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# **Performance of Rubberised Self-Compacting Concrete Exposed to Severe Environmental Conditions**

A Thesis

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Engineering/ Civil Engineering / Construction Materials*

By

**Ehab Abood Hassan Azouz**

Supervised By

**Prof . Dr. Abbas Salim AL-Ameeri**

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1444 A.H.

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

( فَتَعَالَى اللَّهُ الْمَلِكُ الْحَقُّ وَلَا تَعْجَلْ بِالْقُرْآنِ مِنْ قَبْلِ أَنْ  
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## ***Certification***

I certify that this thesis, titled "**Performance of Rubberised Self-Compacting Concrete Exposed to Severe Environmental Conditions**", has been prepared by "**Ehab Abood Hassan Azouz**" under my supervision at the Department of Civil Engineering, the University of Babylon, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

***Supervisor:***

***Signature:***

***name: Prof. Dr. Abbas Salim AL-Ameeri***

***Date:    /    / 2022***

*Dedication*

*To My Love Home IRAQ*

*To The Candles Of My Life  
My Parents*

*To Each One Support Me  
My Family  
My Friends*

*With Love and Respect*

*Ehab*

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*Ehab Abood*  
*2022*

## ABSTRACT

Currently, around the world, the waste materials buildup are considered significant issue, especially in areas with a high population density. Since these waste products are inert by nature, they are either kept in stockpiles or illegally discarded. By using these waste materials in a more environmentally friendly way, the negative environmental impact can be disappeared. Rubber from damaged tyres is one illustration of this substance. Tyre stockpiles are a major global health and environmental issue. Tyre fires can start quickly, burn for a long time, and contaminate the land and air. Recycling contributes to fewer tyres being stored. The use of tyre rubber as aggregate in the manufacture of sustainable concrete is the subject of a great deal of research.

Experimentally, the mixture use cement 475 kg , coarse aggregate 800 kg,sand 800 kg ,w/c 0.36 ,Glenium 54 2% from weight cement. While, crumb rubber tyre was partially replaced fine aggregate. These percentages of replacement were (4%, 8%, 12%, and 16%) by mass of fine aggregate as well as the reference mixture (MC). On the other hand, other two of the crumb rubber tyre percentages (4%, 8%) were modified with SBR in mixes. All concrete specimens were split into two groups after 28 days of cure. The first group was partially submerged in ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) Saline solution. Whereas, the second group was submerged in tap water for comparison. At advance, the rheological characteristic of fresh SCRC (slump flow, T500, L – box, V-funnel, and sieve segregation) tests are evaluated. The compressive, splitting and flexural strength, schmidt hammer, ultrasonic pulse velocity and investigations into drying shrinkage for all varieties of self-compact concrete (SCRC) at 7,28,56,90, and 120 days age to assess the replacing sand by rubber tyre on physical and mechanical properties of SCRC for two groups. Also, water absorption, porosity, surface absorption, chloride penetration depth, chloride migration and chloride concentration test were verified to evaluate the durability of these types of concretes.

The results of this study designated to decrease in fresh properties indicators, slump flow- L-box, sieve segregation, as the crumb rubber tyre content increases in SCRC mixtures. While, V-funnel and T500 tests amplified with increasing rubber tyre content in mixtures of SCRC, it was also found that the mixtures treated with SBR (M1 and M2) decreased in tests (V-funnel and T500) and slump flow, L- box, sieve segregation, compared with same mixtures in tap water. The hardened properties of SCRC, compressive, flexural and splitting strength, schmidt hammer, ultrasonic pulse velocity and drying shrinkage tests were considered the using crumb rubber tyre percentage in these mixes has a detrimental impact on these properties, it was also found that the mixtures treated with SBR 'improved these properties with using the crumb rubber tyre in SCRC mixes compared to same mixtures in tap water .Results reveal that under the influence of saline solution, the rate of improvement in the specimens' mechanical properties was slower as the specimens aged compared to the rate of improvement in the specimens' mechanical characteristics cured in tap water. The percentage reduction in compressive, splitting tensile strength, flexural strength, schmidt hammer and ultrasonic pulse velocity (UPV) for mixtures (MC, M4%, M8%, M12%, M16%) at 56, 90, 120 day age also two mix treatment with SBR of the specimens exposed to ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) solution were ranged between 6%, 6.1%, 5.3%, 4.3%, 4.7%. respectively measured relative to the specimens cured in tap water. While, the durability properties of SCRC, water absorption, porosity, surface absorption, chloride migration and chloride penetration depth, chloride concentration improved these properties with using the crumb rubber tyre in SCRC mixtures compared to control mixture such as water absorption at 28 day 3.7%, 6%, 9%, 15% for M4%, M8%, M12%, M16% respectively .Porosity at 28 day 2.7%, 6%, 4.5%, 4.6% for M4%, M8%, M12%, M16% respectively. chloride penetration depth was improved 24%, 34.5%, 35.2%, 42.2%, for M4%, M8%, M12%, and M16% as comparing with control mixture (MC) respectively at 120 days.

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## List of Abbreviations and Symbols

Abbreviations	Meaning
Ca(OH) <sub>2</sub>	Calcium Hydroxide
CRA	Crumb Rubber Aggregate
C-S-H	Calcium Silicate Hydrate
ITZ	Interfacial Transition Zone
LSP	Limestone Powder
RCS	Redaction Compressive Strength
RFS	Redaction Flexural Strength
RSS	Redaction Splitting Strength
SBR	Styrene Butadiene Rubber
SCC	Self-Compacting Concrete
SCRC	Self-Compacting Rubberise Concrete
SF	Slump Flow
SSD	saturated surface dry
UPV	Ultrasonic Pulse velocity Test
Symbols	Meaning
<i>a</i>	exposed area of the specimen, in mm <sup>2</sup>
<i>B<sub>R</sub></i>	Blocking Ratio
<i>C<sub>i</sub></i>	initial chloride concentration
<i>C<sub>s</sub></i>	surface concentration
<i>d</i>	Cylinder diameter, (mm)
<i>d</i>	density of the water in g/mm <sup>3</sup>
<i>D<sub>a</sub></i>	apparent diffusion coefficient
<i>D<sub>nssm</sub></i>	diffusion coefficient for migration
<i>E</i>	modulus of elasticity
<i>erf</i>	error function for solution of partial equation
<i>f<sub>r</sub></i>	modulus of rupture (MPa)
<i>f<sub>t</sub></i>	Splitting tensile strength, (MPa)
<i>G</i>	Nominal gage length, (250mm)
<i>g<sub>1</sub></i>	mass of oven-dried sample in air
<i>g<sub>2</sub></i>	mass of surface –dry sample in the air after immersion
<i>g<sub>3</sub></i>	mass of sample in Water
<i>H<sub>1</sub></i>	concrete depth directly behind the gate cm
<i>H<sub>2</sub></i>	concrete depth at the end of the horizontal section
<i>I</i>	absorption

$l$	Cylinder length, (mm)
$L$	distance between transducers, (m)
$L_i$	Initial comparator reading of specimen, (mm)
$l_t$	thickness of the specimen in mm
$L_x$	Comparator reading of specimen at x age, (mm)
$m$	weight of the powder sample (g)
$M_a$	Mass of concrete poured onto sieve
$M_b$	Mass of sample passing sieve
$mt$	change in specimen mass in grams, at the time t
$N_1$	normality of the silver nitrate solution
$N_2$	normality of the ammonium thiocyanate solution
$p$	Maximum applied load indicated by the testing machine, (N)
$P_R$	Passing Ratio
$S_R$	Segregation resistance
$T$	effective transmit time, (s)
$T_v$	V-funnel test
$U_v$	applied voltage
$V$	pulse velocity, (m/s)
$V_1$	added amount of silver nitrate solution (ml)
$V_2$	added amount of ammonium thiocyanate solution during the titration (ml)
$W_1$	mass of oven-dried sample in air, g
$W_2$	mass of surface -dry sample in the air after immersion, g
$W_A$	water absorption percentage
$x_d$	Depth Chloride Penetration
$\Delta L_x$	Change in length at x age
$\sigma$	Compressive strength (MPa)

# **CHAPTER ONE**

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# Chapter One

## Introduction

### 1.1 Introduction

Self-compacting concrete, (SCC) is well-known for its superior deformability, great resistance to segregation, and effective use in crowded reinforced concrete buildings with demanding casting conditions that cannot use vibration devices (**Güneyisi, 2010**). For to be primarily used in seismicity for heavily packed reinforced constructions because the longevity of concrete structures has become a major concern in this country. The proper compaction by competent laborers is essential to achieve long-lasting concrete structures (**Patel et al., 2011**). The first developments of this type of concrete was in Japan at the late 1980s. When employing SCC, for example, because of the lack of compaction, the craftsmanship has a significantly smaller impact on the final structural homogeneity than when using regular concrete. However, further experimental study needs be done to confirm this issue (**Almeida Filho et al., 2010**). Many materials (recycled) have been employed to investigate the performance of SCRC and consume them to reduce the solid waste and decrease the cost of this type of concrete. In present study, the tyre rubber waste was used in production of SCRC in order to give the solution of tyre rubber waste disposal disaster by making these waste more sustainable. When leftover tyre rubber aggregates are mixed with SCRC, a new combination called self-compacting rubberised concrete is generated (SCRC) (**Rahman, 2017; Aslani and Khan, 2019**). In this chapter, significance, aim and objective of this study will be presented.

## 1.2 Research Significance

Tyre rubber waste is classified as non-biodegradable waste. Disposal of used tyres is a major concern as inappropriate disposal can lead to significant environmental and unaesthetic problems. According to General Company of Rubber Manufacturer's /Iraq, about 2 million waste tyres are stockpiled at whole Iraq. Significant development in transportation and an enormous increment in the quantity of vehicles create various issues in environmental contamination like the burning millions of tons of waste tyres. The waste rubber tyres as a construction material in concrete has been presented as the proper utilization of scrap tyres. Waste rubber tyres can be incorporated in concrete either as coarse aggregates or fine aggregates. Properties like sound insulation, thermal insulation, and impact resistance get improved on the addition of tyre rubber waste in concrete.

The vast quantity of non-recyclable waste inhabits a large space and reasons environmental risks. When a tyre is burned or used as fuel, poisonous gases are produced which have a negative environmental impact and can cause harsh pollutions of atmosphere air (**Thomas and Gupta, 2015**). Chemically, crumb rubber tyre contains a high concentration of styrene, a highly toxic portion that is extremely harmful to human health (**Kaewunruen et al., 2018**). Waste rubber tyres are ground and used in concrete as a partial substitute for fine or coarse aggregate. Before being used as aggregate in concrete, the scrap tyres are crushed and reduced into smaller particles. In this situation, the steel and thread will be removed from production. Chip rubber is produced by mechanical grinding at ambient temperatures and is used as coarse aggregate in concrete. But, crumb rubber is used as fine aggregate. Cryogenic grinding at low temperatures is used to make it (**Roychand et al., 2020**). The recycle of scrap rubber tyres helps to safeguard the environment while also preserving

natural resources. Waste disposal is one of the most pressing issues confronting the world today, as shown in **Figure 1-1**. It maybe offer a solution for natural aggregate conservation while improving concrete characteristics (**Mohammed et al., 2017**). Also, it maybe improve some properties such as dynamic compressive strength, shock resistance, dynamic splitting tensile strength, dynamic flexural strength, impact, repeated, reversed cycle loads, and seismic loading (**Eltayeb et al., 2021**). Crumb rubber from waste tyres was partially replaced sand, gravel and combined sand and gravel at different proportions to produce self-compacting rubberised concrete (SCRC) (**Najim and Hall, 2012**) (**Yun et al., 2013**) (**Sofi, 2018**) (**Li et al., 2019**). established the compressive strength of SCRC for 5% rubber tyre was greater than the control mixture by ten percentage at age 91 days. Also, this replacement rubber tyre powder gave a considerable increment in anti-sulphate corrosion. However, the drying shrinkage was increase with rise in the amount of rubber tyre used, and reaching its maximum at 20%.



**Figure 1-1** waste tyres (**Assaggaf et al., 2021**)

### 1.3 Self-Compacting Concrete (SCC) and Rubberised Concrete(SCRC)

Self-compacting concrete (SCC) has been dubbed "concrete construction's most significant invention in decades." Even in the presence of dense reinforcing bars, SCC may flow under its own weight without compaction or vibration, completely filling the molds and achieving complete compaction (**Patel et al., 2011**).

Rubberised concrete is a form of concrete that contains rubber (**Khatib and Bayomy, 1998**). Aggregates (fine and coarse aggregate) are one of the most important elements used in the manufacturing of concrete, however they are likely to become scarce. Rubber in concrete can be viewed as a beneficial step toward the development of long-lasting concrete (**Panda et al., 2012**). Waste rubber tyres are diced and utilized in concrete as a partial substitute for fine or coarse aggregate. The usage of scrap rubber tyres helps to maintain natural aggregates while also protecting the environment. Waste disposal is a significant concern all over the world (**Tagba et al., 2021**).

### 1.4 Classification Waste Tyres

#### 1. Shredded or Chipped tyre Rubber

Tyre chips or Shredded rubber generally used as a coarse aggregate and has been partially replaced it for natural gravel (**Ganjian et al., 2009 ; Güneyisi, 2016**).

#### 2.Crumb Rubber Aggregate

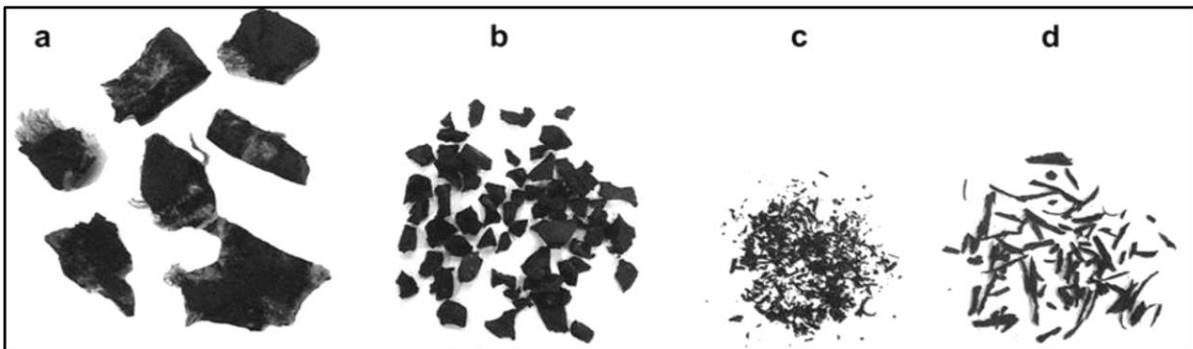
The size of crumb rubber is generally ranges between 4.75 and 0.425 mm. Most of the researchers used it as a partial replacement of natural sand i.e. fine aggregate (**Ling et al., 2009**).

### 3. Grounular Tyre Rubber

It is the rubber aggregate, which passes through 0.425 mm sieve. Some researchers utilized it in SCC mix (**Ganjian et al., 2009**)

### 4. Fibre Rubber Aggregate

Some of the researchers used shredded rubber as short fibre, generally from 8.5 to 21.5 mm in length with an average of 12.5 mm (**Baoshan et al., 2004**), and in the form of 68 mm long strips (**Emiroglu et al 2007**) as presented in **Figure 1-2**.



**Figure 1-2** Classifications of rubber aggregates: (a) chipped rubber, (b) crumb rubber, (c) granular rubber (d) fiber rubber (**Ghosh and Bera, 2016**)

### 1.5 Research Goal and Objective

Firstly, the aim of the current study is to develop eco-friendly concrete that content scrap rubber tyres. Fine aggregate replacement with investigate the durability and mechanical properties of composite self-compacting rubberised concrete exposed to severe salty environmental conditions. The main reasons for uses for rubber are sustainability in terms of the reduction of solid waste in the environment and enhance the concrete properties to be more helpful under certain applications and circumstances, strength to weight ratio and cost properties.

Secondly, the effect of using various substitution ratios of waste tyre aggregate in concrete. More specifically, the research has the following objectives:

- 1- To evaluate the fresh properties of SCRC mixtures. As fresh state tests, the slump flow (D (mm) and  $T_{500\text{mm}}$  (s)), V-funnel time, L-box, and segregation resistance were performed.
- 2- To investigate the effect fine aggregate replacement for hardened properties of SCRC, including the compressive strength, splitting tensile strength, flexural strength, schmidt hammer, ultrasonic pulse velocity (UPV) and dry shrinkage at different ages.
- 3- To investigate the effect fine aggregate replacement for durability characteristics, including water absorption, porosity, surface absorption, chloride migration, chloride penetration and chloride concentration of SCRC.

## 1.6 Layout of the Thesis

This study is broken down into five sections as follows:

**Chapter 1:** A comprehensive overview and background on cast (SCC) self-compacting concrete, as well as tyre waste forms were presented in this chapter. Furthermore, the study's goal and objectives are stated. The goal of the introductory chapter is to outline the scope of the current study and to offer a brief explanation of this thesis.

**Chapter 2:** This chapter covers the theoretical foundation of the materials employed as well as the experimental findings of the concrete using discarded rubber tyres. The chapter also includes some more information on certain adjustments, as well as a literature review of numerous relevant studies that covers the available literature on rubber concrete.

**Chapter 3:** In this chapter, the experimental approach is dedicated. In addition, all experimental works are described in detail in this chapter, including details of the materials used, the mechanical properties of normal and rubber concrete as well as the tests that carried out to investigate the properties self- compacted rubberised concrete such as physical , mechanical and durability.

**Chapter 4:** The results and analysis of self- compacting concrete with and without rubber are presented for different examination, which also identified and investigated the best case of replacement of rubber percentage in this chapter.

**Chapter 5:** Based on the current study, the findings and recommendations for further work were listed in chapter 5 to be guide line to researcher in future.

# CHAPTER TWO

## Chapter TWO

### Literature Review

#### 2.1 Introduction

Before starting the details of the testing program, it is necessary to review the state of the art regarding, self-compacted concrete (SCC), and associated with utilising crumb rubber as partial replacement of fine aggregate. In addition, the effects of severe environmental conditions on concrete structures such as sulfate and chloride penetration are investigated. In this chapter, the current guidelines and specifications for producing self-compacted concrete (SCC) and self-compacting rubberised concrete (SCRC), different tests for predicting fresh properties, mechanical properties, sulfate attack will be reviewed.

#### 2.2 Crumb Rubber (Waste Tyre Rubber)

Over 1.5 billion tyres are produced annually across the globe (**Mohammed et al., 2019**). This is a cause for concern especially pertaining to environmental pollution. Previous studies show that crumb rubber and fibre from scrap tyre is produced at a cheaper rate and provides material for various purposes, for example sport surfaces used for athletics. Adding it to concrete provides a good alternative for waste tyre application, because it enhances weight reduction in concrete giving rise to less dead loads thereby placing less stress on building foundations and enhancing the efficiency of the structure (**Mohammed et al., 2019**). However, the addition of crumb rubber aggregates to concrete systematically causes reduction in the tensile and compressive strengths despite exhibiting a higher level of strain at failure as indicated in previous research (**Dong et al., 2013**).

Crumb rubber from waste tyres has been used to replace aggregates in concrete either in part or in full or to modify bituminous composites. Accumulation of waste rubber tyres especially from light vehicles poses environmental risks in the long term. This is because polymers are difficult to decompose. When stockpiled, tyres can trap water and this could breed insects especially mosquitoes which could result in malaria or dengue fever outbreak (Mohammed et al., 2019). Specifically, when disposed for landfill, chemical leaching and landfill instability could arise. Using aggregates made from recycled crumb rubber (CR) as an alternative for the more popular traditional aggregates in concrete has been investigated over the past decade. This is due to the fact that there is a growing clamour to seek useful applications for crumb rubber waste. (Dong et al., 2013). Crumb Rubber aggregates comprises of 45% polymer, 15% organic materials and 40% carbon black by weight. (Aslani, 2018). Figure 2-1 shows scrap of tyres.



**Figure 2-1** Scrap of tyre (Noor.N.M., 2015)

### 2.2.1 Composition of Waste Rubber Tyres

The tyre is made up mainly by rubber. Its constitution varies a little between the car tyres and heavy truck tyres. The chemical compositions of the rubber are listed in **Table 2.1**.

**Table 2.1** Rubber characteristics (Melik et al., 2014)

Material/element	Mass percentage
Rubber	54%
Carbon black	29%
Textile	2%
Oxidize zinc	1%
Sulfur	1%
Additives	13%

### 2.2.2 Properties of Waste Rubber Tyres

#### 2.2.2.1 Strength

Tensile strength of rubber is high and as a rubber is very flexible. It is highly durable, even after a rubber tyre goes through the vulcanization process (Fazli and Rodrigue, 2020).

#### 2. 2.2.2 Bonding

It has a good bonding quality so that it could be easily bonded with other construction materials (Wang et al., 2019).

#### 2. 2.2.3 Thermal Insulation

Waste rubber tyres has good thermal conductivity (Abdel Kader et al., 2012). Therefore, the rubber tyres are good insulator of heat hence a promising building material.

#### **2. 2.2.4 Acoustic Insulation**

Rubber tyre has poor acoustic conductivity. Therefore, it is a good acoustical insulator (**Sambucci et al., 2020**).

#### **2. 2.2.5 Lightweight**

Since the weight of rubber is light, so it can be used for preparing lightweight construction materials. The specific gravity of rubber tyre ranges from 1.02 to 1.27 (**Bressette, 1984 ; Humphrey and Manion, 1992**).

#### **2. 2.2.6 Water Absorption**

Water absorption tyre rubber aggregates ranges between 2 to 4% of lowered than natural fine aggregate (**Humphrey, 2006**).

### **2.2.3 Advantages and Disadvantages of Using Waste Tyres Rubber**

Utilization of waste tyre rubber in construction technology has many benefits (**Noor, 2015**). These benefits and advantage are summarized in these points.

- 1- Low unit weight.
- 2- Saves natural resources.
- 3- High resistance to abrasion.
- 4- Change behavior of concrete from brittle to ductile.
- 5- High resilience.
- 6- High toughness (absorbing energy).
- 7- Improve shrinkage and cracking.
- 8- Improve water permeability.

While, disadvantages of utilization of waste tyre rubber in construction technology are:

Reduction in compressive strength, splitting tensile strength, and modulus of rupture if a large percentage of rubber replacement is used.

**Topçu and Turhan(2009)** replaced aggregates with rubber contents of 60, 120 and 180 kg/m<sup>3</sup> in SCC by weight. The result of the test conducted by them indicated that compressive strength of rubberised decreases with increment of rubber aggregates. **Mehmet and Erhan(2011)** used four designated crumb rubber contents of 0%, 5%, 15%, and 25% by volume of fine aggregate to replace the fine aggregates i.e. sand. They observed the use of crumb rubber in SCC made it absorbent with a growing rate of crumb rubber content. Their results show that the water absorption of the SCC ranges between 2.73% to 4.25% and between 2.56% to 4.03% at 28 and 90 days depending on the contents of crumb rubber aggregate and fly ash respectively.

