in the plastic viscosity and provided the concretes to be less susceptible to segregation. When the ratio of coarse rubber aggregates are 20% with silica or without silica, value of shear stress and yield stress were observed to be maximum.



(a)



(b)

Figure 4.10 Application of the modified Bingham model on the rheological data for rubberized SCC with: a) 0% and b) 10% silica fume contents

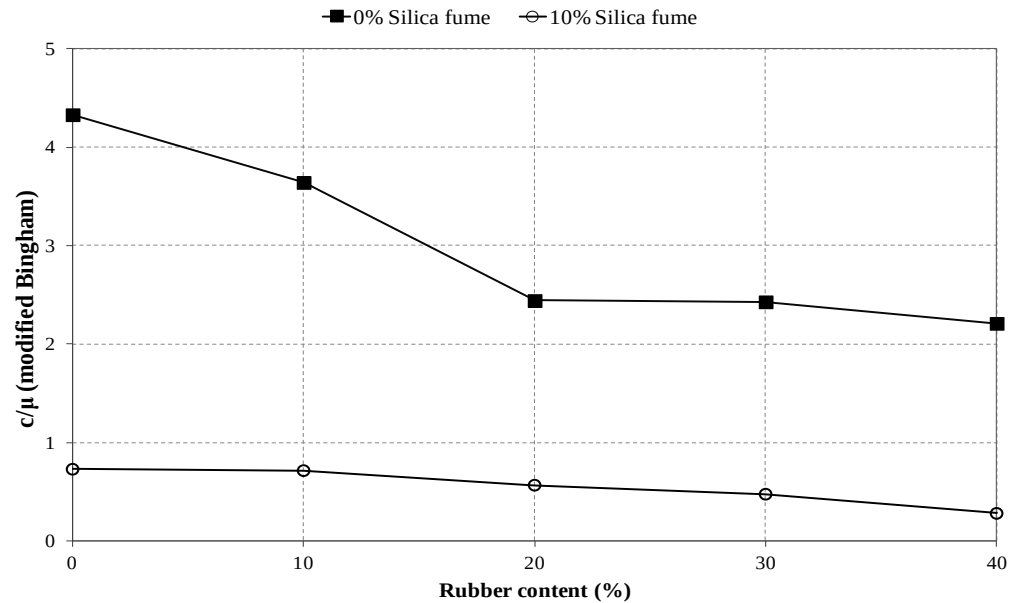


Figure 4.11 Variations in c/μ values (modified Bingham) for SCCs with different silica fume and rubber contents

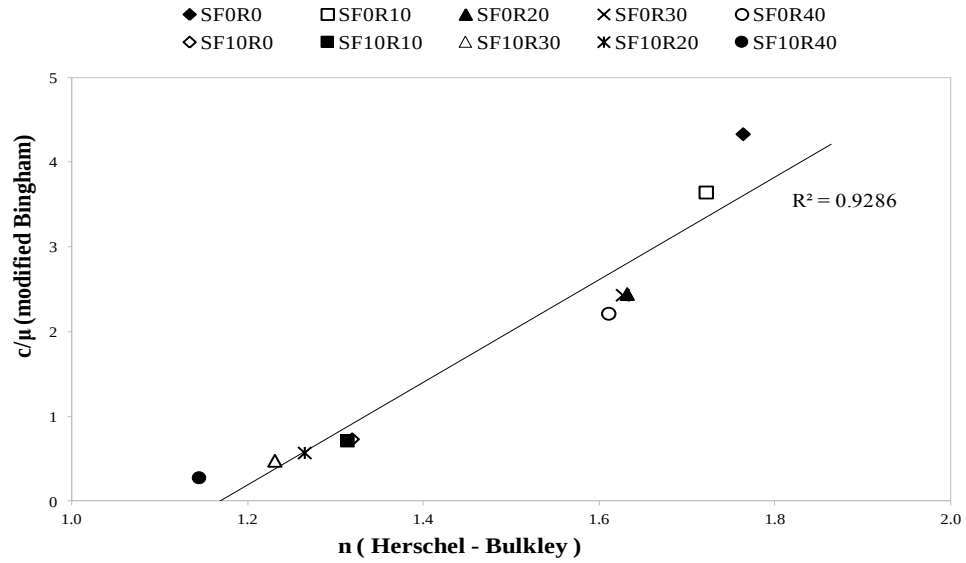


Figure 4.12 Variation in c/μ values (modified Bingham) for SCCs with 0% and 10% silica fume at different rubber contents