**Khalil et al. (2015)** conducted tests on SCC samples with different crumb rubber (max. 2 mm) ratios of 10%, 20%, 30% and 40% sand replacement by volume. According to their test, data flowability (slump test value) decreased 11.5% for 0% to 40% rubber content replacement. The chip and crumb rubbers were used to replace coarse and fine aggregate respectively in four different amounts by volume (5%, 10%, 15%, and 20%) were examination by **Kadhim and Al-Mutairee (2020)**. Even if the inclusion of waste tyre rubber in concrete has specific apparent degradations, the potential benefit seems to overlook the adverse effects and meet the primary significant value of resolution for rubber waste utilization problems. The results show that the substitution of natural fine or coarse aggregates with crump-chip tyre rubber will reduce mechanical properties (compressive, flexural and splitting tensile strength), but increase the impacts resistance to 426% and 396% when 20% coarse aggregates and 20% fine aggregates are replaced by rubber respectively. The proposed mix shows an ability to replace 20% of the aggregate (coarse or fine), and the producing, rubberised concrete, still structural concrete.

## 2.3 Rubberised Concrete

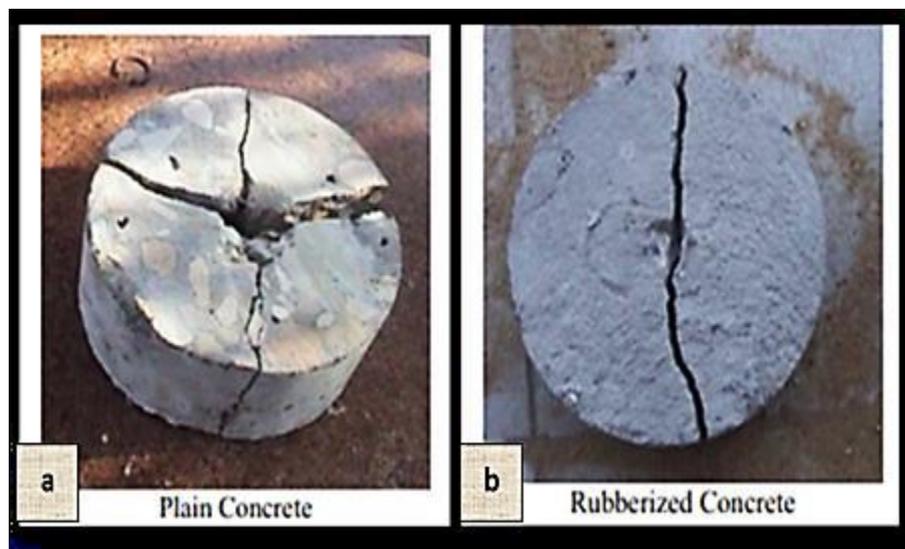
It is a new structural materials using recycled tyres rubber as partial replacement by aggregates (fine and coarse aggregates) in a Portland cement concrete. The percentages of rubber replacement usually range from 5% to 25% by mass of aggregates and sometimes reach 50% and 75%. The percentages more than 25% lead to more negative impact on properties of concrete. (Aiello and Leuzzi, 2010, Antil, 2014, Ali and Saravanan, 2015).

Many researches attempt to use huge amount of rubber waste to produce rubberised concrete. It can be obtained by adding scrap tyres rubber to the concrete mixtures. Fine and coarse aggregate is replaced by waste tyres rubber. Waste tyres rubber is the main waste materials used to obtain rubberised concrete (Eldin and Senouci, 1993).

### 2.3.1 Impact Resistance of Rubberised Concrete

Topçu, and Avcular (1997) mentioned that is one purposes of aggregating rubber is to increase the capacity of concrete to absorb energy. From the results of the review experiments, they were showed that the addition of rubber aggregate into concrete improves concrete's impact resistance. This resistance results from the enhanced ability of Rubberised concrete to absorb energy, safety and sound insulation during impact. In addition, the increase in these properties in concrete samples aggregated with larger size of rubber aggregates became more prominent. These altered characteristics are attributed to aggregated rubber due to its fiber structure, which gives the concrete its flexibility and blow absorption capacity. The effects of adding waste tyre rubber on mechanical properties and impact resistance of normal strength concrete with and without silica fumes were investigated by Sallam et al.(2008). As a partial replacement of sand, three

specific volume ratios of crumb rubber 10 %, 20 %, and 30 % were used. Impact compression was performed on disks of 150 mm diameter and 63 mm height according to repeated drop-weight impact study by (ACI Committee 544). Test results showed that fine aggregate replacement by 10% crumb rubber resulted in a small decrease in concrete compressive strength. The involvement of small sized crumb rubber in concrete improved its crack initiation resistance under impact load, hence. The mode of failure under static and impact compression of Rubberised concrete was as shown in Figure 2-2.



**Figure 2-2** Failure's Mode of plain and Rubberised concretes under impact load (Sallam et al., 2008)

### 2.3.2 Modify CRC by Improving the Bonding

Gesoğlu et al. (2005) tested experimentally some physical and mechanical properties of Rubberised concrete with and without silica fumes. Two types of tyre rubber, chips rubber and tyre crumb, have been used as a coarse and fine aggregate respectively. Rubberised concrete mixtures were formed by partially replacing the aggregate with waste of rubber of total aggregate volume with different rubber content varying between 2.5 to 50%.

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Silica fume replacement of partial cement ranged from 5% to 20%. A total of seventy concrete mixtures with a water cemented content ratio of 0.60 and 0.40 were cast and tested for compressive strength, static elasticity module and split-tensile strength in agreement with appropriate ASTM standards. They were found that there was a marked reduction in the slump, unit weight, strength and elastic module with increased rubber content. In particular, the use of silica fume improved the mechanical properties of non-Rubberised and Rubberised concrete. **Hamza, and Ghedan (2011)** presented the compressive strength and thermal conductivity tests for CRC. The results showed that adding chips tyre rubber particles to the concrete to obtain a lightweight one cause a reduction in the compressive strength by about 49.8%, but this property was improved when using hydroxide of sodium (**NaOH**) to treat the surface of chips rubber particles and it was found to be very effective in improving the compressive strength so that this strength reduced by about 12.9% from traditional concrete. Also, the added rubber particles decreased the thermal conductivity of the Rubberised concrete by about 26.7% from traditional concrete but when chips rubber particles treated with (**NaOH**), thermal conductivity increased around 17.8% from traditional concrete.

### **2.3.3 Properties of Concrete Mixed with Crumb Rubber**

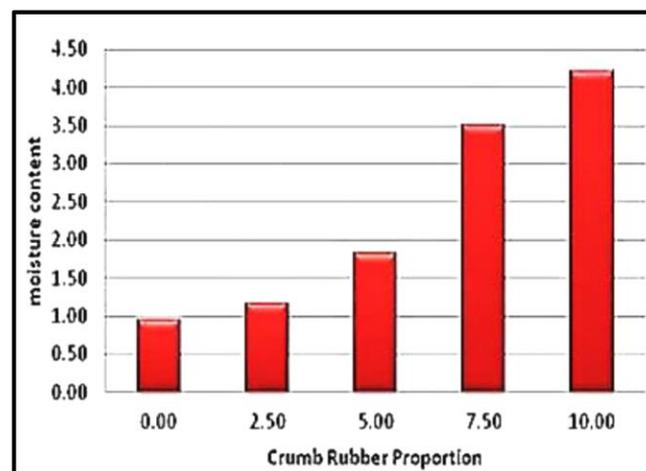
Extensive studies have been carried out over the years on the material properties of crumb rubber concrete. Information on the mechanical properties of crumb rubber concrete in terms of compressive, tensile, and flexural strengths are quite well known. According to previous studies (**Sukontasukkul and Wiwatpattanapong, 2005; Sukontasukkul and Chaikaew, 2006**), the strength of concrete mixed with crumb rubber is quite low (as compared to plain concrete) and tend to decrease with increasing rubber content at the replacing rate of 10%, both compressive and flexural

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strengths were found to decrease by 35% and 28%, respectively. At 20%, the strength of crumb rubber was decreased to only about 22–28% of that of plain concrete. With its poor strength, the crumb rubber concrete does not seem to find a use in structural applications. On the contrary, with lower density, it seems that the best way to use crumb rubber concrete might be as an insulator. However, information on the performance of crumb rubber concrete on thermal and sound properties is limited. Therefore, in this study of (Sukontasukkul, 2009), both thermal and sound properties of crumb rubber concrete panel are investigated in details, specifically, thermal conductivity factors, thermal resistance with heat transfer, conductance value, sound absorption at different frequencies and noise reduction. The performance of the crumb rubber concrete compared with normal concrete in terms of overall heat resistivity is also presented. Antil (2014) investigated the effects of utilizing crumb rubber as sand in various percentages of replacement (0%, 5%, 10%, 15% and 20%). He observed that concrete containing higher proportion of tyres rubber has high toughness. The slump value of concrete increased about 1.08%, with the crumb rubber replacement of 10%. The results also showed the splitting tensile strength, compressive strength, and modulus of rupture of the concrete decreased by about 20%, 37%, and 69 % respectively, when 20% fine aggregate was replaced by rubber (crumb rubber).

Ali and Saravanan (2015) have replaced the sand (fine aggregate) by a single gradation of crumb rubber (0.9 mm) varying from 5% to 20% by mass of fine aggregate. The test results demonstrated that the value of slump decreased with the increase in rubber content. The test results also showed that the addition of rubber aggregate led to a decrease in compressive strength and splitting tensile strength of concrete when compared with the reference mixture. The reduction in compressive and splitting tensile

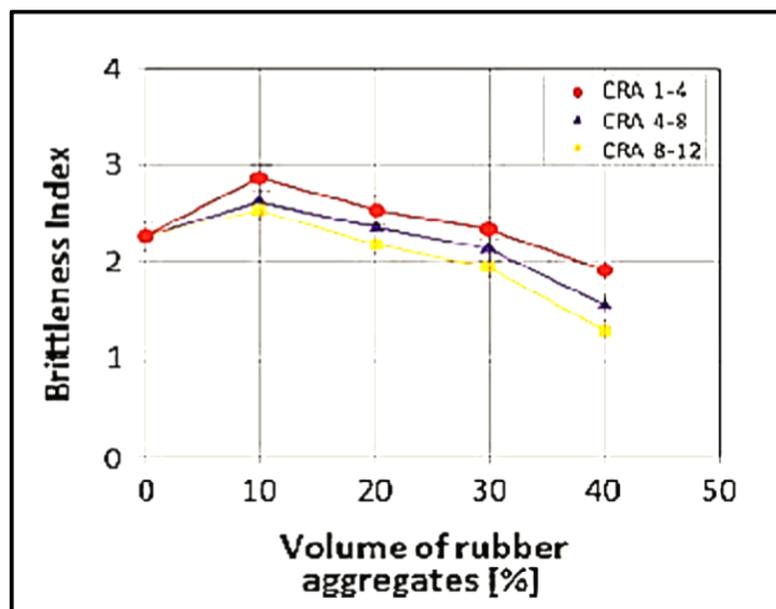
strength were 29.5% and 60.8% respectively at 28 days of curing (20% replacement by weight of fine aggregate). The increase in modulus of rupture (flexural strength) was obtained with rubber replaces 10% of the fine aggregate. **Bhatt et al. (2017)** used crumb rubber as a sand replacement with percentage 0%, 2.5%, 5%, 7.5% and 10 % by weight of fine aggregate. They observed that the percentage of crumb rubber about 10% exhibited a reduction in compressive strength about 29.7% and 45.8% at 7 and 28 days, respectively. The flexural strength comes optimum when 5% of crumb rubber replaced by fine aggregate. The water absorption increases as crumb rubber proportion increases as shown in **Figure 2-3**.



**Figure 2-3** Consequences of water absorption (**Bhatt et al., 2017**)

The properties of split tensile strength and flexural are significantly reduced at a slow average compared to compressive strength. As foretell, the strength of cement composites thereafter improved with the reduction of tyre rubber and the act that mechanical strength is closely connected with the dynamic elasticity module (**Topcu, 1995; Segre and Joekes(2000); Pierce and Williams, 2004; Turatsinze et al.(2005); Oikonomou and Mavridou(2009)**) found out that the bonding between the rubber elements and the matrix can be achieved by several ways. As much as styrene

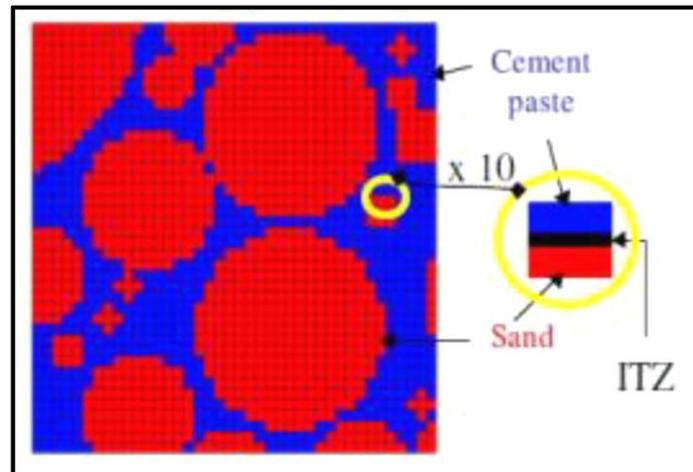
butadiene rubber is disrupted by liquid and anionic bitumen suspension, microscopic studies have shown that these types of extracts are well bound to the surface of rubber particles, thereby reinforcing the bond between cement mortar, aggregate additives, and rubber particles. Also, the ductility in the stress-strain relation may be increased with adding waste rubber particles and increasing size of particles (**Benazzouk et al., 2003**). The brittleness index BI was computed to estimate the ductility index of concrete as shown in **Figure 2-4**. The top value was obtained when the percentage of waste tyre rubber was 10%. After this percentage the modes of failure change from brittle to ductile. The decline in the index of brittleness with a rubber percentage above P 10% leads to an increase in plastic energy.



**Figure 2-4** Brittleness indices of different concrete kinds (**Benazzouk et al., 2003**)

**Li et al. (2004)** made comparison between larger chips rubber particles and waste tyre rubber in the form of fibers; they found the CRC with waste tyre rubber in the form of fibers resulted in greater resistance. **Benboudjema et al. (2004)** explained that interfacial transition zone (ITZ)

is represented the zone between aggregates and cement paste (Zone around the aggregate particles) as shown in **Figure 2-5**. ITZ is very important to calculate the mechanical properties of mixes.



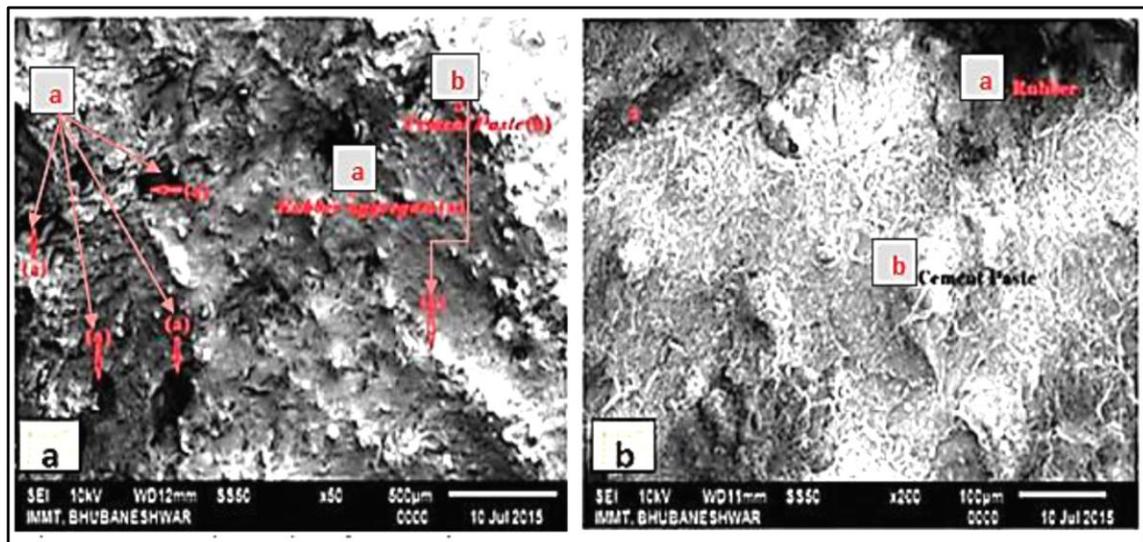
**Figure 2-5** Interfacial transition zone (Benboudjema et al., 2004)

The substitution of rubber aggregates would decrease the strength of cement based products. This decrease varies with the kind of cement and depending on the size and surface texture of the rubber particles and the replacement amount ( Oikonomou and Mavridou, 2009; Turatsinze et al., 2005; Siddique and Naik, 2004). Benazzouk et al., 2007 presented water absorption of cement mixtures that had scratched rubber waste, use of tyre rubber as a fractional substitute for cement to make efficient lightweight structural materials. Test results for the hydraulic transport properties showed that the mixture of tyre rubber in these compounds tends to reduce water absorption in the collections. The mixture of concrete is a heterogeneous material under macroscopic scale; these mixes have aggregates (fine and coarse aggregates) and cement paste. From mechanical demeanor, these mixes contain three stages, particles of aggregates, matrix of cement paste, and ITZ. Chips rubber particles do not exhibit any separation or breaking but tend to slip out of the cement paste, thus causes in poor ITZ (Yıldız et al., 2007).

In CRC, the smooth and softness of waste chips rubber particles lead to weak bonding between aggregate particles and cement matrix, thus weakness in the ITZ decreases in mechanical properties of CRC (**Ganjian et al., 2009**). They replaced the coarse aggregate by chips waste rubber with percentages of 5%, 7.5% and 10% from total weight of coarse aggregate. The consequences demonstrated that elasticity modulus, strengths of compressive and splitting-tensile reduced with increasing chips rubber amount.. The decrease in the splitting-tensile strength and elasticity modulus was about 30 percent to 60% and about 17% to 25% if the rubber substitution was 5percent to 10%, respectively. The water absorption varies from 2% to 4%, respectively. Chip tyre rubber was used by **Aiello and Leuzzi (2010)** to substitute coarse aggregates with size from 10 mm to 25 mm and plasticizer around 1% by weight of cement. The amount of chip rubber was 25%, 50% and 75% by gross volume of coarse aggregate. They noticed that the workability increased as the contents of chip tyres increased. The tests also showed a reduction in compressive strength as the amount of rubber increased. The reduction in compressive strength was 47.8%, 54.4% and 62.3%, when the rubber substitution was 25%, 50% and 75%, respectively.

**Brito and Saikia (2012)** used techniques to get better ITZ between cement paste and rubber particles by using chemical treatment of waste rubber particles as NaOH solution. In addition, they calculated that the use of waste tyre rubbers increased concrete's post-cracking resistance by absorbing energy. Also, they found that this kind of concrete can be used in applications where impact or blast resistance was necessary, such as bunkers and jersey barriers, or where vibration damping such as foundation pads in railway stations is required. **Abd et al. (2016)** mentioned that many of the ASTM specifications relating to recycle rubber, such as **ASTM D5644** test methods for rubber compounding materials-determining the particle size

distribution of recycled vulcanized particulate rubber, explain methods for measuring particle size and particle size distribution for recycling rubber and standard classification **ASTM D5603** for rubber compounding materials-recycling materials. The Classification of rubber compounding materials-recycling materials, this reduction of fine aggregates by tyre rubber can be understood by the lower volume of pores in mortars and by the fact that these pores cannot simply be obtained by means of water (**Abd et al., 2016. Padhi, and Panda 2016**) Scanning electronic microscope (SEM) analysis displayed that crumb rubber particles make voids and result in a weak bond between rubber particles and cement paste as shown in **Figure 2-6**. In addition, the water absorption increases as waste crumb rubber proportion increases, and their results showed that the decrease in compressive strength and splitting tensile strength was about 43.4% and 46.4% respectively, when the fine aggregate was replaced with rubber particles passing through 4.75 mm sieve with crumb rubber replacement of 15%. The modulus of rupture increased when the percentage of crumb rubber was 5%.



a-SEM observation for sample SCR10  
(50X, marker 500µm).

b-SEM observation for sample SCR10  
(200X, marker 100µm).

When red letters on plate represented; (a) Rubber aggregate (b) Cement Paste

**Figure 2-6 SEM test for SCR10 (Padhi, and Panda, 2016)**

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## 2.4 Self - Compacting Concrete (SCC)

For the proper compaction of the conventional concrete, additional compacting methods such as the vibrating table need to be utilized. To overcome the problem of compaction, Okamura from Japan invented self-compacting concrete (SCC) in 1986, which was later introduced to French construction in the 1990s (**Loukili, 2013**). SCC is often used as a solution for filling congested reinforced structural members, removing vibration noises, and for reducing the workload for workers during handling and placing concrete. SCC does not require vibration as it can fill formwork as a viscous liquid due to its good homogeneity. Compared to conventional concrete, SCC is known to have higher flexural and tensile strengths owing to its improved microstructure, interfacial transition zone, and denser paste (**Aslani and Nejadi, 2012**). The self-consolidating or compacting concrete is defined the concrete has “highly flow able, non-segregation concrete that can spread into place, fills the mold, and encapsulates the reinforcement without any mechanical compaction” (**ACI Committee 237R, 2007**).

SCC is a type of concrete that flows and spread into the form without the need for mechanical vibration. It can also be described as a modified form of high performance concrete that was developed to solve the durability shortcomings which may likely take place as a result of insufficient compaction in conventional concrete (**Najim and Hall, 2010**). It is a non-segregating concrete that is normally placed by virtue of its own weight. Its major importance is attributed to the fact that it maintains all of concrete's durability and characteristics of meeting expected performance requirement. Under certain scenarios, the addition of super-plasticizers to the mix design may be necessary in order to reduce or prevent bleeding in addition to segregation. Self-compacting/consolidating concrete (SCC) class of concrete is ideal for application for highly congested reinforcement members with

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good workability. With more advancement in concrete technology in producing SCC, its use is becoming more widespread.

### 2.4.1 Advantages and Disadvantages of Self- Compacting Concrete

The use of SCC proved some advantages; these advantages are often accompanied by some disadvantages (**Chai, 1998**).

#### ❖ Advantages

- 1- Fast in construction.
- 2- Easier placing.
- 3- Uniform compaction without vibration.
- 4- Better finishing.
- 5- Improve durability.
- 6- Increase bond strength.
- 7- Noise reduction.

#### ❖ Disadvantages

- 1- High cost of materials.
- 2- High quality control is required for producing this type of concrete.
- 3- High lateral pressure on the molds.