4.2 Compressive strength

The change in the compressive strength of the SCC mixtures with respect to replacement level of rubber is illustrated in Figure 4.13. Two grades of SCC having initial compressive strengths of about 78 and 83 MPa were achieved for 0% and 10% silica fume, respectively. The results indicated that replacing the natural aggregate with waste rubber decreased the compressive strength since the rubber particle was softer (elastically deformable) and weaker than natural aggregate. For this reason, the cracks are initiated quickly around the rubber particles in the mix that accelerates the failure of the rubber-cement matrix. Besides, due to the lack of adhesion between the rubber particles and the paste, soft rubber particles may behave as voids in the concrete matrix. Therefore, the increasing the waste rubber content resulted in a systematic decrease in compressive strength. The results indicated that the compressive strength of higher than 60 MPa was achieved at both SCC series of 0% and 10% silica fume content. In addition, it can be clearly seen from the figure that the use of silica fume increased the compressive strength of the SCC at all replacement level of rubber. Silica fume incorporation increased the compressive strength value as much as 5.9% for plain

concrete and 5.2% for 40% rubber content. This was expected due to high pozzolanic characteristic of silica fume and also since the silica fume had finer particle size that provides filling and a good adherence between the aggregate/rubber and the cement matrix.

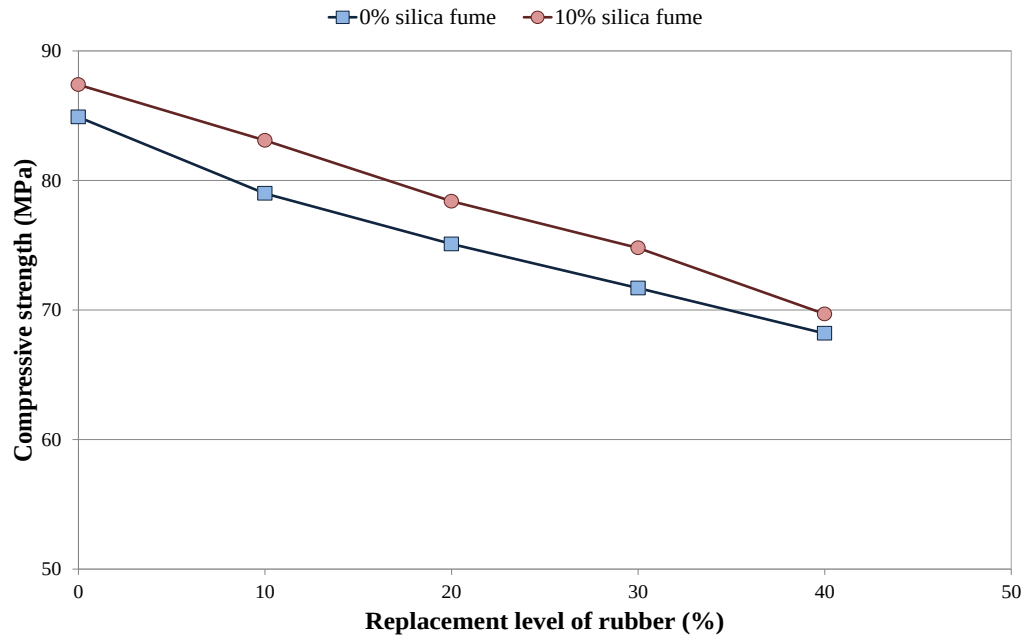


Figure 4.13 Variation in the compressive strength of SCC versus replacement level of rubber

CHAPTER 5

CONCLUSIONS

- All of the mixtures were designed to give a slump flow diameter of 67 to 80 mm which was tried to achieve by adjusting the dosage of the superplasticizer used. However, defined target slump flow diameter was not executed at the concretes containing high amount of waste coarse rubber aggregate. Using waste coarse rubber increased the need of superplasticizer of the mixtures whereas with the use of SF a gradual fall was observed in the amount of superplasticizer used.
- Using WCR increased V-funnel flow times of the produced concretes. Moreover, increasing the WCR content increased T₅₀ and V-funnel flow times gradually. However, using SF resulted in a steady decrease at the T₅₀ and V-funnel flow times of the concretes with respect to the concretes without SF.
- L-box H₂/H₁ height ratio ranged from 0.85 to 0.97 depending mainly on binder used in concrete and w/b ratio. At 0.32 w/b ratio concretes, use of mineral admixtures (SF) and WCR in the production of SCC, not much impact on the H₂/H₁ ratio with the increasing of replacement level of mineral admixtures.
- While the use of WCR remarkably increased the viscosity of the SCRC, use of SF decreased the viscosity. Concretes containing both WCR and SF diminished the negative effect of WCR and decreased the viscosity of concretes.
- This study investigated that the utilization of waste coarse rubber significantly effected on the compressive strength. Moreover, with increasing the quantity systematically of waste coarse rubber caused to reducing the value of compressive strength.

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