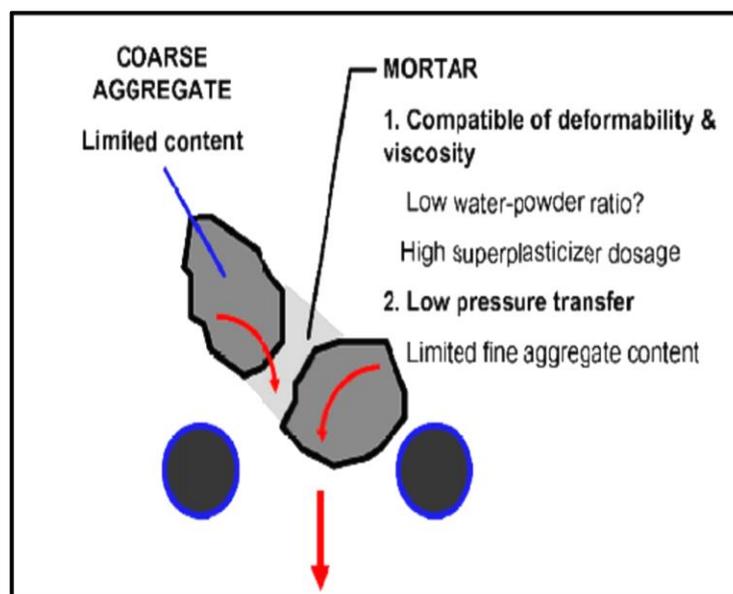
### 2.4.2 Mechanism for Achieving SCC

The technique for accomplishing self-compatibility includes not only high deformability of mixtures, but also to prevent segregation between cement paste and coarse aggregate when the concrete moves between congested reinforcement. The following points were applied for achieving the requirements SCC (**EFNARC, 2005**).

1. Increase powder content from cementitious materials and filler.
2. Decrease coarse aggregate content.

3. A low water to binder ratio (w/b), (binder includes cement and pozzolanic materials such as silica fume)
4. Using chemical admixtures like superplasticizer (SP) and viscosity modifying admixture (VMA) to improve cohesion and segregation resistance.

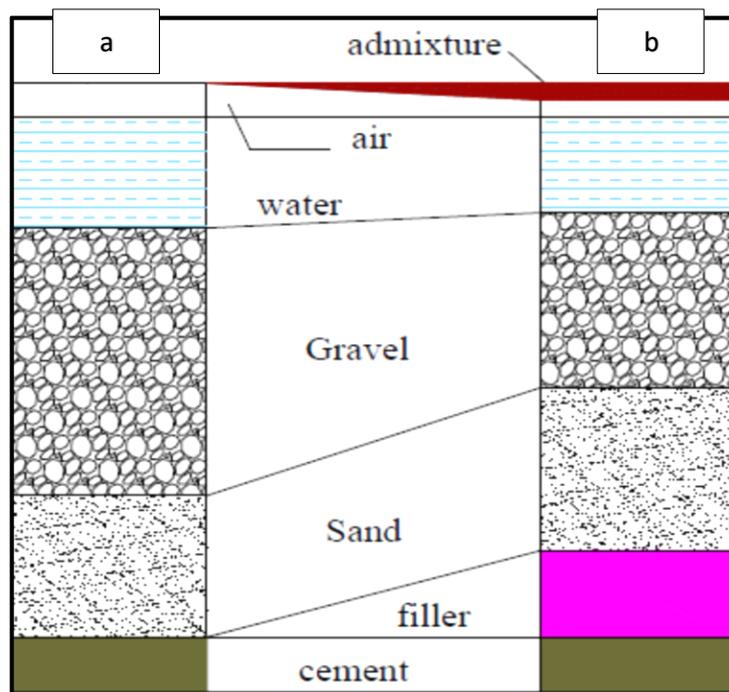
The contact and collision between particles of aggregate can increment as the relative spacing between these particles decreases and then inner stress increased when concrete is deformed. Studies of **Okamura et al. (2000)** and **Kebaïli et al(2015)** have shown that the energy required to achieve flow is consumed by increasing the generation of internal stress between aggregate particles, resulting in blockage of these particles. When the amount of coarse aggregate is reduced, the energy consumption will be low and lead to avoid this type of blockage. The viscosity of the paste is also required to avoid the blockage of gravel (coarse aggregate) when concrete moves through obstacles as shown in **Figure 2-7**. High deformability can be achieved by using chemical admixtures and reducing water to binder ratio (**Okamura and Ouchi, 2003**).



**Figure 2-7** Mechanism to achieve SCC (**Okamura and Ouchi, 2003**)

### 2.4.3 Materials for SCC

The materials used to produce SCC are the same as those utilized in ordinary concrete, satisfying with EN 206-1, but include some mineral admixtures (filler and pozzolanic materials) to achieve the requirements of SCC (Okamura and Ouchi, 2003). Figure 2-8 shows the materials used in normal concrete (NC) and self-compacting concrete (SCC).



**Figure 2-8** Materials used: (a) NC, (b) SCC (Holschemacher and Klug, 2002)

#### 2.4.3.1 Cement

EFNARC (2005) stated that all types of cement can be utilized to produce self-compacting concrete. These types of cement which satisfy to EN 197-1. The right decision to choose cement type depends on the requirements of each application. Al-Rawi (2008) examined that it is possible to create self-compacting concrete by utilizing low content of ordinary Portland cement ( $250 \text{ kg/m}^3$ ) with a constant cementitious and filler content ( $500 \text{ kg/m}^3$ ). The results showed that the compressive strength of this

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type of concrete is (34 MPa). This value increased by about 15% and 59% with cement content 300 kg/m<sup>3</sup> and 400 kg/m<sup>3</sup> respectively.

#### 2.4.3.2 Aggregates

The main requirements of **EFNARC, 2005**, is the normal weight aggregates should be satisfied EN 12620. Moreover, this code mentioned that the effect of fine aggregates on the fresh properties of self-compacting concrete is essentially more prominent than that of coarse aggregate, size of particles less than 0.0125 cm should be presence in the paste to contribute the powder content of the SCC. Also, the **EFNARC, 2005** recommended to use the maximum size of aggregate should be restricted to 12 – 20 mm because the spacing between reinforcement is the main factor that effects on determine the maximum size of aggregate to prevent blocking of aggregate. On the same way, **Su et al. (2002)** investigated the effect of sand ratio (S/A ratio) (volume of fine aggregate /volume of total aggregate) on the fresh properties and modulus of elasticity for SCC. The results showed that the flow ability of self-compacting concrete was increased when S/A ratio increased. The modulus of elasticity was not significantly influenced by S/A ratio when the volume of aggregate remained constant. On the other hand, increase of size of coarse aggregate has negatively impact on flow ability of self-compacting concrete and the mechanical properties of SCC with the 10 mm size of coarse aggregate were higher than with the 20 mm size of coarse aggregate (**Khaleel et al. 2011; Bobba and Rao 2016**). **Yanai et al. (2000)** investigated the fresh and hardened properties of SCC using different proportions from lightweight aggregate (LWA). The results observed that the flow ability, filling ability, and compressive strength were increased when the density of LWA increased.

#### 2.4.4 Mineral Admixtures

To achieve the fresh properties of SCC, mineral admixtures such as pozzolanic materials or filler, are commonly employed to improve the cohesion of mixes and resistance to segregation. These binder materials also govern the amount of cement in SCC mix and reduce the heat of hydration (Neville, 2011; EFNARC, 2005). Esping (2008) studied the fresh and hardened properties of SCC containing filler admixture (limestone dust). The results observed that the compressive strength increased by using limestone dust. In addition, the flowability of mix was decreased by using this dust. On the other hand, the utilization of limestone dust and slag allows increasing the flowability of the mix but has a negative effect on the stability of the mixture (Kenai, 2015). Using natural pozzolana decreases the workability and increase the viscosity of the mixtures. This improves the stability of the SCC mix. Iqbal et al. (2017) studied the effect of increase the content of fly ash in SCC that may improve the fresh properties. With the increase content of fly ash from 100 kg/m<sup>3</sup> to 125 kg/m<sup>3</sup>, the compressive strength increased by 13.5 % but decreased by 4.5 % when the fly ash quantity was further increased to 150 kg/m<sup>3</sup>. There is a significant increase of 26 % in splitting tensile strength and 11 % in modulus of rupture when 25 kg/m<sup>3</sup> of fly ash was added.

#### 2.4.5 Chemical Admixtures

Lachemi et al. (2004) studied the effect of different doses and types of viscosity modifying admixture (VMA) in addition to the superplasticizer on the flowability and viscosity. They observed that the values of slump flow and viscosity was increased when the dose of VMA increased from 0.025% to 0.075% with a constant dose of superplasticizer. Also the combination of the appropriate dose of 0.05% VMA and 0.25% SP can produce high

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performance cement paste with high fluidity and moderate cohesion. All types of VMA with constant water to binder ratio (w/b) reduce flow value of mortar (increase flow time). The viscosity of the mix increased as VMA increased with constant w/b ratio (Leemann **and Winnefeld, 2007**). These results of compressive strength showed that the mixture containing VMA have a high compressive strength compared to the mixture without VMA. The test of slump flow of mixture with fly ash and SP (superplasticizer) gives a good workability in addition to increment in compressive strength. Adding superplasticizer alongside with 11% fly ash of cement content accelerates the growth of compressive strength of SCC (Dumne, **2014**).

## **2.5 Rheological Properties of Fresh State of Self-Compacting Concrete**

Any concrete mixture could be classified as SCC if it fulfills the following workability criteria (EFNARC, **2005**):

### **- Filling Ability:**

The concrete mixture (SCC) flows due to its own weight and fill all the edges of the framework. The filling ability of fresh concrete is measured by tests such as slump flow, V-funnel, etc.

### **- Passing Ability:**

SCC is able to flow under its weight through tight openings, such as spaces between steel reinforcement bars. The ability to pass may be measured by L-Box, U-box, J-Ring and Fill-box testing methods

### **- Resistance to Segregation:**

The SCC should satisfy the requirements of the filling capacity and the ability to pass with constant and fixed composition in the transport and placement route (Al-Bayati, **2017**).

European guideline, EFNARC, **2005** has developed several different tests to obtain the three Rheological properties of fresh state of self-

compacting concrete. The tests of SCC according to **EFNARC, 2005**, are listed in **Table 2.2**.

**Table 2.2 Tests of SCC (EFNARC, 2005)**

<b>Characteristic</b>	<b>Test Method</b>	<b>Measured value</b>
<b>Flowability/filling ability</b>	Slump flow	Total spread
	Kajima box	Visual filling
<b>Viscosity/flowability</b>	T500	Flow time
	V-funnel	Flow time
	O-funnel	Flow time
	Orimet	Flow time
<b>Passing ability</b>	L-box	Passing ratio
	U-box	Height difference
	J-ring	Step height, total flow
	Kajima box	Visual passing ability
<b>Segregation resistance</b>	Penetration	Depth
	Sieve segregation	Percent laitance
	Settlement column	Segregation

Because of its special performance in fresh state, SCC requires modified fresh concrete testing methods compared with conventional concrete. The difficulty consists of the fact, that SCC responds very sensitive to deviations of mixture proportions. Slightest deviations can already lead to a concrete that does not have one or more of those characteristics. This is usually connected with substantial lack of the finished construction unit, which lower not least the durability drastically and make in the worst case a construction useless (**Wustholz, 2003**) whereby a number of methods had been developed to assess the key properties of SCC. The most common tests that had been devised include slump flow, V-funnel, L-box, sieve segregation resistance and T-ring test.

### 2.5.1 Slump Flow Test and T500mm Test

The slump flow test aims to investigate the filling ability of SCC. The basic equipment used is the same as for the conventional Slump. The test measures two parameters: flow spread and flow time T500. The flow spread indicates the free, unrestricted deformability and determined by measuring the mean of two orthogonal diameters of the concrete base following the removal of the slump cone. Moreover, flow time T500 indicates the rate of deformation within a defined flow distance and determined by recording the time from lifting the slump cone to the concrete reaching a 500mm diameter (**Schutter, 2005**). Maximum deformability refers to the maximum flow value, while speed of deformability takes into account the rate of deformation. These flow notions are, of course, related to the yield value and the viscosity of the concrete. It is important to insure both high flowability (low-yield value) and a high resistance to segregation (moderate viscosity) to secure an SCC that can flow readily around various obstacles and achieve good filling capacity (**Khayat, 1999**). Viscosity can be assessed by the T500 time during the slump-flow test or assessed by the V-funnel flow time. The time value obtained does not measure the viscosity of SCC but is related to it by describing the rate of flow. Concrete with a low viscosity will have a very quick initial flow and then stop. Concrete with a high viscosity may continue to creep forward over an extended time, moreover, a high viscosity refers to a high segregation resistance (**European Project Group, 2005**). The longer the flow time, the higher is the viscosity of the SCC (**Hadiwidodo and Mohd, 2008**).

### 2.5.2 L-Box Test

The aim of this method is to assess the passing ability of SCC. Originally, it was developed in Japan for underwater concrete; the test is also

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applicable for highly flowable concrete. 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. After the concrete comes to rest in the apparatus, the heights of the concrete at the end of the horizontal portion, H2, and in the vertical section, H1, are measured. The blocking ratio,  $H2/H1$ , for most tests should be  $>0.80$ . If the concrete being tested is truly self-leveling, like water, the value of the blocking ratio will be unity (**Hadiwidodo, 2009**).

### 2.5.3 V-Funnel Test

This method goals to determine the viscosity and filling ability of SCC. It was first introduced in Japan. It measures flow time. The V-funnel flow time is the period at a defined volume of SCC needs to pass a narrow opening and gives an indication of the filling ability of SCC provided that 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 (**Schutter, 2005**). The funnel is filled completely with concrete and the bottom outlet is opened, allowing the concrete to flow out. The flow of the concrete is noted as the lapse of time between the removal of the outlet and the seizure of the flow. An alternative way to perform this test is to observe the flow from the top side of the funnel and report the flow time as the time between the removal of the outlet gate and the time when the light becomes visible from the bottom. A high flow time can be associated with either a high viscosity which indicates high segregation resistance, a high antiparticle friction, or a blockage of the flow (**Khayat, 1999**). A concrete mixtures can only be classified as SCC if the requirements for all the fresh properties are fulfilled (filling ability, passing ability, and segregation resistance). These requirements are to be fulfilled at the time of placing. Likely changes in

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workability during transport should be taken into account in production. Typical acceptance criteria for SCC with a maximum aggregate size up to (20mm) is shown in **(European Project Group, 2005)**.

#### **2.5.4 Segregation Resistance**

Segregation resistance is fundamental for SCC in-situ homogeneity and quality. The SCC can suffer from segregation during casting and also after placing but before stiffening. Segregation which occurs after placing can be most detrimental in tall elements but even in thin slabs, it can lead to surface defects such as cracking or a weak surface. In the absence of relevant experience, the following general guidance on segregation resistance classes is given: Segregation resistance becomes an important parameter with higher slump-flow classes and/or the lower viscosity class, or if placing conditions promote segregation. If none of these apply, it is usually not necessary to specify a segregation resistance class **(EFNARC, 2005)**.

### **2.6 Mechanical Properties of Self-Compacting Concrete**

#### **2.6.1 Compressive strength**

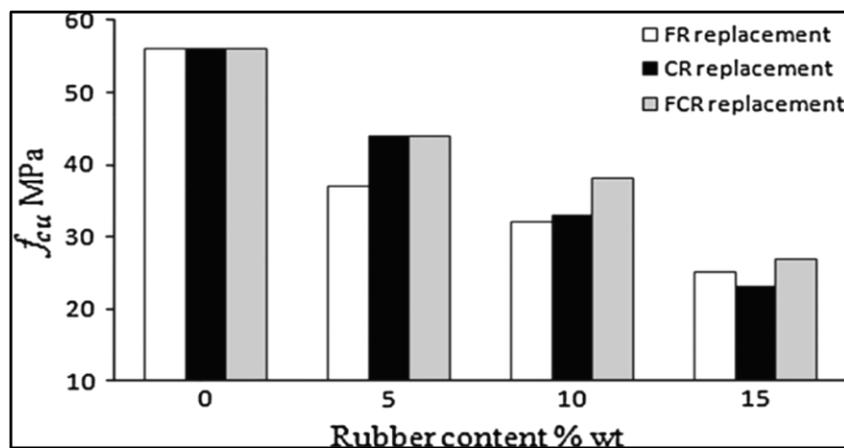
Compression strength of concrete is one of the most important attributes of hardened concrete considering its classification into the relevant class. The reasons for possible differences between the properties of hardened self-compacting concrete and common concrete are as follows **(Hela and Adam, 2005)**.

➤ Better microstructure and homogeneity of self-compacting concrete, microscopic tests show the better microstructure of self-compacting concrete in comparison with common compacted concrete.

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- The porosity of SCC is significantly lower in the transition zone between the cement paste and the aggregate and the distribution of pores is much more uniform.
  - The higher content of very fine pores and the use of additives – the characteristic of the SCC composition is the high portion of fine particles under 0.25 mm, the utilization of efficient superplasticizers and in the case of need also stabilizing agents.
  - The admixtures and additives necessary for SCC are in the case of common concrete used rather rarely, - or in much lower doses.

Self-compacting concrete with a similar water cement or cement binder ratio will usually have a slightly higher strength compared with traditional vibrated concrete, due to the lack of vibration giving an improved interface between the aggregate and hardened paste. **European Project Group(2005)** and **Tviksta (2000)**, reported that if limestone powder is used, higher compressive strengths are noticeable at the beginning of hardening process. **Najim and Hall(2012)** studied the correlation between unconfined compressive strength and both type and amount of rubber aggregate replacement as shown in **Figure 2-9**. The deterioration in compressive strength is similar to that indicated for plain Rubberised Concrete (PRC) (**Najim and Hall 2010**), which can logically be attributed to (i) the low modulus of elasticity (E) for rubber particles and high Poisson ratio ( $\nu$ ) which may encourage premature cracking under load, (ii) increased porosity due to air entrainment from rubber particles (**Garros et al., 2006;Topçu and Bilir, 2009;Bignozzi and Sandrolini, 2006**) and (iii) weak bonding in the interfacial transition zone between the cement paste and rubber particles which could be due to crack initiation from the voids that form between crumb rubber particles and cement paste, as observed by (**Emiroglu et al, 2007**). Therefore, under compression loading the aggregates can be susceptible to pullout resulting in particle perimeter voids and crack

initiation sites. The FCR replacement offered the best results, whereas in FR replacement the reduction in mortar phase (and hence cohesion) reduced homogeneity and so had the biggest influence on strength reduction. All of the concrete mixtures met/exceeded the minimum strength for structural concrete, i.e.  $f_c > 17$  MPa (Neville, 2011), and mixtures with 610 wt% crumb rubber replacement meets the target of 28– 35 MPa compressive strength that is required for civil infrastructure applications (Zheng et al., 2008).



**Figure 2-9** Effect of rubber content on the compressive strength (Najim and Hall,2010)

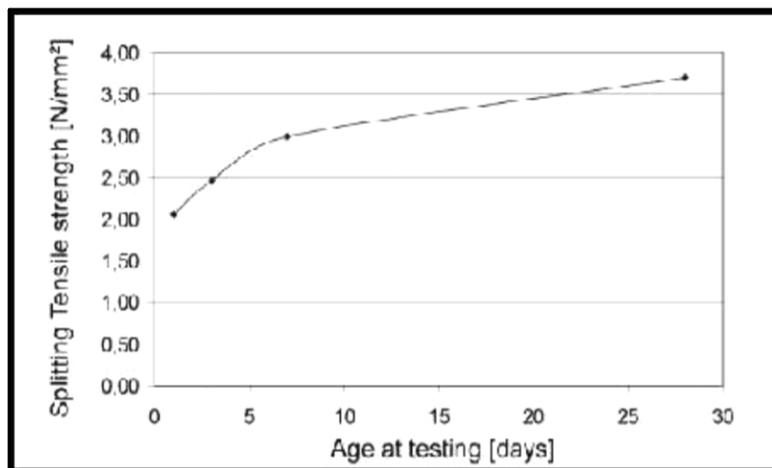
### 2.6.2 Splitting Strength

Tensile strength was assessed indirectly by the splitting test on cylinders or cubes. The splitting tensile strength of concrete have a close relationship with compressive strength. However the ratio of the two strengths depends on the general level of the strength of concrete. In other words, as the compressive strength increases, the tensile strength also increases but at a decreasing rate (Neville, 2011). For SCC, both the tensile strengths themselves, and the relationships between tensile and compressive strengths were of a similar order to those of traditional vibrated concrete (Tviksta, 2000). Holschemacher and Klug (2002) concluded from using a

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self-compacting concrete with different types of filler such as fly ash, silica fume, limestone powder, quartzite filler and blast furnace slag, that all parameters which influence the characteristics of the microstructure of the cement matrix and of the interfacial transition zone (ITZ) are of decisive importance in respect of the tensile load capacity behavior. They reported that most results of the measured splitting tensile strength values are in the range of valid regulations for normal vibrated concrete with the same compressive strength. However, in about 30% of all measured data points a higher splitting tensile strength is recorded. The reason for this fact is given by the best microstructure, especially the smaller total porosity and more even pore size distribution within the interfacial transition zone of SCC. Also, the self-compacting concrete can be obtained in such a way, by adding chemical admixtures and additions, so that its splitting tensile and compressive strengths are higher than those of normal vibrated concrete (**Cristian, 2003**). An average increase in compressive strength of 60% has been obtained for SCC, whereas 30% was the increase in splitting tensile strength. In addition, the SCC tensile strengths after 7 days were almost as high as those obtained after 28 days for normal concrete. Also, due to the use of chemical admixtures and additions, self-compacting concrete has shown smaller interface microcracks than normal concrete, fact which led to a better bonding between aggregate and cement paste and to an increase in splitting tensile and compressive strengths. A measure of the better bonding was the greater percentage of the fractured aggregate in SCC (20-25%) compared to the 10% for normal concrete. Some aspects regarding the tensile strength of self-compacting concrete were studied by **Druta (2003)**. He showed that the use of chemical and mineral admixtures in SCC can improve the bonding between the aggregate and cement paste, thus increasing splitting tensile strength of concrete. A measure of the better bonding was the greater percentage of the fractured aggregate in SCC (20-25%) compared to the 10%

for normal concrete. Whereas (EFNARC, 2005) stated that the tensile strength may be safely assumed to be the same as the one for a normal concrete as the volume of paste (cement+finer+water) has no significant effect on tensile strength. (Dehn et al., 2000) showed the time development of splitting tensile strength for SCC as in **Figure 2-10**.



**Figure 2-10** Time development of the splitting tensile strength (Dehn et al, 2000)

### 2.6.3 Flexural Strength

Flexural test estimated according to (ASTM C78, 2003). The specimen was a beam 100x100x400 mm. The beams were cured in the standard manner and are then tested in flexure in two-point loading. Klug and Holschemacher (2003) stated that the flexural and tensile strengths of SCC were typically improved relative to normally placed concrete due to the improved microstructure of the paste particularly the improved interfacial transition zone and the denser bulk paste. The modulus of rupture was an important property in the calculation of the cracking moment of concrete and thus determining how a concrete member will behave post-cracking (Myers et al., 2012).

The most important way to estimate the tensile strength of concrete is by the flexural test, the specimen is a beam (100x100x400) mm. The beams are cured in the standard manner and are then tested in flexure in two-point loading. Flexural strength is often related to compressive strength. The interfacial transition zone characteristics tend to affect flexural strength to a greater degree than compressive strength (**Mehta, 1973**). When normal concrete is vibrated, water will tend to migrate to the surface of the coarser particles causing porous and weak interfacial zones to develop. The most effective way of improving the ITZ is by the adding chemical admixtures and additions. Since chemical admixtures and additions are essential components for SCC, it is expected to have higher flexural strength than normal concrete. The flexural and tensile strengths of SCC are typically improved relative to conventionally placed concrete due to the improved microstructure of the paste particularly the improved interfacial transition zone and the denser bulk paste (**Turcry et al., 2002**). **Klug and Holschemacher(2003)** found that the flexural strength was slightly higher for SCC than a conventional mixture of comparable compressive strength. According to **European Project Group (2005)** the SCC should exhibit similar tensile strength as conventionally place.

#### **2.6.4 Drying Shrinkage**

Shrinkage strain of concrete at short terms is the sum of the autogenous and the drying shrinkage. Autogenous shrinkage occurs during setting and is caused by the internal consumption of water during hydration. The volume of the hydration products is less than the original volume of un-hydrated cement and water and this reduction in volume causes tensile stresses and results in autogenous shrinkage. Drying shrinkage is caused by the loss of water from the concrete to the atmosphere. Generally, this loss of

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water is from the cement paste, but with a few types of aggregate, the main loss of water is from the aggregate. Drying shrinkage is relatively slow and the stresses it induces are partially balanced by tension creep relief. The aggregate restrains the shrinkage deformations of the cement paste and so the higher the volume of the aggregate and the higher the E-value of the aggregate, the lower the drying shrinkage. A decrease in the maximum aggregate size which results in a higher paste volume increases the drying shrinkage. The values and formulae given in the Eurocode for normal concrete are still valid in the case of SCC.

As concrete compressive strength is related to the water cement ratio, in SCC with a low water/cement ratio, the drying shrinkage reduces and the autogenous shrinkage can exceed it. Tests performed on creep and shrinkage of different types of SCC and a reference concrete (**Bressette, 1984**) show that

- The deformation caused by shrinkage may be higher
- The deformation caused by creep may be lower
- The value for the sum of the deformations due to shrinkage and creep are almost similar

Due to the restraint of the presence of reinforcement in a cross section, the shrinkage strain can cause tension in concrete and compression in the reinforcement (**EFNARS, 2005**). Shrinkage is also another important property of hardened concrete. Most of the cracks in concrete are formed due to shrinkage. Shrinkage in concrete may be classified as Plastic Shrinkage, drying shrinkage, carbonation Shrinkage etc. **Uygunoglu and Topçu (2010)** prepared SCC by replacing sand with different scrap rubber (1-4 mm) ratios 0%, 10%, 20%, 30%, 40% and 50% (by weight of sand) with various water/powder ratio. They conclude that shrinkage improved with an increase in rubber aggregate content in SCC. He reported the maximum shrinkage can be obtained with maximum w/p ratio whereas the lowest shrinkage can be

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achieved in SCRC with the minimum w/p ratio. **Wang Her Yung et al.(2013)** concluded that the shrinkage of SCC would become higher as more waste tyre rubber powder is added.

### 2.6.5 Ultrasonic Pulse Velocity Test (UPV)

The ultrasonic pulse velocity is defined as the traversed distance of the pulse or sonic wave per unit transit time. This is obtained from the path length (length of the interposed concrete specimen) and transit time. The ultrasonic pulse velocity of concrete is mainly influenced by the mixture composition of concrete, moisture and age of concrete, curing conditions, and temperature. Generally, a high ultrasonic pulse velocity through concrete indicates that the concrete is of good quality. An ultrasonic pulse velocity above 4.575 km/sec states the ‘excellent’ quality of concrete whereas an ultrasonic pulse velocity below 2.135 km/sec reveals the ‘very poor’ condition of concrete. Ultrasonic pulse velocity can be used to evaluate the physical quality of concrete. It is also useful to detect the cracks and flaws, and to study the freeze-thaw durability of concrete. The ultrasonic pulse velocity in high strength concrete (HSC) is expected to be much higher than that of ordinary concrete. This is due to the refined pore structure and dense microstructure of HSC (**Shetty, 2001**).

### 2.7 Durability of Concrete

Durability of concrete plays a critical role in controlling its serviceability. Furthermore, durability of concrete is mainly dependent on the capacity of a fluid to penetrate the concrete’s microstructure, which was called permeability. High permeability concrete leads to the introduction of molecules that react and destroy its chemical stability (**Mehta and Monteiro, 2006**). Moreover, low permeability concrete can improve the resistance to the penetration of water, sulphate ions, chloride ions, and other

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harmful substances which caused chemical attack (**Alhozaimy, 1996**). Concrete permeability have a close relationship with the characteristics of its pore structure in the cement paste and the intensity of microcracks at the aggregate-cement paste interface as well as within the paste itself ( **Schutter and Audenaert, 2004**). Hence, pore structure mainly involved volume and size of the interconnected capillary pores. As it is known, the hydration reaction of cement results in a product consisting of solid and pore systems. The pore network of a cement paste matrix provides passage for the transport of fluid into concrete. The pore voids development depends on a number of factors including the properties and composition of the concrete constituent materials, the initial curing condition and its duration, the age at testing, and the climatic exposure during drying and conditioning of the concrete (**Ramli and Tabassi, 2012; Shafiq and Cabrera, 2004**). The temperature of curing and the duration of moist curing are the key factors for proper pore structure. The effectiveness of initial curing becomes more important when mineral admixtures like fly ash are used as partial substitution for cement in concrete. Numerous researcher have reported that mineral admixtures require a relatively long curing period for the favourable pozzolanic effect on the performance and penetrability of concrete to be realized (**Hassan et al., 1997; Tasdemir, 2003**).

### **2.7.1 Water Absorption**

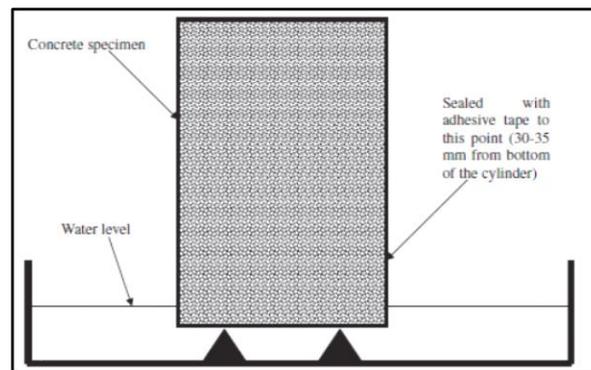
Absorption is a process by which a liquid gets into and tends to fill the open pores in a porous solid body such as a component of concrete (**ASTM C125: 2004**). The absorption is generally more significant in surface layer than the core of concrete due to strong capillary action. The rate at which a dry concrete surface absorbs a liquid can be taken as a predictor of the durability of concrete. Water is the most common liquid with which the concrete comes in contact. Hence, water absorption is widely used to indicate

the absorptivity of concrete. It can be determined based on the increase in mass of a concrete specimen due to the penetration of water into its open pores. Water absorption is directly related to concrete's resistance to water penetration, which plays an important role in various deterioration mechanisms and carries many deleterious agents from the surroundings. Like other engineering properties, the water absorption of concrete is directly influenced by the porosity. The porosity controls the microstructure and thus the absorption of concrete, depending on the relative quantities of the pores of various types and sizes (**Hearn et al., 1997**). When the porosity decreases, the water absorption is also reduced. It was reported that high performance concrete (HPC) provides a water absorption in the range of 3 to 6% (**De Schutter et al., 2003; Vanwalleghem et al., 2003**).

**Siddique, 2013** showed that the water absorption is used to determine the amount of water absorbed under specified conditions which indicates the degree of porosity of a material. The water absorption test was conducted by completely immersing dried cube specimens in water at 25 °C for 96 hrs and noting the amount of water absorbed per unit initial mass in percentage. This gives percentage water absorbed. It was conducted at the age of 7 and 28 days after initial curing of 28 days. **Gupta et al. (2014)** proposes that the water absorption test was carried out according to **BS 1881-122:2011+A1:2020**. Three oven-dry specimens were placed for 24 hrs in water bath. The initial weight and final weight were recorded and the percentage of water absorption was determined as per the guidelines of the codes.

### 2.7.2 Surface Absorption

Surface Absorption is an index of moisture transport into unsaturated specimens, and recently it has been recognized as an important index of concrete durability (**Dias, 2000**). During Surface process, the driving force for water ingress into concrete is capillary suction within the pore spaces of concrete, and not a pressure head (**Hall, 1989**) as shown in **Figure 2-11**.

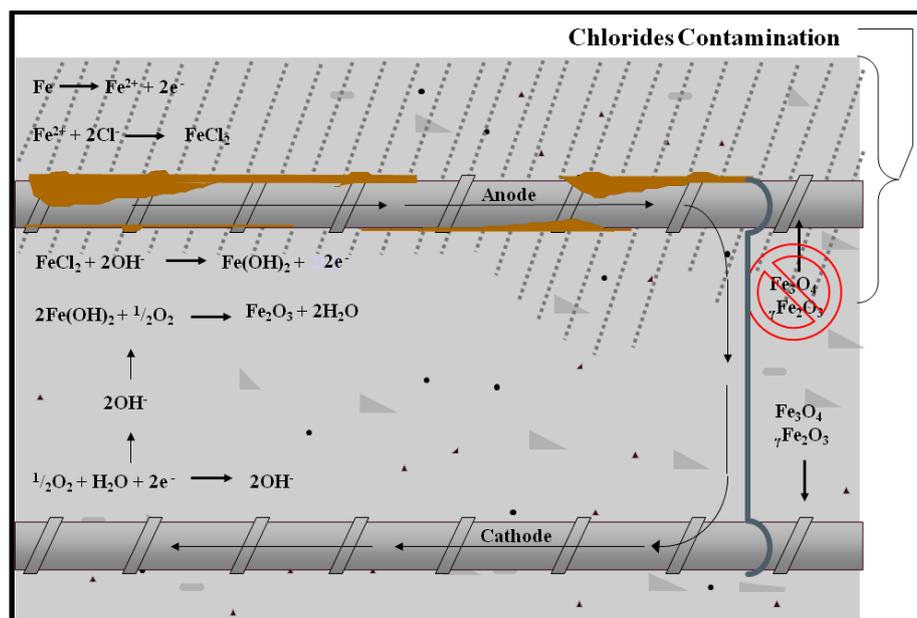


**Figure 2-11** Schematic diagram of Surface Absorption

A detailed characterization of the pore structure of the concrete can be analysed by many kinds of techniques, but the advanced methods are cumbersome and are neither available nor useful for daily concrete practice (**Schutter and Audenaert, 2004**). Surface Absorption is also more representative of typical field conditions. Some experts have suggested that the method can also be used to measure the total pore volume of capillary and gel pores in the concrete (**Mohr, 2004**). The Surface Absorption coefficient is essential to predict the service life of concrete as a structural material and to improve its performance (**Martys and Ferraris, 1997**).

### 2.7.3 Chloride Penetration and Concentration

Chloride ions ( $\text{Cl}^-$ ) can diffuse through liquid phases in the concrete and maybe reach the steel surface that can disrupt the passive layer and induce corrosion, even in a high-pH environment. Chloride ions maybe react with iron compounds in the passive layer to create an iron-chloride complex ( $\text{FeCl}_2$ ). The iron-chloride subsequently reacts with hydroxide ions within the surrounding concrete to form ferrous hydroxide ( $\text{Fe}(\text{OH})_2$ ). This process is shown schematically in **Figure 2-12**. Then the available iron hydroxide continues the development of corrosion products and the chloride is released to further react with the passive layer (**Zivica, 2003**).



**Figure 2-12** Chlorides Reinforced Steel Corrosion (**Timbara and Tufino 2008**)

Chlorides can come from several sources. They can be cast into the concrete or they can diffuse in from the outside. Chlorides cast into concrete can be due to:

1. Deliberate addition of chloride set accelerators (calcium chloride,  $\text{CaCl}_2$ , was widely used until the mid-1970s);
2. Use of sea water in the mix;
3. Contaminated aggregates (usually sea dredged aggregates which were unwashed or inadequately washed).

Chlorides can diffuse into concrete as a result of:

- Sea salt spray and direct sea water wetting;
- Deicing salts;
- Use to chemicals (structure used for salt storage, brine tanks, aquaria, etc.) (**John, 1997**).

#### 2.7.4 Sulfate Attack

Most of the aggregates used in Iraq for concrete are sea deposits which have become contaminated with sulphates due to the tropical dry climate. These sulphates are the source of the problem of internal sulphate attack in concrete (**Al-Harbi et al., 1993**). Concrete maybe crack due to internal expansion resulting from sulfate attack. This type of deterioration is the result of two chemical reactions: the combination of sulfates with lime to form gypsum, and the combination of sulfates with hydrated calcium aluminates to form ettringite (**Lea, 1971**). The final reaction product occupies a larger volume than the original constituents. It is also postulated that crystallization of sulfate salts generates stresses that can cause disruption. To protect against sulfate attack, cements with low tricalcium aluminate ( $\text{C}_3\text{A}$ ) content, pozzolanic materials that react with lime and low permeability concretes can be used (**ACI 201, 1994**). **Khatib and Wild (1998)** showed that in sodium sulphate solution metakaolin had greatly

reduced the damage caused by sulphate attack, and the expansion due sulfate attack was reducing with increasing of percentages of MK replacements. **AL-Robayi (2005)** studied the resistance of high performance concrete (HPC) to external and internal sulfate attack. He found that high performance concrete exposed to  $MgSO_4$  and  $Na_2SO_4$  solutions (external sulfate attack) showed lower strength at all ages with respect to the mix that carried in water. High performance concrete exposed to external attack began to lose strength in age ranged between (60-90) days. Meanwhile, the reduction in strength for HPC exposed to internal sulfate attack was obvious as early as 7-days age. In internal sulfate attack, there was a reduction in strength at early ages (less than 28 days) for normal and high performance concrete. The reduction was positively correlated to the  $SO_3$  presented in sand. At later ages (more than 28 days) in HPC, the reduction in strength decreased while in normal concrete it increased continuously. The low permeability and pozzolanic action of high reactive metakaolin (HRM) could be the cause of strength improvement. **Hussain (2008)** studied the effect of sulfate in fine aggregates on some mechanical properties of SCC, he found that there was an optimum gypsum content at which the compressive strength is maximum beyond which content the compressive strength decreases. The optimum gypsum content for these mixes is about (0.5% by weight of fine aggregate), note that sulfate ratio used in his research were 0.16%, 0.5%, 1.0%, 1.5% by weight of fine aggregate, he found also there was a reduction in strength at age (90 days) for self-compacting concrete while at later ages (180 days) the reduction in strength decreases. The reduction is positively correlated with the increase in  $SO_3$  present in fine aggregates. **Hadi (2009)** studied the effect of sulfates in groundwater on some mechanical properties of self-compacting concrete. He found that SCC mixes exposed to  $(Cl^- \& SO_4^{2-})$  solution showed a considerable reduction in compressive strength, splitting tensile strength, static modulus of elasticity and UPV as compared with the mixtures cured in

tap water. While, **Collepari (2003)** reported a slight reduction in compressive strength of specimens exposed ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) solution to at 180 days was due to attack of sulfate ions which gave rise to the formation of expansive compounds such as ettringite and calcium aluminate hydrate. The strength deterioration was also due to leaching out of salts deposited in the voids of concrete. **Mahmoud(2012)** studied the effect of sulfate on the properties of self-compacting concrete reinforced by steel fiber. He found that the optimum  $\text{SO}_3$  content, at which a higher mechanical properties and little tendency to the expanding were obtained, was at  $\text{SO}_3$  equal to 5 (% by weight of cement), note that sulfate ratios in concrete which used in his study were (3.9, 5, 6, 7, and 8%) by weight of cement. Further increasing in sulfates content in concrete after this optimum value showed a considerable reduction in mechanical properties, compressive strength, splitting tensile strength, flexural strength, static modulus of elasticity, and UPV, splitting tensile strength was more sensitive to sulfate attack than the other mechanical properties.

## 2.8 Chloride Impact on Reinforced Concrete

The passivity provided by the alkaline conditions can also be destroyed by the presence of chloride ions, even though a high level of alkalinity remains in the concrete. The chloride ion can locally depassivate the metal and promote active metal dissolution (**Bertolini et al., 2004**). Chloride reacts with the calcium aluminates ( $\text{C}_3\text{A}$ ) and calcium aluminoferrite ( $\text{C}_4\text{AF}$ ) in the concrete to form insoluble calcium chloroaluminates and calcium chloroferrites in which the chloride is bond in non-active form; however, the reaction is never complete and some active soluble chloride always remains in equilibrium in the aqueous phase in the concrete. At the low concentration levels of chloride in the aqueous phase,

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the rate of corrosion is very small, but higher concentration increases the risks of corrosion (**Persson, 2000**). Thus, the amount of chloride in the concrete and, in turn, the amount of free chloride in the aqueous phase (which is partly a function of cement content and of the cement type) will influence the risk of corrosion. While, the concrete remains in uncarbonated state the level of free chloride in the aqueous phase remains low (perhaps 10% of the total Cl). However, the influence of severe carbonation is to break down the hydrated cement phase and, in the case of chloroaluminates, the effect is to release chloride. Thus more free chloride is available in carbonated concrete than in uncarbonated materials (**AL-Ameeri et al., 2021; ACI Committee 201 2R-92**).

Intrusion of chloride ions ( $\text{Cl}^-$ ) in reinforced concrete can cause corrosion if oxygen and moisture are present and that giving low electrical resistance in the concrete and easy transport of ions so the anodes and cathodes can separate easily (**John, 1997**) (there is no corrosion in dry concrete even in high concentration of  $\text{Cl}^-$ ) (**James and Arnie, 2001; ACI Committee 222 R -96**). According to the European standard EN 206, the maximum allowed chloride contents are 0.2 - 0.4% chloride ions by mass of binder for reinforced concrete and 0.1 - 0.2% for prestressed concrete (**John, 1997**). The level of chloride ions required to initiate corrosion in concrete corresponds to 0.1% soluble chloride ion by weight of cement. This is equivalent to between 0.6 -0.8 kg of chloride per  $\text{m}^3$  of concrete (**Bavarian, 2002**). According to the ACI **Table 2.3** shows, the chloride limits for new construction (**ACI Committee 222 R -96**) and **Table 2.4** shows chloride concentration in reinforced concrete and classification degree of corrosion (**California Department of Transportation, 2003**).

**Table 2.3** Chloride limits for new construction (ACI Committee 222 R - 96)

Category	Chloride limit for new construction as a percentage of concrete mass	
	Acid –soluble ASTM C1152	Water –soluble ASTM C1218
Restressed concrete	0.08	0.06
Reinforced concrete in wet condition	0.10	0.08
Reinforced concrete in dry condition	0.20	0.15

**Table 2.4** Chloride concentration in reinforced concrete (California Department of Transportation, 2003)

Cl <sup>-</sup> concentration kg/m <sup>3</sup>	Cl <sup>-</sup> concentration lb/yd <sup>3</sup>	Assumed condition
0 to 0.7	0 to 1.2	Passive (non- corroding )
0.9 to 1.8	1.2 to 3.0	Corrosion initiation
> 1.8	>3.0	Active corrosion

There is a ‘chloride threshold ‘ for corrosion given in terms of the chloride /hydroxyl ratio. When the chloride concentration exceeds 0.6 of the hydroxyl concentration, corrosion is observed. This approximates to a concentration of 0.4% chloride by weight of cement cast into concrete (Persson, 2000; John, 1997).

## 2.9 Conclude Remarks

From the foregoing studies have been reviewed of this chapter, the following principles were concluded:

- 1-Self-compacting concrete (SCC) has been dubbed "concrete construction's most significant invention in decades." Even in the presence of dense reinforcing bars, SCC may flow under its own weight without compaction or vibration, completely filling the molds and achieving complete compaction.
- 2-Rubberised Concrete is a new structural materials using recycled tyres rubber as partial replacement by aggregates (fine and coarse aggregates) or by Portland cement concrete. Rubber in concrete can be viewed as a beneficial step toward the development of long-lasting concrete.
- 3-Rubber waste is a highly durable material and it is highly resistant to most natural environments. As a result, disposal of used tyres is a major concern as inappropriate disposal can lead to significant environmental and unaesthetic problems. According to General Company of Rubber Manufacturer's /Iraq, about 2 million waste tyres are stockpiled at whole Iraq Crumb rubber from waste tyres has been used to replace aggregates in concrete either in part or in full or to modify bituminous composites.
- 4-The vast quantity of non-recyclable waste inhabits a large space and reasons environmental risks. When a tyre is burned or used as fuel, poisonous gases are produced which have a negative environmental impact and can cause harsh pollutions of atmosphere air.
- 5-The Effect rubber Replacement on Mechanical Properties of Self-Compacting Concrete:

**a- rheological properties of fresh concrete (SCRC)**

The rheological properties of fresh concrete (V-funnel and T500) tests amplified with the increasing rubber tyre content in mixes of SCRC and the (slump flow, sieve segregation, L-box) tests decrease with increasing replacement of rubber percentage.

**b- Mechanical Properties of Self-Compacting Rubberised Concrete**

Mechanical characteristics which including compressive , flexural strength ,splitting strength , ultrasonic pulse velocity, Schmidt Hammer and drying shrinkage in self- compacting Rubberised concrete are considerably lower due to weakness of rubber particles, modulus of elasticity and bonding with cement paste.

**c-** As for the durability of Rubberised concrete, there are some studies which investigate the parameters that affect durability of concrete depending of case and type of concrete.

Finally, this study will focus on performance and impact of rubber tyre waste on fresh and hardening properties of self – compacting Rubberised concrete as well as the durability of this self- compacting concrete in order to cover the lack in an information of this type of concrete (SCRC) to be comprehensive study.

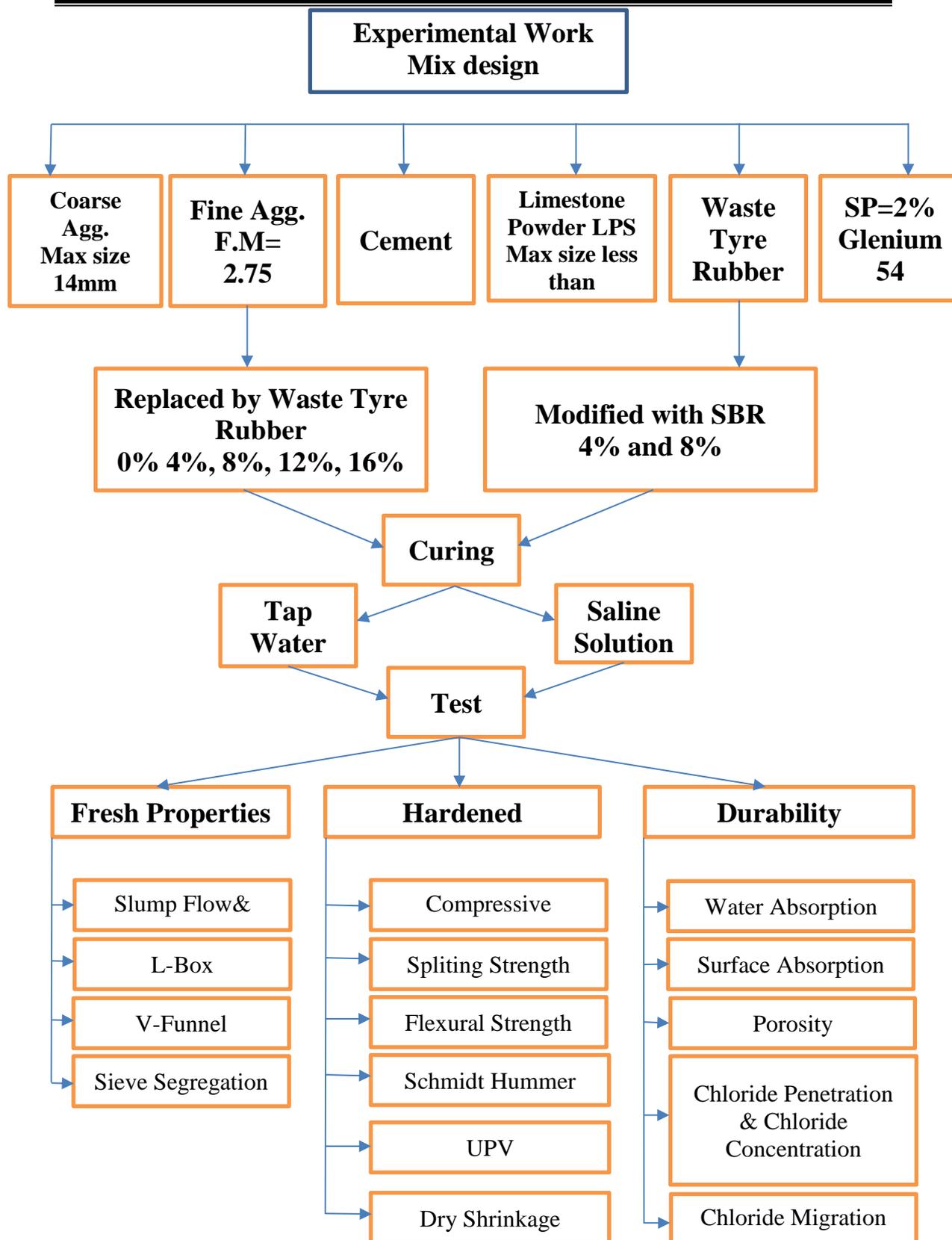
# **CHAPTER THREE**

## CHAPTER THREE

### Methodology and Experimental Programmer

#### 3.1 Introduction

In this chapter, the details of the experimental programmer of the study are presented. Those include the materials used, mixture proportions, specimens' preparation, and the tests carried out. **Figure 3-1** illustrates the details of experimental work of this research. The practical aspect involves the production of self-compacting concrete (SCC) by replacing rubber tyre particles by fine aggregate replacing with different percentages. On the other hand, the styrene butadiene rubber (SBR) was used to modify the properties of rubber particles bonding in SCC. The fresh, mechanical and durable properties were conducted to investigate the effect of rubber on properties of SCC.



**Figure 3-1** Schematic diagram for experimental work of the work

## 3.2 Materials

### 3.2.1 Portland Cement

As shown in **Figure 3-2**, Portland limestone cement, CEM II/A-L grade 42.5R made in Iraq by Lafarge Company commercially called (**KARASTA**) was used to cast all the specimens in this study. Its chemical composition and physical properties are given in **Table 3.1**. It was consistent with Iraqi Code Specification **IQS 5:2019** and **BS EN 197- 1: 2011**.



**Figure 3-2** Cement used in mixtures of study

**Table 3.1** Chemical, physical properties and main compounds of cement used

<b>Composition</b>	<b>Test result</b>	<b>Limits of (BS EN 197-1:2011).</b>
SiO <sub>2</sub>	20.58	-
Al <sub>2</sub> O <sub>3</sub>	5.60	-
Fe <sub>2</sub> O <sub>3</sub>	3.29	-
CaO	62.77	-
MgO	1.94	5.0% (Max)
SO <sub>3</sub>	2.35	2.8 (Max)
Loss on Ignition	1.94	5% (Max)
Insoluble Residue	1.21	1.5% (Max)
LSF	0.91	--
C <sub>3</sub> S	50.14	--
C <sub>2</sub> S	19.05	--
C <sub>3</sub> A	3.25	≤ 3.5
C <sub>4</sub> AF	10.11	--
Compressive strength at 2day ( MPa )	23.2	≥ 20 MPa
28 day ( MPa)	47.9	≥ 42.5 MPa
Setting time (min)		
Initial	143	≥ 45 min
Final	191	---

Chemical tests were conducted in The National Center for Construction Laboratories and Research University in Babylon.

### 3.2.2 Fine Aggregate

There are important factors that should be taken into consideration when producing SCC, which are (the amount of fine aggregate, grading and the shape of the particle). In this study, natural sand available locally from in the Al-Akhaider area was used. The gradation, physical and chemical properties of fine aggregate used are shown in **Table 3.2** and **Figure 3.3**. Through the results, it was found that the fine aggregate is located within the third gradient zone and conforms to the Iraqi standards **IQS 45:1984** and **BS EN 12620:2002+A1:2008**.



**Figure 3-3** Fine aggregate used

**Table 3.2** Sieve analysis some properties of fine aggregate

Sieve size [mm]	Percentage passed %	Limits of Reference standard BS EN 12620:2002+A1:2008
4.75	100	90-100
2.36	87	75-100
1.18	78	55-90
0.60	41	35-59
0.30	15	8-30
0.15	3.7	0-10
Physical & Chemical properties	Test Result	Limits of Reference standard BS EN 12620:2002+A1:2008
fineness modulus	2.75	-
SO <sub>3</sub> content %	0.303	≤0.5
Specific gravity	2.6	-
Water absorption %	2.5	-

\*Physical Tests and Sieve Analysis were conducted by the constructional materials laboratory in the University of Babylon.

### 3.2.3 Coarse Aggregate

The rounded and washed gravel from the Al-Nabai'i area with a single maximum size of 10 mm was employed in this study. The gradation and other properties of coarse aggregate are tabulated in **Table 3.3**, and **Figure 3-4**. Through the results of the examination, it was found that the

coarse aggregate conforms to the Iraqi standard specifications IQS 45:1984 and EN 12620:2002+A1:2008.

**Table 3.3** Sieve analysis some properties of coarse aggregate

Sieve size [mm]	Percentage passed%	Limits of Reference standard BS EN 12620:2002+A1:2008
14	100	100
10	95	85-100
5	22	0-25
2.36	1.5	0-5
Physical & Chemical properties	Test Result	Limits of Reference standard BS EN 12620:2002+A1:2008
SO <sub>3</sub> content %	0.0813	0.1
Specific gravity	2.6	-
Absorption	1.5	-

\*Physical Tests and Sieve Analysis were conducted by the constructional materials laboratory in the University of Babylon.



**Figure 3-4** Coarse aggregate used

### 3.2.4: Limestone Powder (LSP)

A white fine material was provided from grinding of natural limestone was used in the experimental work as shown in **Figure 3-5**. The limestone particle size should be less than 0.125 mm according to the European guidelines **EFNARC 2005 Table 3-4** and **3.5** show the chemical composition and Physical properties of limestone.

**Table 3.4** Chemical analysis of LSP

Oxide	Content %
CaO	60.01
Fe <sub>2</sub> O <sub>3</sub>	0.2
Al <sub>2</sub> O <sub>3</sub>	0.61
SiO <sub>2</sub>	1.22
MgO	0.32
SO <sub>3</sub>	0.1
L.O.I	3.65

**Table 3.5** Physical properties of LSP

Physical properties	LSP
Physical form Powder	Powder
Color	Color White
Surface area (Blaine Method), m <sup>2</sup> /kg	310
Sulfate content as SO <sub>3</sub> %	0.1
Specific gravity	2.7

\*Physical Tests were conducted by the constructional materials laboratory in the University of Babylon.



**Figure 3-5** Limestone dust used

### **3.2.5 Superplasticizer**

High range water reducing admixture was used in order to reduce the amount of water used in mix design and keep the fluidity of the concrete mixture and it should maintain the dispersing effect during the time required for transport and application. The (GLENIUM 54) superplasticizer was used in concrete mixture. It is produced by BASF Company as shown in **Figure 3-6** and the properties illustrated in **Table 3.6**. It meets the requirements for superplasticizer to **BS EN 934-2:2009+A1:2012**.

**Table 3.6** Typical properties of High Range water Reducing Admixture

Form	Viscous liquid
Commercial name	Glenium 54
Apparance	Whitish to straw- colored Viscous liquid
pH	5-8
Relative density	1.07 gm/cm <sup>3</sup> @20 °C
Chlocontentride	Nil
Storage	Should be stored in original containers and @ above 5 °C
Transport	Not classified as dangerous
Alkali content (as NaO <sub>2</sub> ) equivalent	0.26%

*\*According to manufacturer data*



**Figure 3-6** Superplasticizer used in study

### 3.2.6 Waste Tyres Rubber

Waste rubber tyre or crumb rubber aggregate (CRA) was used in the current study; it was obtained from the General Company for Rubber Industries and Tyres/ governorate of Al-Najaf al-Ashraf. The crumb rubber tyre has specific gravity of 1.13 and bulk density of 0.45 g/cm<sup>3</sup>. In this process, the result crumb tyres that looks like the sand by size 4.75 mm maximum and the shape as shown in **Figure 3-7**. The physical

characteristics, chemical composition and Sieves analysis are illustrated in **Table 3.7** and **3.8, 3.9** respectively.



**Figure 3-7** Tyre rubber as fine aggregate

**Table 3.7** Physical properties of the used rubber

<b>Properties</b>	<b>Results</b>
Specific gravity	1.13
Finesse modulus	3.12
Water absorption	0.61 %
Bulk Density	0.45 g/cm <sup>2</sup>

**Table 3.8** Chemical composition properties of the used rubber

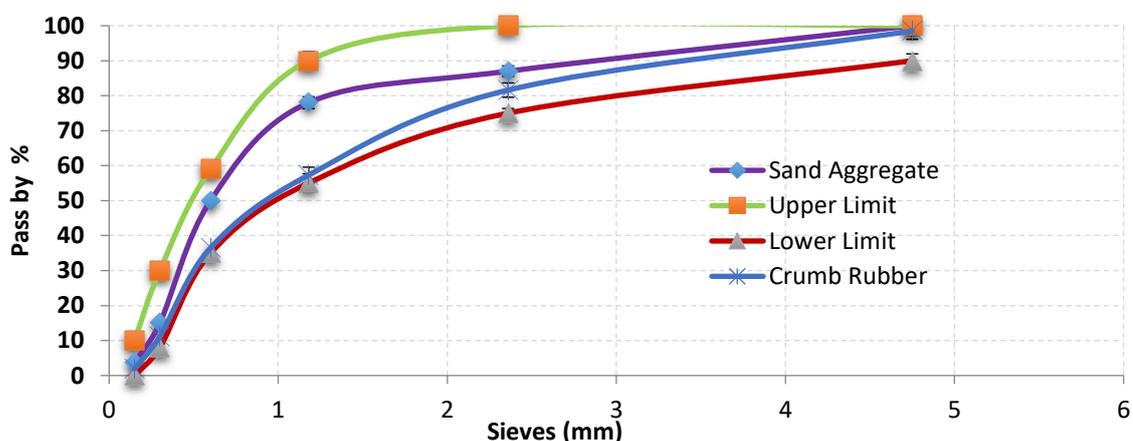
<b>Major rubber components</b>	<b>Results%</b>
Natural rubber content	31
Rubber hydrocarbon	25 - 35
Carbon black content	25 - 30
Melal content	0.03
Acetone extract	10 - 20
Ash content @550 °C	8

\*Physical and chemical analysis were conducted at General Company for Rubber Industries and Tiers/ Al-Najaf al-Ashraf .

**Table 3.9.** Sieve analysis of the crumb rubber used as (fine aggregate nature)

Sieve size [mm]	Percentage passed %
4.75	98.5
2.36	75.6
1.18	50.3
0.60	33.5
0.30	10
0.15	0.9

\*Physical Tests and Sieve Analysis were conducted by the constructional materials laboratory in the University of Babylon



**Figure 3.8** particle size distribution of the crumb rubber and sand aggregate

### 3.2.7 Styrene-Butadiene Rubber (SBR)

The families of SBR are derived from styrene and butadiene. This combined materials have a good abrasion resistance and good aging stability. **Figure 3-8** show the type of SBR used in study. It is produced by DCP Company, while, the properties of SBR presented in **Table 3.9**. SBR influences the properties of the rubber particles to harder than untreated particles.



**Figure 3-9** Type of SBR used in study

**Table 3.10** Technical Properties of SBR

Color	White
Specific gravity	Around 1.0
Slant Shear Strength ASTM C1042-99	$\geq 5.0$ Mpa
Tensile bond strength ASTM C932	$\geq 1200$ Kpa

\*According to DCP Company

### 3.2.8 Water

Tap water was used throughout this work for both making and curing the specimens.

### 3.3 Concrete Mixes

The main objective of this research is to study the effect of replacement of sand by rubber on the SCC properties, fresh and hardened. Five different mixes replacements of rubber percentage ranges, (0, 4%, 8%, 12% and 16%) by mass of sand were used to investigate effect on the rubber replacement on properties and durability of SCRC. These mixtures are listed in **Table 3-11. The EFNARC,2005 (EFNARC, 2005)** Guidelines for SCC method was employed for design these concrete mixtures. The sixth and seventh mixture were used to improve properties of rubber bonding and SCC by treating waste rubber by styrene butadiene rubber (SBR). The mixtures (M4% and M8% were modified by using the styrene butadiene rubber (SBR) to improve the values of the mechanical properties and durability.

0

Table 3.11 Concrete mixes proportion used

Mix	w/c	Mass per one meter cube of concrete (kg / m <sup>3</sup> )						
		Cement	Gravel	Sand	Water	Crumb rubber	Lime stone powder , LSP	SP
MC	0.36	475	800	800	170	0	125	9.5
M 4%	0.36	475	800	768	170	32	125	9.5
M 8%	0.36	475	800	736	170	64	125	9.5
M 12%	0.36	475	800	704	170	96	125	9.5
M 16%	0.36	475	800	672	170	128	125	9.5
M 1	0.36	475	800	768	170	32	125	9.5
M 2	0.36	475	800	736	170	64	125	9.5

### 3.4 Mixing, Placing and Curing Procedures

1. The coarse aggregate with fine aggregate were mixed for 1 minute in a drum mixer (capacity 250-300kg).
2. The cement, limestone were added and mixed for 1 minute.
3. Half amount of the required water , admixture and crumb rubber (Glenium 54) were gradually added to the mixture prepared previously and mixed for 1½ minutes
4. The amount of remaining water was added and mixed for 1 minute.
5. Finally, the self-compacting concrete mixture was discharged and tested for fresh properties and cast specimens as shown in **Figure 3-10**.



**Figure 3-10** Samples were cast

The mixing procedure was conducted according to the following steps transporting and curing of specimens were according to **BS EN 12390-2:2009**. The specimens were cast in (2) layers to get the homogenous concrete. The samples were de-moulded and treated using drinking water till the time of exam.

The placing process of the concrete mix is the most critical moment. For SCC mixtures which require no compaction work, the mixes being cast into the tight plastic molds until their fully filled without any compaction. All plastic molds were prepared for casting by placing oil along the interior surfaces of the mold in order to prevent adhesion with concrete after hardening. A (100 \* 100 \* 100) mm cube samples was employed to find the compressive strength of concrete and surface absorption. Prism concrete, (100 \* 100 \* 400) mm was used to determine the flexural strength. The splitting strength was measured by concrete cylinder of 100 mm dia with 200 mm height. Concrete prism of (100 x 100 x 200) mm was employed to determine the depth chloride penetration ( $x_d$ ). A 100 mm dia cylinder specimens with 50 mm height was also used to test the migration of chloride penetration. All specimens were demoulded after 24 hrs and 28 days initial curing in tap water was performed. After that, half of the specimens were submerged in a curing tank containing aggressive solution at concentrations identical to those existing in soil and groundwater of southern parts of Iraq. Firstly, one face of the sample was subjected to specific environmental condition (drying and wetting cycles two week used), while the other faces were covered by coating of water-proofing based. These specimens were addressed to the ions of chloride solution of (5% NaCl, 3% CaCl<sub>2</sub>.2H<sub>2</sub>O and Na<sub>2</sub>SO<sub>4</sub>) within a periodical of wetting and drying for 120 days in total. The specimen were tested in (56,90, and 120 day), while the other half of specimens were kept in tap water until the end of long-term curing (120 days) test the specimen in (7,28,56,90, and 120 days). **Figure 3-11** and **3-12** show the curing process done in this research.



**Figure 3-11** Specimens immersed in tap water



**Figure 3-12** Specimens submerged in aggressive solution

### 3.5 Preparation of Aggressive Solutions (Saline solution)

One of the major problems of concrete durability is the deterioration of concrete structures exposed to external attack of sulfate and chloride salts, especially those present in soil and groundwater in southern parts of Iraq. The results of groundwater analysis prepared by the National Center for Geological Survey cited by (Tawfiq, 1992) show that the chloride ion concentration ranges between (20000-40000) ppm, while the sulfate ion concentration lies between (5000-7000) ppm. cations concentration is (10000-20000) ppm for sodium, (1500-2000) and (1000-1500) ppm for calcium. In this investigation one types of sulfates ( $\text{Na}_2\text{SO}_4$ ) and two types of chlorides ( $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$  &  $\text{NaCl}$ ) are used. Potable water is used as a solvent for these salts. **Table 3.12** and **3.13** illustrate the types and concentrations of salts used in curing solution and the actual anions and cations provided by such salte.

**Table 3.12** Types and concentration of salts used in curing solution

Type of salt	Concentration		Salt content % by mass of water
	ppm	mg/l	
$\text{Na}_2\text{SO}_4$	20000	20	2
$\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$	30000	30	3
$\text{NaCl}$	50000	50	5

**Table 3.13** Types and concentration of ions used in curing solution

Anions		Cations	
Type	Concentration ppm	Type	Concentration ppm
$\text{Cl}^-$	37364	$\text{Ca}^{2+}$	8219
$\text{SO}_4^{2-}$	13521	$\text{Na}^+$	26306

## 3.6 Experimental Tests

### 3.6.1 Testing of Fresh Concrete

In this research, environmentally friendly self-compacting concrete by replacing rubber with sand was produced. This type of concrete can be called rubberised concrete (**Raffoul.et.at 2016**) and achieved the self-compacting concrete by fulfilling the fresh properties of this type of concrete such as flow ability, passing ability, viscosity, and segregation resistance (**EFNARC, 2005**). The rheological properties of fresh SCC are slump flow,  $T_{500}$ , L box, V- funnel, and Sieve segregation tests.

### 3.6.2 Slump Flow and $T_{500}$ mm Tests

The slump-flow test is the simplest and most widely used to assess the workability of concrete. It is a mix of the slump and flow diameter. In the absence of obstruction the slump flow. The value of (D) characterises the maximum spread of mixes of concrete that is called slump flow (SF) or final diameter. While, the time required to reach the concrete flow a circle with 500 mm diameter represents  $T_{500}$  test, it can be expressed in seconds to the nearest 1/10 seconds. The equipment used and the test technique is defined in the **BS EN 12350-Part 8:2019**. **Figure 3-13** shows the equipment and the slump flow of the fresh concrete mixture. The slump flow is the average of diameters  $D_1$  and  $D_2$  expressed to the nearest (10) mm as shown in *Equation (3-1)*.

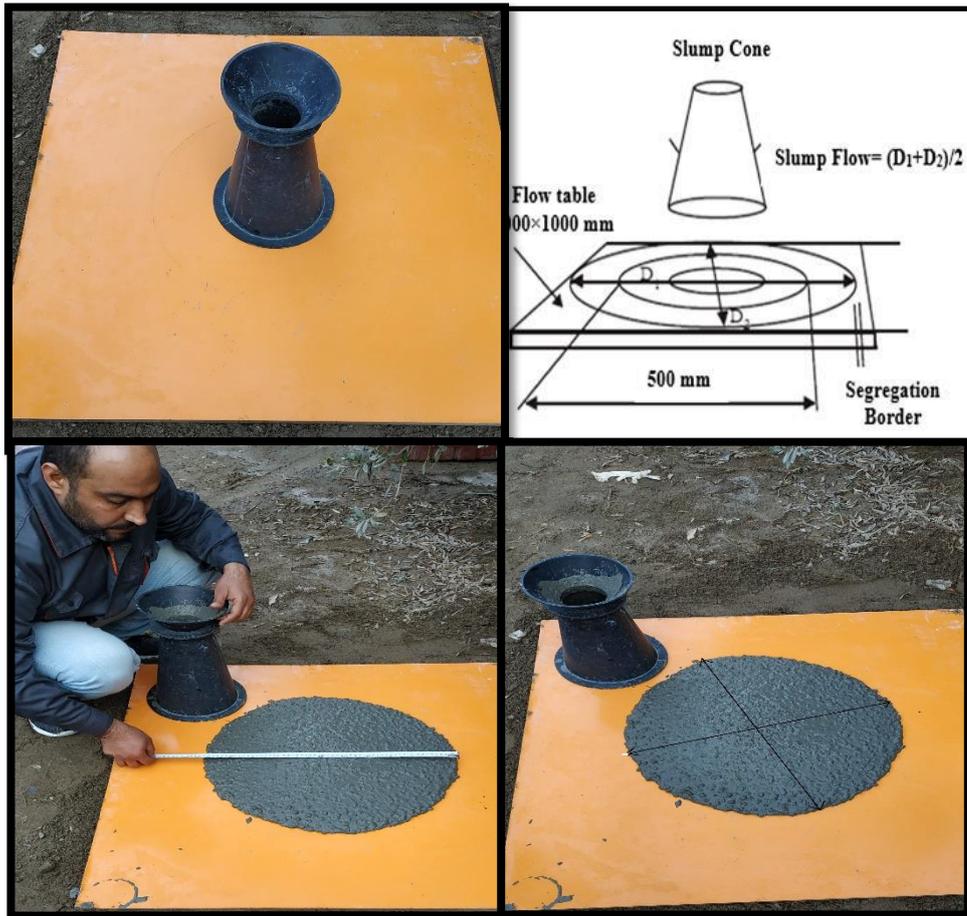
$$SF = \frac{D_1 + D_2}{2} \quad (3-1)$$

where :

SF = Slump Flow ,

$D_1$  = diameters in X axes.

$D_2$  = diameters in Y axes.

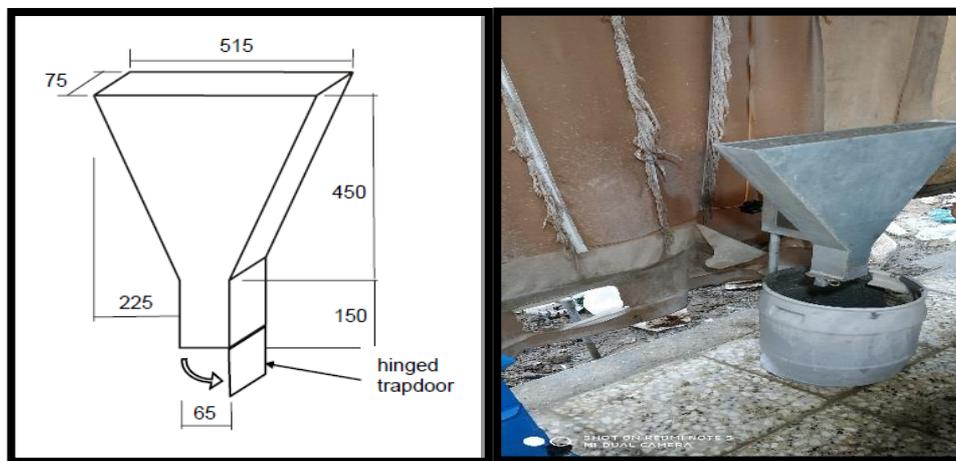


**Figure 3-13** Slump flow test

### 3.6.3 V-Funnel Test

The filling ability and viscosity of SCRC can be determined by the V-funnel test. This test is evaluated by measuring the time of empty mixture from V-funnel ( $T_v$ ). Whereas, the test procedure and the apparatus used are described in **BS EN 12350-Part 9:2019**. Also, this test can be used to judge the segregation resistance. The apparatus of the V-funnel test used in this study are shown in **Figure 3.14**. The test was conducted by placing the V funnel vertically on a flat, stable surface, with the top opening positioned horizontally. Using a wet sponge or towel, we moisturize the inside of the funnel and remove excess water by opening it. Noting that the inside of the funnel remains "wet." Then we close the gate and place a bucket under it to keep the concrete to be passed. Then the funnel is filled

with concrete from SCRC without applying any pressure or rodding. Any excess concrete is removed from the top of the funnel using a straight edge. After a waiting period of  $(10 \pm 2)$  seconds, we open the gate, and at the same time, the stopwatch starts. After that, we look inside the funnel and upon seeing visible areas we stop the watch. The stop watch reading is recorded as V-funnel streaming time, as shown in **Figure 3-14**. The V-funnel flow time is the period from releasing the gate until the first light enters the opening, expressed to the nearest (0.1) second.



**Figure 3-14** V-Funnel test

### 3.6.4 L-box Test

The L-box test is used to assess the passing ability of SCRC to flow through tight openings including spaces between reinforcing bars and other obstruction without segregation or blocking ratios ( $BR=H_2/H_1$ ). There are two variations; the two bar test and the three bar test. In this work, the three bar test was used. The used apparatus and test procedure are described in the **BS EN 12350-Part 10:2010**. The acceptance criteria of this test is  $(H_2/H_1) \geq 0.75$ . L-box equipment in this study are shown in **Figure 3.15**. Rule graduated from (0-30) cm in intervals of (1) mm. The container containing the sample and not less than (14) liters in volume. As with the

other tests, the test equipment was cleaned and in a just-moist state before the start of every test. First, the L-box was placed centrally in a stable and level position. Then, filled the vertical part of the L box with fresh SCRC. Let the concrete be placed in the vertical part for (1) minute. Concrete will be displayed during this time whether or not it is stable (Segregation). Second, we raise the sliding gate and allow the concrete to flow outward into the horizontal section. When concrete stops and concrete depth at the end of the horizontal section as  $H_2$  mm. The passing ratio (PR) or the blocking ratio (BR) is calculated by using the *Equation (3-2)* or (3-2') expressed in dimensionless to the nearest (0.01).

$$P_R = \frac{H_2}{H_1} \quad (3-2)$$

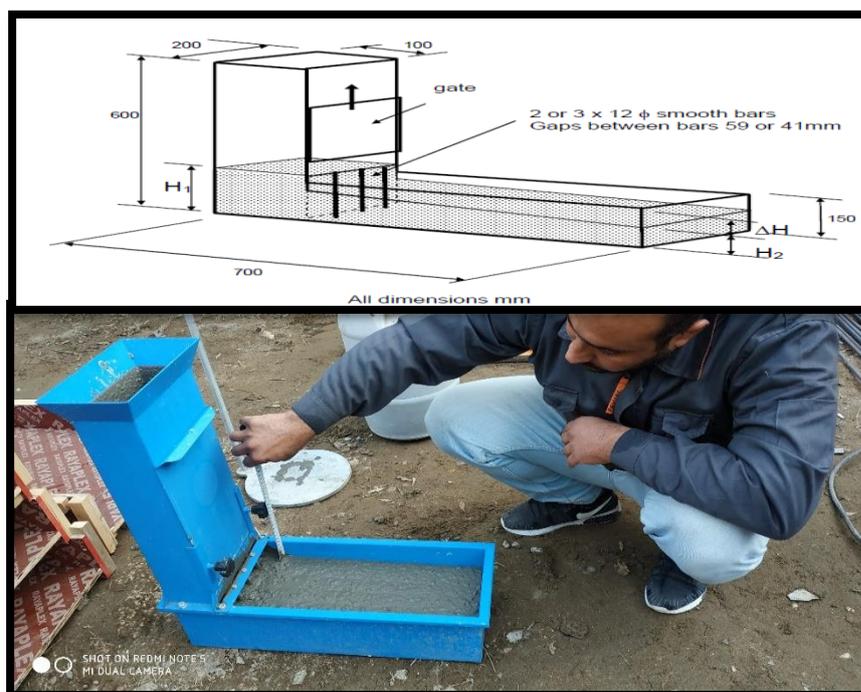
$$B_R = 1 - \frac{H_2}{H_1} \quad (3-2')$$

where:

$P_R$ = Passing Ratio ,  $B_R$ =Blocking Ratio

$H_1$ = concrete depth directly behind the gate cm.

$H_2$ = concrete depth at the end of the horizontal section



**Figure 3-15** L– Box Test

### 3.6.5 Sieve Segregation Test

This test is used to evaluate the resistance to segregation (stability), the equipment and the test protocol are defined in the **BS EN 12350-part 11:2010**. Segregation resistance is the ability of a fresh mix to maintain its original, adequately uniform distribution of constituent materials. A photograph of the test is shown in **Figure 3-16**. About 10 liters of concrete were poured into a bucket, covered to prevent moisture loss and left to settle for about 15 minutes to allow any internal segregation. Then a sample of  $4.8 \pm 0.2$  kg of the concrete was poured from a height of 500 mm onto 5 mm sieve with a diameter of 350 mm, ( $M_a$ ) and left for 2 minutes to allow any laitance or mortar to pass through and standing on a sieve pan with a weight scale. ( $M_b$ ). The segregation index was calculated as the percentage of the weight of laitance relative to the weight of the original sample on the sieve using the *Equation (3-3)*.

$$S_R = \frac{M_b}{M_a} * 100 \quad (3-3)$$

where:

$S_R$ : Segregation resistance.

$M_b$  : Mass of sample passing sieve.

$M_a$  : Mass of concrete poured onto sieve



**Figure 3-16 Sieve Segregation Test**

### 3.7 Tests of Hardened Self-Compacting Rubberised concrete

#### 3.7.1 Compressive Strength

At (7, 28, 56, 90 and 120 day) days, compressive strength test was carried out in accordance with **BS EN 12390-3:2009** using (100x100x100) mm cube. The test was conducted by using hydraulic compression machine (2000 kN capacity) with a loading rate of 18 MPa/minute as shown in **Figure 3-17**. The mean value and coefficient of variation of three specimens were taken. The compressive strength values are computed from this *Equation (3-4)*:

$$\sigma = \frac{P}{A} \quad (3-4)$$

where:

$\sigma$ : Compressive strength (MPa)

P: Applied force (N)

A: Area (mm<sup>2</sup>)



**Figure 3-17** Compressive strength test

### 3.7.2 Splitting Tensile Strength

This test was carried out according to **BS EN 12390-6:2009** [15]. Three cylinders specimens of 100 mm × 200 mm were cast and tested after 7, 28, 56, 90 and 120 days. The cylinder was placed horizontally between two plates of wood to distribute the loads of the compressive machine uniformly on the upper and lower sides of the cylinder and lower bearing blocks which were a (2000) kN hydraulic compression machine as shown in **Figure 3-18**. The average value and coefficient of variation of splitting tensile strength for the three cylinders is calculated from **Equation (3-5)**:

$$f_t = \frac{2p}{\pi l D} \quad (3-5)$$

Where:

$f_t$  : Splitting tensile strength, (MPa).

$p$  : Maximum applied load indicated by the testing machine, (N).

$d$  : Cylinder diameter, (mm).

$l$  : Cylinder length, (mm).



**Figure 3-18** Splitting tensile test

### 3.7.3 Flexural Strength Test

The flexural strength, expressed as the modulus of rupture, was calculated by using the results obtained from a simple beam with third-point loading test according to **BS EN 12390- Part 5:2009**. Test prisms measuring (100×100×400 mm) were used. A hydraulic compression machine of 1800 kN was used for the test as shown in **Figure 3.19**. The flexural strength is calculated as following *Equation (3-6)*:

$$f_r = \frac{PL}{bd^2} \quad (3-6)$$

where:

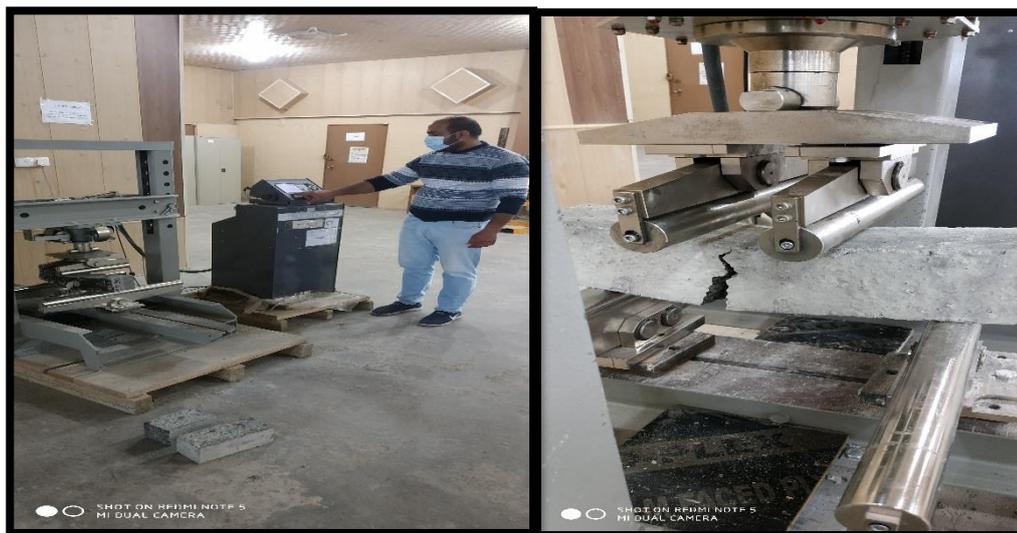
$f_r$  = modulus of rupture (MPa)

$P$  = failure load (N)

$L$  = span length between supports center to center (mm)

$b$  = width of prism cross section (mm)

$d$  = depth of prism cross section (mm)



**Figure 3-19** Flexural strength test

### 3.7.4 Ultrasonic pulse velocity test

The ultrasonic pulse velocity test (UPV) method is a non-destructive method, as the technique uses compressional waves resulting in no damage to the concrete element being tested. To determine the UPV, the same cubes specimens used to measure compressive strength were cast for each mix, and triplicate 100 mm x 100mm x 100 mm samples were tested after 3, 7, 28, 56, and 90 days of curing. The pulses are introduced into the concrete by a piezoelectric transducer and a similar transducer acts as a receiver to monitor the surface vibration caused by the arrival of the pulse. The nominal frequency of the transducers used for testing concrete cubes was 54 kHz, and the transmission time was measured at microseconds, with accuracy as high as 0.1  $\mu$ s. The test method for pulse velocity through concrete is described in **BS EN 12504-Part4:2004**, (*Equation: (3-7)*) as shown in **Figure 3.20**.

$$V = \frac{L}{T} \quad (3-7)$$

Where:

$V$ = pulse velocity, (m/s).

$L$  = distance between transducers, (m).

$T$  = effective transmit time, (s).



**Figure 3-20** Ultrasonic pulse velocity test

### 3.7.5 Schmidt Hammer Test

Schmidt hammer was used to estimate the surface hardness of concrete specimens by recording the rebound number, which could be used as a measure of the concrete strength and percentage of voids. The hammer readings were taken on concrete cubes while supported in compression testing machines under 20kN load. Angle of hammer axis was zero. This test was carried out according to **BS EN 12504-2:2012**. The test is illustrated as shown in **Figure 3-21**.



**Figure 3-21** Schmidt hammer test

### 3.7.6 Dry Shrinkage Test

This test method involves the measurement of length change, which permits assessment of the potential for volumetric expansion or shrinkage of concrete due to various causes other than applied force. According to **ASTM C 157/ C157M, 2004** and **ASTM C490, 2004**, prisms of (75×75×285) mm of concrete with a special pin extend 17.5 mm into the both ends of the specimens to facilitate length change measurement were used. The change in length is monitored by using comparator at designated test times as shown in **Figure 3-22**. Three specimens are prepared for each test condition. The change length is given by the following *Equation(3-8)*:

$$\Delta L_x = \frac{(L_x - L_i)}{G} \times 100 \quad (3-8)$$

Where:

$\Delta L_x$ : Change in length at x age

$L_x$  : Comparator reading of specimen at x age, (mm)

$L_i$  : Initial comparator reading of specimen, (mm)

G : Nominal gage length, (250mm)



**Figure 3-22** Dry shrinkage test

### **3.8 Durability of Self-Compacting Rubberised Concrete Tests**

#### **3.8.1 Water Absorption**

The water absorption test of the concrete specimens was conducted in accordance with **ASTM C642: 2013**, for establishing the permeable voids in hardened concrete and determine the increase in resistance towards moisture penetration in concrete. Three 100 mm cubic specimens at each mixture of SCC were prepared and tested at the ages of 7, 28, 56, 90 and 120 days after initial curing of 7 days and the average values were recorded. To perform this test, cube specimens were dried in an oven at  $105 \pm 5$  °C to constant weight ( $W_1$ ) as seen in **Figure 3-23**. Then, the specimens were then totally immersed in tap water and weighed after 24 hours to check the increase in mass, until the increase in mass was less than 0.5% of the heavier mass which defines the saturation stage. After the desired immersion period have passed, the specimens were taken out and surfaces were wiped with a wet cloth quickly then the saturated surface dry

(SSD) specimen was weighed ( $W_2$ ), immediately. At the result of this test, the total volume of penetrable pores was determined. The percentage of water absorption ( $W_A$ ), was calculated using the *Equation (3-9)* and averaged based on the results of three specimens.

$$W_A \% = \frac{(W_2 - W_1)}{W_1} * 100 \quad (3-9)$$

where:

$W_A$ : water absorption percentage

$W_1$  : mass of oven-dried sample in air, g.

$W_2$  : mass of surface -dry sample in the air after immersion, g.



**Figure 3-23** Water absorption test

### 3.8.2 Porosity

The total porosity of the different SCC mixes was evaluated in this study. Three cubes (100 mm x 100mm x 100mm) concrete samples were prepared for porosity testing. This method was used to measure the porosity in surface of concrete according to **ASTM C642: 2013**. As samples were tested at the ages of 7,28, 56,90 and 120 days after the initial curing in water for 7 days, for this test the sample was dried at 105

° C until the weight became constant ( $g_1$ ). After that, the dried samples were immersed in water for 24 hours. When the immersion period was completed, the samples were taken out, and the surfaces were wiped with a damp cloth. Then, the samples that were classified as a saturated dry surface are immediately weighed as ( $g_2$ ). Besides, the weight of the samples is recorded in water as ( $g_3$ ) as shown in **Figure 3-24**. The porosity of the concrete was calculated according to *Equation (3-10)*.

$$\text{Porosity \%} = \frac{g_2 - g_1}{g_2 - g_3} \quad (3-10)$$

where:

$g_1$  = mass of oven-dried sample in air.

$g_2$  = mass of surface –dry sample in the air after immersion.

$g_3$  = mass of sample in Water.



**Figure 3-24** Oven-Dried and Buoyancy Balance to Check the Porosity Test

### 3.8.3 Surface Absorption

The rate of surface absorption of self-compacted concrete was measured for the hardened state as presented in **ASTM C1585-2013**. The surface absorption of water conducted when the surface of specimen exposed to water. The surface absorption was indication for the durability condition of concrete by the capillary pore system of concrete when during initial contact with water. The standard test specimen is a 100 mm cubic each mixture of SCC was prepared and tested at the ages of 7, 28, 56,90 and 120 days. In this test method, only one surface is exposed to water at room temperature while the other surfaces are sealed simulating water absorption in a member that is in contact with water on one side only. The specimens were dried, in the environmental chamber used in this test, a chamber that allowed for air circulation and was able to maintain a temperature of 50 °C for 24 hrs. (W dry). Then after, the samples were immersed in water at 5mm depth for 24 hours and weight (W wet) as shown in **Figure 3-25**. The absorption (SA) was calculated using the **Equation (3-11)** and averaged based on the results of three specimens.

$$\text{surface absorption}(SA) = \frac{W_{wet} - W_{dry}}{\text{Area}} \quad (3-11)$$

Where:

W wet = mass of surface -dry sample in the air after immersion (5mm) in water, g

W dry = mass of oven-dried sample in air, g

SA = the surface absorption g/cm<sup>2</sup>



**Figure 3-25** Surface absorption test

### 3.8.4 Penetration of Chloride

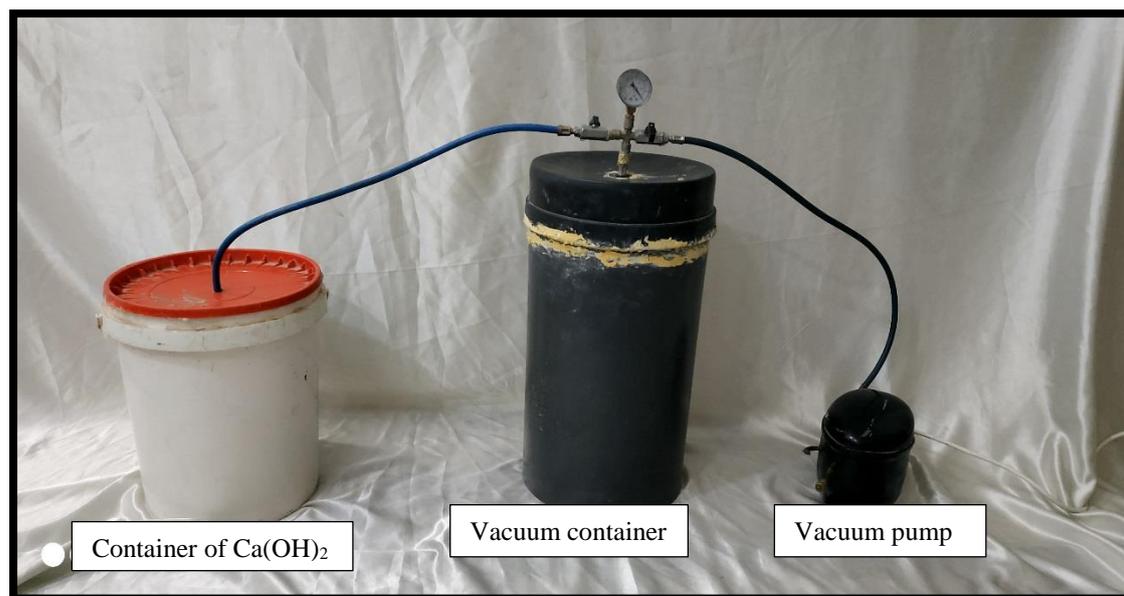
The primary goals of this study were to examine the impact of replacement of rubber on the characteristics and durability (penetration of chloride) of rubberised self-compacting concrete. In this case, of durability of SCC, Concrete prism of 100 mm x100mm\* 200 mm was employed to determine the depth chloride penetration  $x_d$ . The depth of chloride penetration,  $x_d$  and migration of chloride resistance were examined. Seven different replacements of rubber percentage ranges, (M0, M4%, M8%, M12%, M16%, M1 and M2 by sand were used. Firstly, one face of the sample was subjected to specific environmental condition (**drying and wetting cycles periods two week**), while the other faces were covered by coating of water-proofing based. These specimens were addressed to the ions of chloride and sulfate solution (5% NaCl, 3% CaCl<sub>2</sub>.2H<sub>2</sub>O and 2%

$\text{Na}_2\text{SO}_4$ ) ( see **Table 3.11** and **Table 3.12**) within a periodical of wetting and drying for 120 days in total as shown in **Figure 3- 26**.



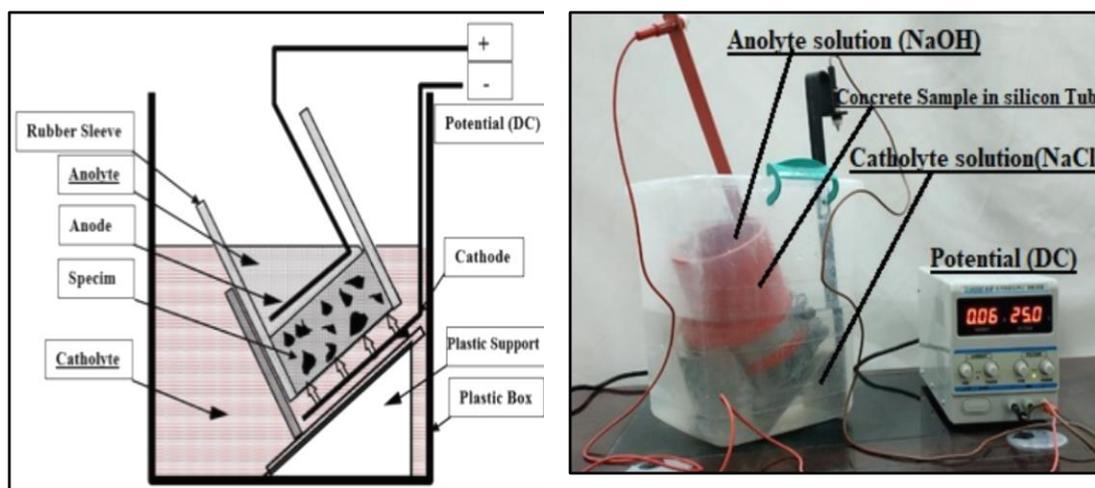
**Figure 3-26** Salts used in preparation saline solutions

**Secondly**, the migration of chloride test was carried out with short concrete cylinders at the 28 days age. A 100 mm diameter cylinder specimen with 50 mm height was also used to calculate migration of chloride penetration. When the specimens are surface dry, place them in the vacuum container for vacuum treatment as shown in **Figure 3- 27**.



**Figure 3-27** Vacuum treatment

Both end surfaces must be exposed, absolute pressure in the vacuum container to a pressure in the range (1-5 kpa) within a few minutes maintain the vacuum for three hours and then, the vacuum pump still running, fill the container with saturated  $\text{Ca(OH)}_2$  solution (by different pressure between the vacuum container and the other container contain  $\text{Ca(OH)}_2$  so as to immerse all the specimens to avoid the leaching of  $\text{Ca(OH)}_2$  (**NT Build 492:1999**)). Maintain the vacuum for hour before allowing air to re-enter the container. Keep the specimens in solution for  $18 \pm 2$  hours and then, the migration of chloride penetration is fast-tracked by applying an electrical circle on two different solutions, NaCl and NaOH according to **NT Build 492:1999**. The first face of the specimens was addressed to 10% of NaCl solution and the second face is exposed to sodium hydroxide solution of 0.3% of NaOH as shown in **Figure 3-28**. These samples of concrete were exposed to two solutions and electrical circle with (DC) of 30Voltage for 24 hrs.

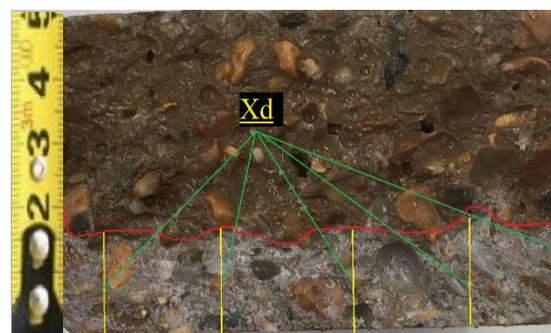


**Figure 3-28** NT Build 492 (1999)

These tests are based on depth of chloride penetration ion,  $x_d$  which is tested by spraying silver nitrate ( $\text{AgNO}_3$ ) solution of a certain concentration of 0.1 N on the split short prism and cylinder sample (see **Figure 3-29**) and measured the chloride penetration ( $x_d$ ) due to a reaction between  $\text{Cl}^-$  with  $\text{Ag}^+$  to find chloride penetration depth for prism. While, the chloride penetration depth in short cylinder can be employed to find the diffusion coefficient for non-steady state migration ( $D_{\text{nssm}}$ ) as shown in **Equation (3-12)** and **Figure 3-30**. **Figure 3-31** shows the silver nitrate  $\text{AgNO}_3$ ,  $\text{NaOH}$  used in this test.



**Figure 3-29** Short cylinder sample for chloride migration test



**Figure 3-30** Penetration of Chloride measured by spraying  $\text{AgNO}_3$

$$D_{nssm} = \frac{0.0239(273+T)l_t}{(U_v-2)t} \left( x_d - 0.0238 \sqrt{\frac{(273+T)l_t x_d}{U_v-2}} \right) \quad (3-12)$$

where:

$D_{nssm}$  : non steady-state migration coefficient,  $\times 10^{-12} \text{ m}^2/\text{s}$

$T$  the mean of the final and initial temperature in the anolyte part (NaOH),  $l_t$  would be the thickness of the specimen (mm),  $x_d$  is the mean of depth of penetration of chloride, time,  $t$

$U_v$  the applied voltage.



**Figure 3-31** NaCl, AgNO<sub>3</sub> and NaOH used in this test

### 3.8.5 Chloride Concentration (Profile of Chloride)

The Volhard Titration was used to discover the chloride content in concrete according to **NT BUILD 208 -3:1996**. This test method used for determination of the total chloride content in hardened by dissolving the concrete dust in a solution of nitric acid followed by Volhard Titration.

Theory of this test as follows:

- A solution containing ions of chloride to an excess of silver nitrate. The chlorides precipitate as silver chloride.



- The excess of silver ions is titrated with thiocyanate solution



- The excess of thiocyanate ions is indicated by the formation of a red iron(III)- complex



Preparation of test sample is based by Core drilling machine with a diameter of at least 18 mm used to take sample in depth (5,15,25,35 and 45) mm from the specimen after splitting short prism(10×10×200)mm and A 100 mm diameter cylinder with 50mm height as shown in **Figure 3-32**.



**Figure 3-32** Core drilling for taking the powder samples

The selected test samples should be crushed with hammer or similar tool to size that no material is lost and the ground in the mill until a particle size less than 0.1mm is obtained as shown in **Figure 3-33**.



**Figure 3-33** Concrete powder samples

The Procedure of the chloride concentration test can be carried out by **NT BUILD 208 -3:1996**

- Weight 1 gm from the sample is placed in the glass bottle (volume 250 ml), then added about 20 ml of distilled water and shaken the bottle so that the particles separate. The shake the bottle is done by magnetic stirrer.
- Add about 10mm concentrated nitric acid, shake the bottle by magnetic stirrer.
- Boiling hot distilled water and shake again.
- Let the mixture to cool for about one hour until it reach ambient temperature.
- Filter the solution and rinse the filter 1% nitric acid at least twice.
- Add distilled water until all the sample have same volume.

- Use two burettes, each with a volume 25 ml .One to be used for the silver nitrate solution and the other for the ammonium thiocyanate solution.
- Add silver nitrate ( $\text{AgNO}_3$ , 0.1N) solution in excess from burette, about 10 ml.
- Add (2-3) ml benzyl alcohol ( $\text{C}_7\text{H}_8\text{O}$ ) and (1) ml ammonium thiocyanate ( $\text{NH}_4\text{SCN}$ ).(0.1N) solution insert the stopper into glass bottle and shake the bottle by magnetic stirrer
- Titrate the reaming amount of silver nitrate with saturated ammonium ferri-sulphate ( $\text{NH}_4 \text{Fe}(\text{SO}_4)_2 \times 12\text{H}_2\text{O}$  about 400 g/l) solution. Shake the glass bottle by magnetic stirrer and Continue the titration at a slower rate during a continuous intensive mixing until the solution attain a permanent weakly red colour.

The material used and the procedure of this test is shown in **Figure 3- 34** and **Figure 3-35**.



**Figure 3-34** Material used in this test

The content of chlorides (Cl% by mass of concrete powder) is then calculated according to *Equation (3-16)*:

$$\text{Cl}\% = 3.545 * \frac{V_1N_1 - V_2N_2}{m} \quad (3-16)$$

Cl% = The content of chloride

V<sub>1</sub>=the added amount of silver nitrate solution (ml)

N<sub>1</sub>= the normality of the silver nitrate solution

V<sub>2</sub>=the added amount of ammonium thiocyanate solution during the titration (ml)

N<sub>2</sub>= the normality of the ammonium thiocyanate solution

m= the weight of the powder sample (g).



**Figure 3- 35** Steps of the test to find chloride content

### 3.8.6 Apparent Chloride Diffusion of Cementitious Mixtures

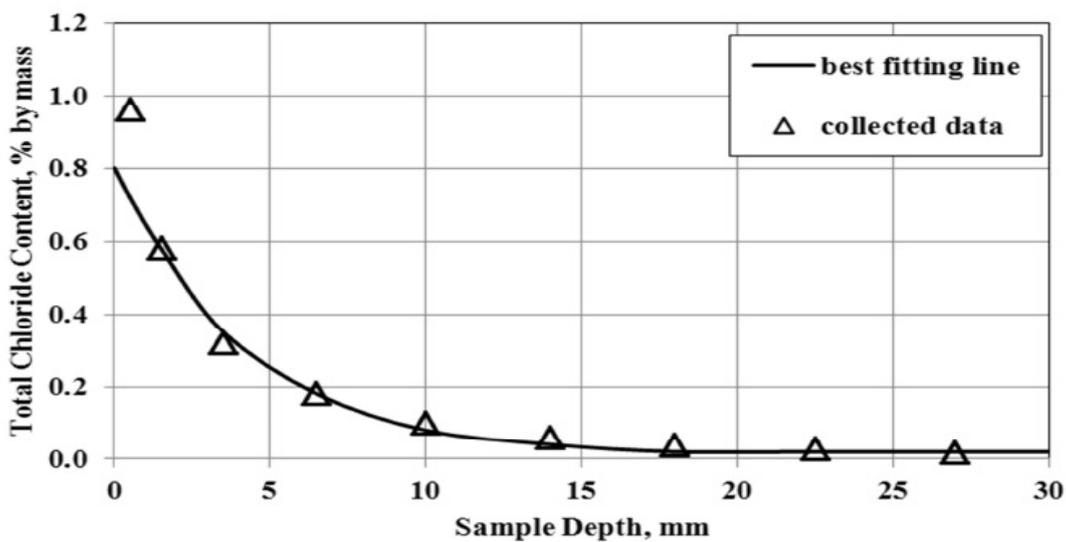
This test method covers the laboratory determination of the apparent chloride diffusion coefficient for hardened cementitious mixtures. The total chloride concentration profile was used to find apparent diffusion coefficient,  $D_a$  and surface concentration,  $C_s$  according to **BS EN 12390-11:2015** or **ASTM C 1556-11a.2016**

The  $D_a$  and  $C_s$  can be found by the least square difference between the experimental results of chloride concentration profile and the non-linear best fitting of Fick's Second Law of *Equation (3.17)*, as shown in **Figure 3-36**.

$$C(x, t) = C_i + (C_s - C_i) \left[ 1 - \operatorname{erf} \left( \frac{x}{2\sqrt{D_a \cdot t}} \right) \right] \quad (3.17)$$

where:

$C(x, t)$  is the chloride concentration at depth ( $x$ ) with time  $t$ ;  $C_i$  is initial chloride concentration (% mass of concrete);  $C_s$  is the surface chloride concentration (% mass of concrete);  $D_a$  is the diffusion coefficient of chlorides ( $\text{m}^2/\text{sec}$ );  $\operatorname{erf}$  is the error function for solution of partial equation.



**Figure3-36** Chloride profile with fitted curves for surface chloride content **BS EN 12390-11:2015** or **ASTM C 1556-11a 2016**



# **CHAPTER FOUR**

## **CHAPTER FOUR**

### **Results and Discussion**

#### **4.1 Introduction**

The practical programme of this investigation focuses on study and evaluate the behavior of self-compacted concrete with different proportions of tyre rubber as partial replacement of natural sand with and without treated rubber particles with SBR exposing to tap and saline solution curing at different ages. In this chapter, results were presented and discussed for all experimental work that described in chapter three. The discussion presents the results of fresh test, mechanical, and durable properties of self-compacted rubberised concrete. Which include slump flow, V-funnel, L-box and sieve segregation for fresh test. Compressive, splitting, flexural strength, drying shrinkage for hardened test, and water and surface absorption, chloride migration, chloride penetration and chloride concentration for durable test will also presented and discussed.

#### **4.2 The Fresh Properties of Self- Compacting Rubberised Concrete (SCRC)**

In fresh state, SCC is required to have three characteristics; filling ability, passing ability and segregation resistance. Therefore, several test methods are implemented in this study in order to ensure that SCC mixtures satisfy these requirements. The requisite test methods reported by (EFRANC 2005; ACI 237R- 2007). The workability tests were carried out on fresh concrete immediately after mixing including slump flow,  $T_{500}$ , V-funnel, L-box and sieve segregation. These tests were carried out to ensure that the mixtures satisfy the requirements of SCC. **Table 4.1** summarizes the results of the fresh properties for each mix.

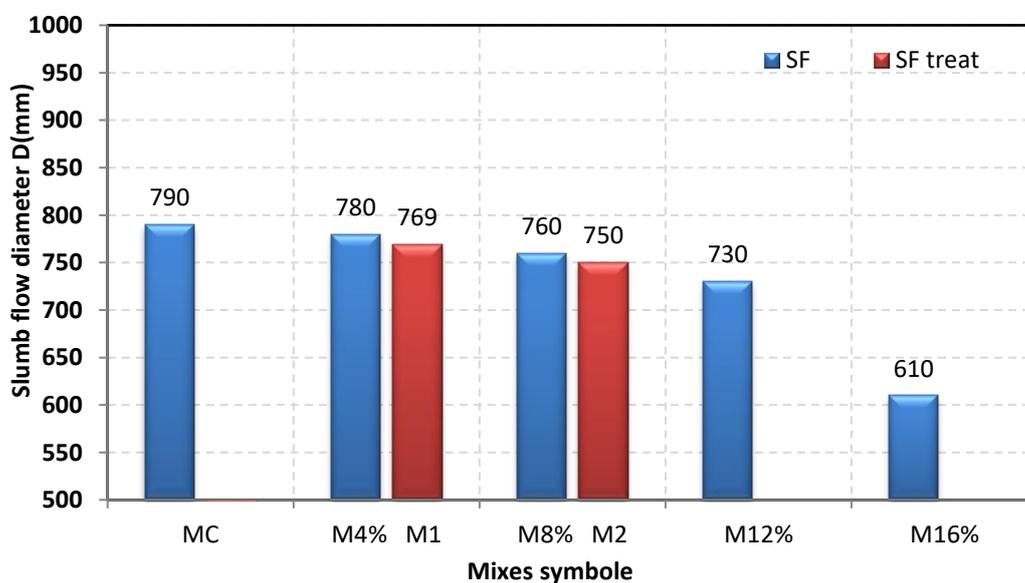
**Table 4.1** Fresh properties of SCC mixes

<b>Mix Symbol</b>	<b>Slump Flow (mm)</b>	<b>T<sub>500mm</sub> Tests(sec)</b>	<b>L-Box Test</b>	<b>V-Funnel Test(sec)</b>	<b>Sieve Segregation Test %</b>
<b>Mix control (MC)</b>	790	3.5	0.95	10.00	16%
<b>M 4%</b>	780	4	0.909	11.00	15.5%
<b>M 8%</b>	760	4.56	0.904	13.25	15%
<b>M 12%</b>	730	4.60	0.85	13.45	14%
<b>M 16%</b>	610	5.00	0.818	20.00	13.25%
<b>M1</b>	769	4.25	0.91	12.00	15%
<b>M2</b>	750	5.00	0.91	14.50	14.25%

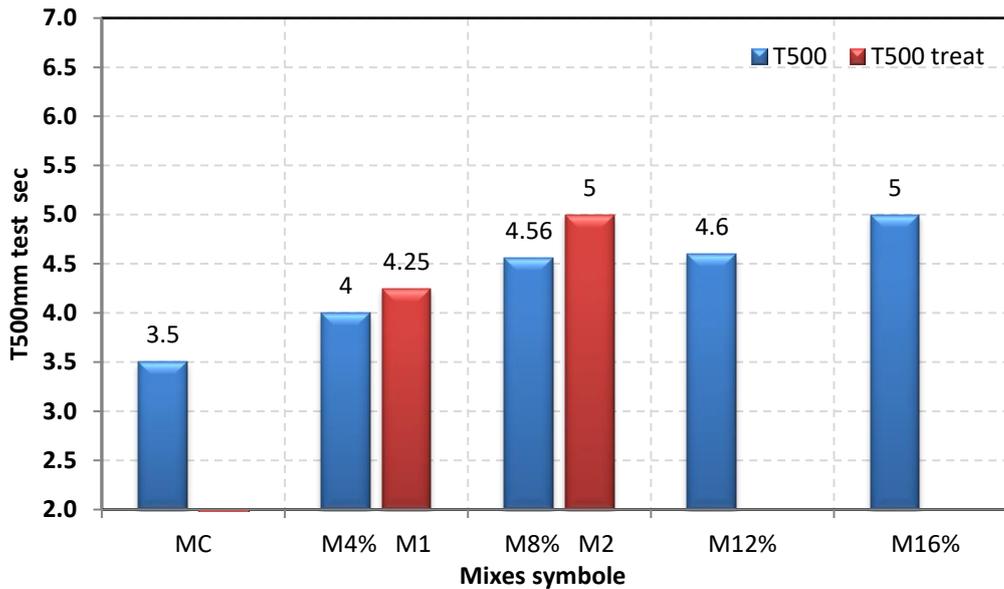
#### 4.2.1 Slump Flow (SF) and T<sub>500</sub> Test

The score of the slump flow and T500 tests are listed in Figure 4-1 and 4-2. The value of D characterises the maximum spread of mixes of concrete that is called slump flow (SF) or final diameter. While, the time required reaching the concrete flow a circle with 500 mm diameter represents T500 test. The results of the slump flow range between (610-790) mm as shown in Figure 4-1. Where, the results indicated that increasing rubber replacement by sand reduced the slump flow diameter and this increase of rubber in SCC led to increase the time required to blow-out the diameter of 500 mm. Significant reduction in SF (D) and increase in T500 have been noticed with rubber replacement percentage (4% to 16%) in self- compacting concrete mixes. However, all results of SF and T500 of SCRC mixes can be achieved the self-compacting concrete requirement of EFNARC, 2005. This can be accounted for, the natural, form and size of crumb rubber aggregate, these properties of rubber forms in relatively hindered movement with increased rubber replacement percentage or content. As a result, relatively large amount of energy of flow may be consumed because the present of this material, due to the roughness of rubber particles. Therefore,

concrete mixtures like to be cohesive and yield stress value may be increased producing the reduction in flow ability. Finally, replacing sand by crumb rubber tyre increased the resistance to stream and decrease the flow ability owing to increase the friction and interlocking among rubber tyre particles and aggregates (Li et al., 2019). When modified rubber particles with SBR, the slump flow provided a reduction by 1.4% and 1.3% for M1 and M2 as comparing with M4% and M8% respectively. In addition, the T500 test present unnoticeable increase in time with utilizing SBR for treated rubber by 25 second for M1. The time for M2 was 4 second as while the time for M8% was 4.56 second. This behaviour is due to lower in water absorption for coated rubber particles with SBR (being hydrophobic) by the membrane surrounding them (Vahabi et al., 2021). As seen in Table 4.2, most concrete mixes MC, M4% and M8% could be conformed to SF3 class in terms of slump flow according to (EFNARC, 2005). Except for the mixes M12%, M1% and M2 which were located within the SF2 class, while M16 containing 16% Crumb rubber was located within the SF1 class.



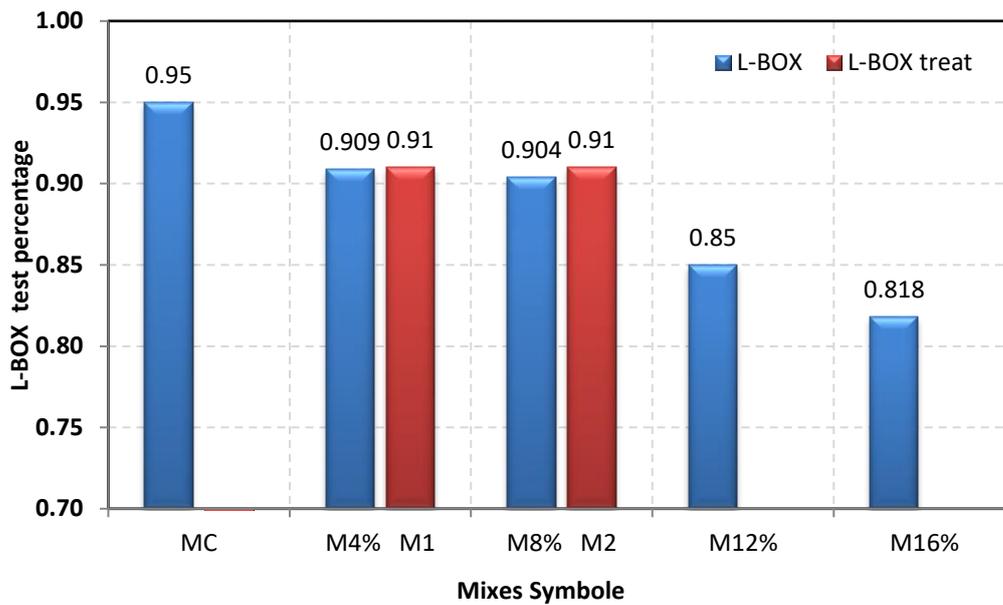
**Figure 4-1** Effect of replacement percentage of tyre on slump test



**Figure 4-2** Effect of replacement percentage of tyre on  $T_{500}$  test (sec)

#### 4.2.2 L-Box test

In this study, L-Box with three bars was employed to measure the passing capability of self-compacting concrete mixtures. The results of L-box test is measured results of blocking ratios ( $BR=H_2/H_1$ ) of the test as listed in **Figure 4-3**. The BR results of this test were between 0.818-0.95. The BR ratios results indicated to decrease in mixtures with increasing the rubber replacement percentage. This decrease is likely due to increase yield stress and viscosity with increase of rubber replacement percentage (**Li et al., 2019**) as shown in V-funnel test results and **Figure 4-3**. However, all mixtures in this study had a good passing ability because the BR ratio of these mixtures were more than 0.8. Where **EFNARC, 2005** refers, the BR ratio of this mixture is equal and more than 0.8 represents a good passing ability. Generally, the BR results do not effect when treated rubber tyre particles with SBR (**Ardalan et al., 2020**). As it is observed, all SCC mixes with increasing the crumb rubber replacement percentage, (M0, M4%, M8%, M12%, M16%) and, M1, M2 were classified as PA2 ( $H_2/H_1 \geq 0.80$  for three bars) in terms of the passing ability. The mixtures in this class would have a good passing ability where it was greater than 0.8, which is considered the minimum critical value according to (**EFNARC, 2005**).

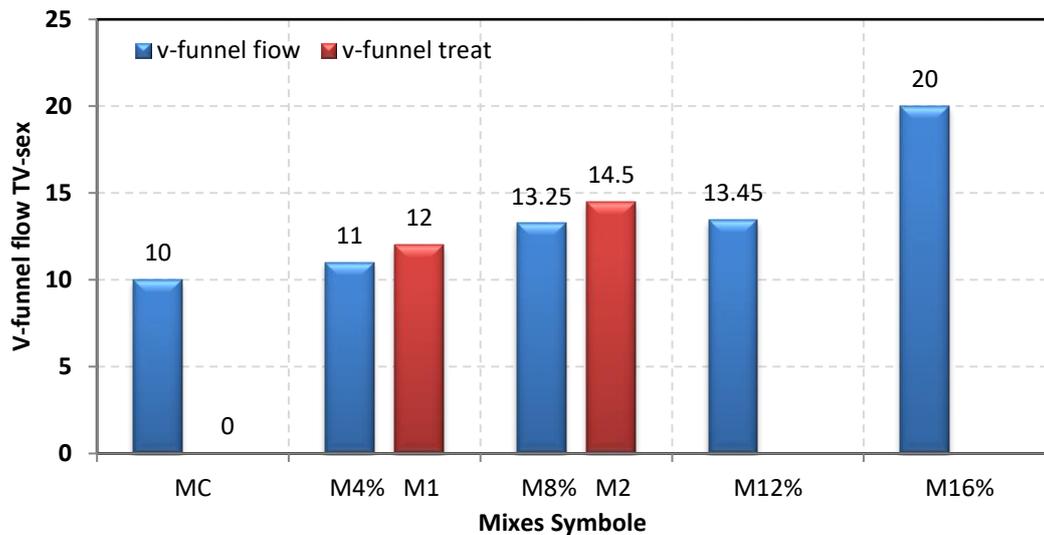


**Figure 4-3** Effect of replacement percentage of tyre on L-Box test

### 4.2.3 V-Funnel Test

The filling ability and viscosity of SCC can be calculated by the V-funnel test. The test results of V- funnel are listed in **Figure 4-4**. These tests are evaluated by measuring the time of empty mixture from V-funnel ( $T_v$ ). The results ( $T_v$ ) ranged (10-20 sec). It is clear from the results that the  $T_v$  increased as the rubber tyre content increased in the SCRC mixes. A main reason of increase  $T_v$  is the increase rubber replacement percentage leads to increase yield stress and viscosity these mixes.

And this increase in viscosity results from increase the friction and interlocking between the rubber tyre particle and aggregates, the interlocking of rubber tyre with each other and balling of these particles which can extend the increase of the empty time of the V- funnel test (Li et al., 2019).



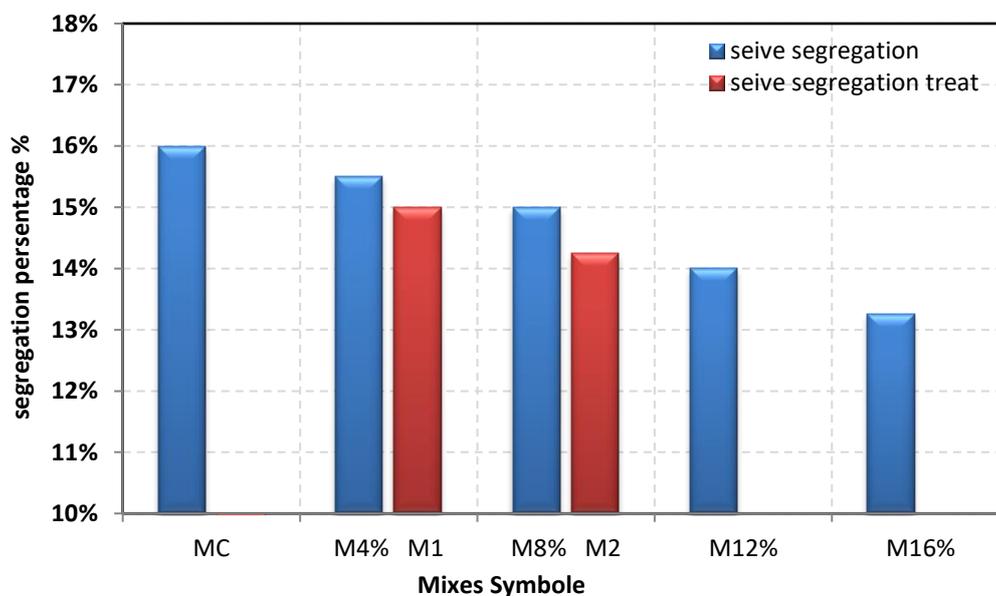
**Figure 4-4** Effect of replacement percentage of tyre on V- Funnel test

SBR modified rubber particles led to increase the time for V-Funnel test. The increase was 9.1% and 9.4% for M1 and M2 as comparing with M4% and M8%. Generally, the great effect of SBR additives on the fresh properties of SCC including workability, filling ability, passing ability and homogeneity was observed in these mixtures (Issa and Assaad, 2017). According to (EFNARC, 2005), SCC is classified as VS1/VF1 when T500 mm and V-funnel flow time is  $\leq 2$  s and 8 s, respectively, while SCC is categorized as VS2/VF2 when T500 mm exceeds 2 s and V-funnel flow time ranges from **9 to 25** s. Therefore, all the mixes for crumb rubber can be classified into the VS2/VF2 class .

#### 4.2.4 Test of Sieve Segregation

The sieve segregation and resistance test is used to assess the segregation and resistance of self-compacting concrete. Any separation of seep water is noted after allowing the fresh concrete to stand for 15 minutes. The top of the sample is then poured through a sieve with 5 mm square apertures. After 2 minutes, the weight of the material that has passed through the sieve is recorded. The segregation ratio is then calculated as the fraction of the sample that passes through the sieve. The result of sieve

segregation test decreased with increasing rubber content in the mix of SCC from (16%-13.25) for untreated with SBR and (15% for M1 and 14.25 for M2) for treated rubber with SBR as shown in **Figure 4-5**. This reason returns to increase viscosity and increase the friction between the rubber particle and other material in these mixtures that lead to reduce the cement mortar pass through the sieve a square apertures (**Li, et al., 2019**). On the other hand, the SBR did not affect fresh properties excessively, the movement of water and fine aggregates away from the bulk concrete was minimized and a homogeneous composition was maintained (**Ardalan et al., 2020**). According to (**EFNARC, 2005**), all the mixes can be classified into the  $SR \leq 20\%$  class.



**Figure 4-5** Effect of replacement percentage of tyre on Test of sieve segregation

### 4.3 The Mechanical Properties of Self- Compacting Rubberised Concrete (SCRC)

The hardened property and or mechanical strength of mortar or concrete Self-Compacting Rubberize Concrete (SCRC) are the property that is most obviously required for structural uses. The strength of mortar or concrete depends on the cohesion of the cement paste, on its adhesion to the aggregates particle, and a certain extent on the strength of the aggregate itself. The key hardened properties of SCC in this study were

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tested for compressive strength, splitting tensile strength, flexural strength, ultrasonic pulse velocity, schmidt hammer and drying shrinkage. The results of these tests for SCC mixtures are described and discussed below in detail.

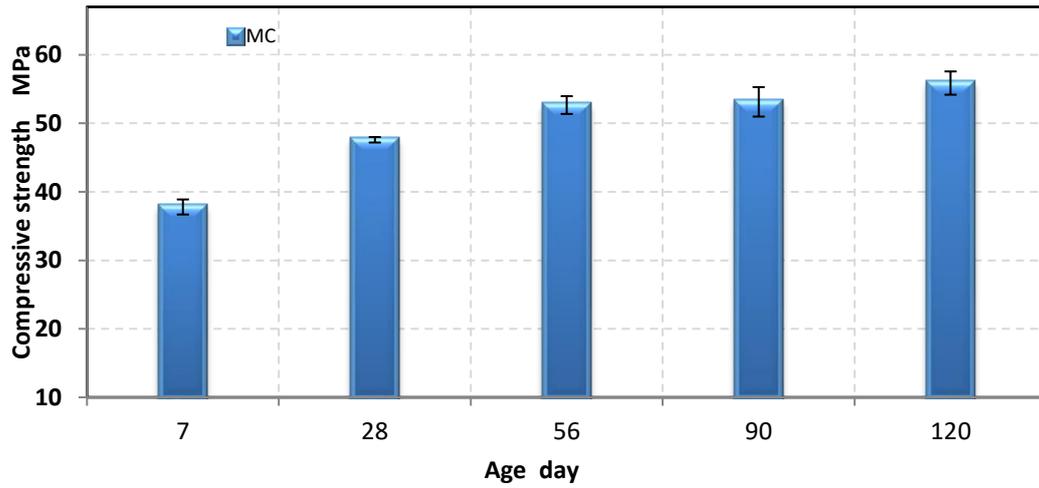
### 4.3.1 Compressive Strength Results

The compressive strength is one of the most important properties of hardened concrete for Self-Compacting Rubberize Concrete(SCRC). The test for all mixtures were experimentally carried out according to BS EN 12390- 3:2000 by using 100 mm cube specimens at 7, 28 , 56, 90 and 120 days with different exposure or immersion in tap water or in saline solution of ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ). Results for both treatment of rubber tyre particles by SBR solution and un-treatment samples are presented in **Table 4.2**.

Key observations from the compressive strength results are:

#### 4.3.1.1 Effect of Age for Normal Curing

There is a significant increase in the compressive strength with increasing the curing age at 28 and 56 days compared to 7 days. Whilst, the growth in this strength was a slight at 90 and 120 days for the exposure environment, tape water for all percentage replacement of rubber tyre as shown in **Figure 4-6**. The increase in compressive strength was 25.9%, 39.3%, 40.6%, and 47.8% for 28, 56, 90, and 120 days as comparing with 7 days respectively. The increase in compressive strength with age because of cement reaction led to produce more C-S-H and improving the microstructure of concrete (Neville, 2011).



**Figure 4-6** Effect age on compressive strength for SCC under tap water curing

**Table 4-2** Result of compressive strength of SCRC mixtures used in study

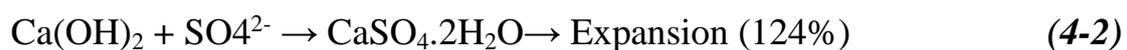
Mixture symbol	Average of compressive strength MPa at									
	7 days		28 days		56 days		90 days		120 days	
	Curing Type									
	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution
<b>M C</b>	37.79	-	47.60	-	52.67	42.33	53.14	50.51	55.88	52.50
<b>M 4%</b>	32.08	-	36.80	-	40.00	36.72	42.51	40.57	44.49	41.36
<b>M 8%</b>	26.94	-	28.45	-	33.26	32.80	35.61	32.50	37.06	34.53
<b>M 12%</b>	14.96	-	17.67	-	18.48	17.34	20.00	19.07	21.31	19.27
<b>M16%</b>	11.66	-	15.63	-	16.76	15.35	18.55	17.44	19.43	18.12
<b>M1</b>	36.83	-	37.80	-	43.45	40.00	44.67	42.00	47.93	43.25
<b>M2</b>	28.42	-	32.62	-	34.23	30.83	36.02	33.36	37.46	33.52

- Curing in a tap water
- Saline solution is a mix of  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  Ions solution curing at 28 days as mentioned in Chapter 3

### 4.3.1.2 Effect of Saline Solution Curing

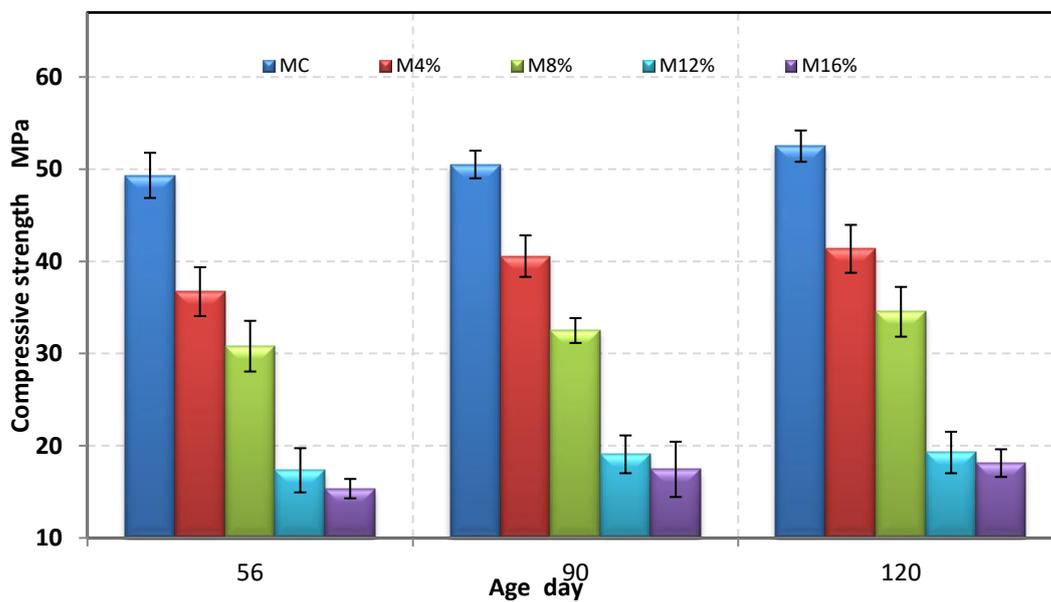
The strength changes for sample exposed to saline solution of chloride and sulfate at 56, 90 and 120 days was presented in **Table 4.2**. A significant reduction for compressive strength happened under saline solution curing. The reduction was 19.6%, 5%, and 6% for 56, 90, and 120 days as comparing with tap curing in the same ages respectively. Solution when diffused inside the samples made a chemical reaction between the aggressive agent (sulfate and chloride) and cement products and that reaction accelerated due to solution effects. On the other hand, the higher absorption of the solution for the same time of immersion accelerated the degradation reaction in microstructure of concrete (**Robert et al., 2009 and Robert et al., 2013 and Govalkar & Lal, 2020**).

**Figure 4-7** and **Table 4.2** illustrated degradation of compressive strength for self-compacted concrete containing rubber tyre when exposed to solution ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) as compared with same sample exposed to tap water. While, **Table 4.3** exhibit the reduction in compressive strength for samples with rubber content (0, 4, 8, 12, 16) % for age (56, 90, and 120 days) in addition to modified rubber by SBR (M1 and M2). This deterioration in compressive strength is due to attack of sulfate ions, which causes the formation of expansive compounds such as ettringite (hydrated calcium sulfoaluminate) and gypsum. These products are formed from reaction between external sulfate ions (in saline solution) and internal sulfate ions in concrete components with hydrated calcium aluminate as shown in *Equation (4-1)* and *(4-2)* (**Neville, 2011**).



**Table 4.3** deterioration percentage in compressive strength due to sulfate attack

Mixture symbol	Change in compressive strength % at		
	56 days	90 days	120 days
	For Curing Type (Saline Solution)		
MC	6.3	4.9	6.0
M 4%	8.2	4.6	7.0
M 8%	7.4	8.7	6.8
M 12%	6.2	4.7	9.6
M16%	8.4	6.0	6.7
M1	7.9	6.0	9.8
M2	9.9	7.4	10.5



**Figure 4-7** Effect of rubber at different age on compressive strength by exposed ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) curing

### 4.3.1.3 Effect of Percentage Replacement of Rubber Tyre

The compressive strength decreases progressively further into the self-compacting concrete for mixtures with higher percentage replacement for (all exposure condition). In particular, lower compressive strengths were observed in concrete samples with 12% replacement of rubber tyre for the both exposure, tap water and saline environment. The outcomes shown in **Figure 4-8** for all SCRC specimens that cured in tap water indicate the compressive strength decrease with increasing percentage replacement of rubber tyre as comparing with reference mixture. The reduction percentage in compressive strength are listed in **Table 4.4**.

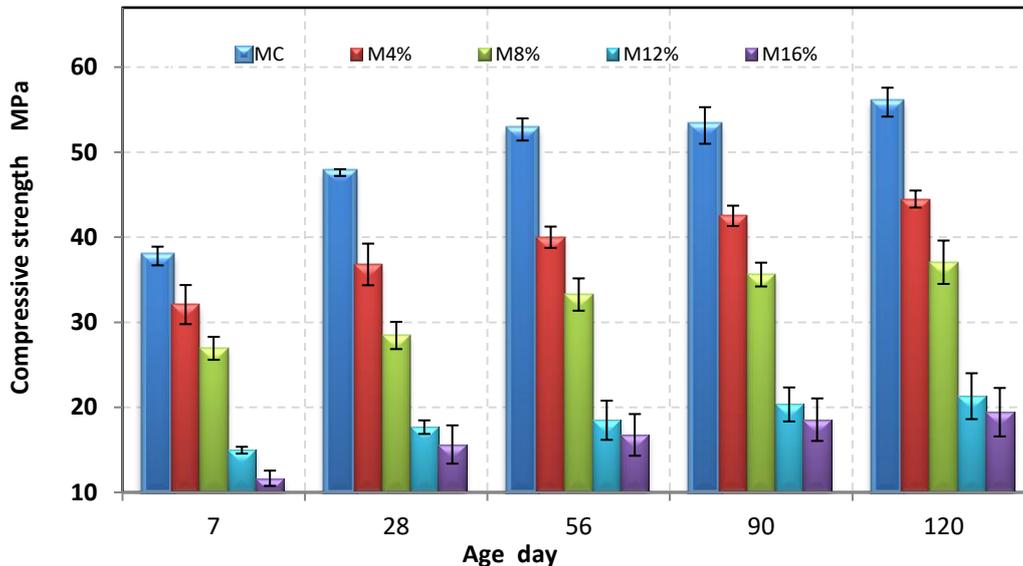
**Table 4.4** Redaction in Compressive Strength (%) for SCRC

Redaction in Compressive Strength (%)								
Mixture symbol	7 days	28 days	56 days		90 days		120 days	
	Curing Type							
	Tap water	Tap water	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution
<b>M 4%</b>	15.1	22.7	24.1	25.6	20	19.7	20.4	21.2
<b>M 8%</b>	28.7	40.2	36.9	37.6	33	35.7	33.7	34.2
<b>M 12%</b>	60.4	62.9	64.9	64.8	62.4	62.2	61.9	63.3
<b>M16%</b>	69.1	67.2	68.2	68.9	65.1	65.5	65.2	65.5

This behaviour of reduction of compressive strength due to replacement the sand by particles of waste rubber tyre may be associated to the decrease of modulus of elasticity (E) of recycled tyres. On the other hand, the main reason of poor adhesion in the interface region between cement paste and recycled rubber could have been defected initiation from voids formed by the interaction of cement paste and crumb rubber molecules especially in un-treatment samples.

There is an agreement between researchers that the percentage of replacement in the concrete mixtures has a significant influence on the compressive strength of the

concrete samples. These mechanisms largely contribute to weakening ITZ bonding and leading to initiation and increase microcracks that develop around runner particles under loading, differential strain rates (Najim and Hall, 2012) (Karunarathna.et, al., 2021).

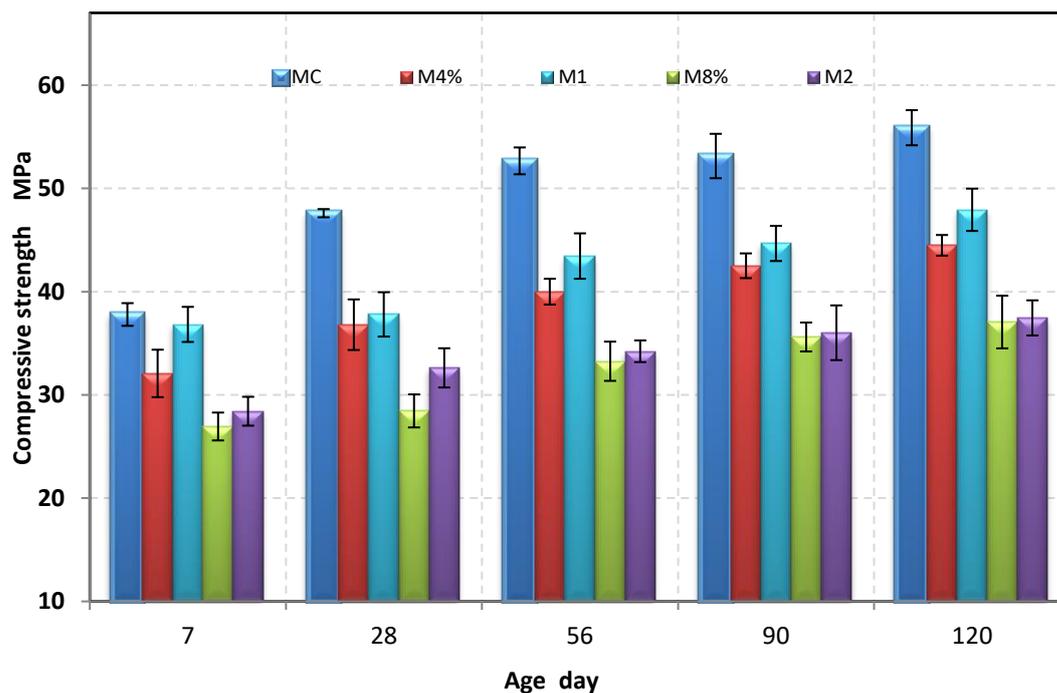


**Figure 4-8** Effect of rubber at deferent age of tap water curing on compressive strength

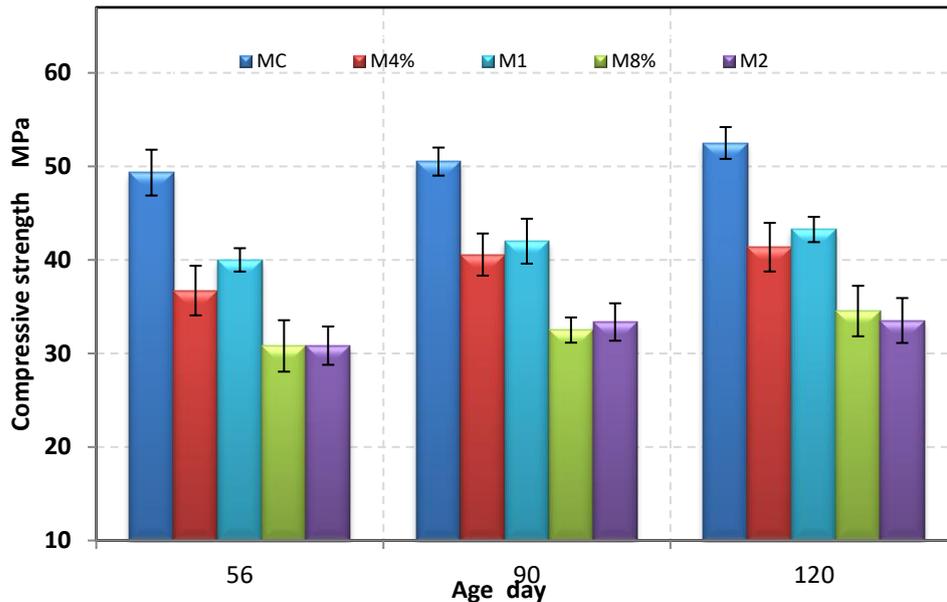
#### 4.3.1.4 Effect of Coating of Rubber Tyre Particles

The treatment of rubber tyre particles with SBR has noticeable influenced the compressive strength and resistance to deterioration due to sulfate attack into the self-compacting concrete for mixtures with replacement 4% and 8% rubber tyre as shown in **Figure 4-9** and **4-10**. The coat of the rubber particle by SBR could alter the mechanism of failure in sample due to improvement of bonding between the cement paste or mortar and rubber particle that enhances the compressive strength of samples in mixtures M1 and M2. The enhancement in compressive strength was 14.4%, 2.7%, 8.6%, 5.1%, and 7.7% for 4% of replacing rubber and 5.5%, 14.7%, 2.9%, 1.2%, and 1.1% for 8% of replacing at 7, 28, 56, 90, and 120 days respectively as comparing with same percentage of replacing rubber without treated. SBR presented a high resistance to degradation due to sulphate attack to the self-compacting concrete for mixtures with

replacement 4% and 8% of rubber tyre. The increase in compressive strength was 7.9%, 6%, and 9.8% for 4% of replacing rubber and 9.9%, 7.4%, and 10.5% for 8% of replacing at 56, 90, and 120 days respectively as regarding to mixture with same percentage of replacing rubber without treated. The experimental data these mixtures indicated that the M1 with replacement 4% and coated gave the highest improvement in compressive strength of self- compacting concrete for different exposure and age of test. Beyond this value (rubber replacement = 8%), the strength improvement decreases due to increase the percentage of rubber and the coating will be less effect. SBR admixtures, which, in turn strengthens the bonding characteristics between cement, paste and the surface of rubber aggregates by 'bridging the gaps and that agree with (Lee et al., 1998).



**Figure 4-9** Effect of rubber with SBR at different age of tap water curing



**Figure 4-10** Effect of rubber with SBR at different age of exposed ( $\text{Cl}^-$  &  $\text{SO}_4$ ) solution curing

### 4.3.2 Splitting Tensile Strength

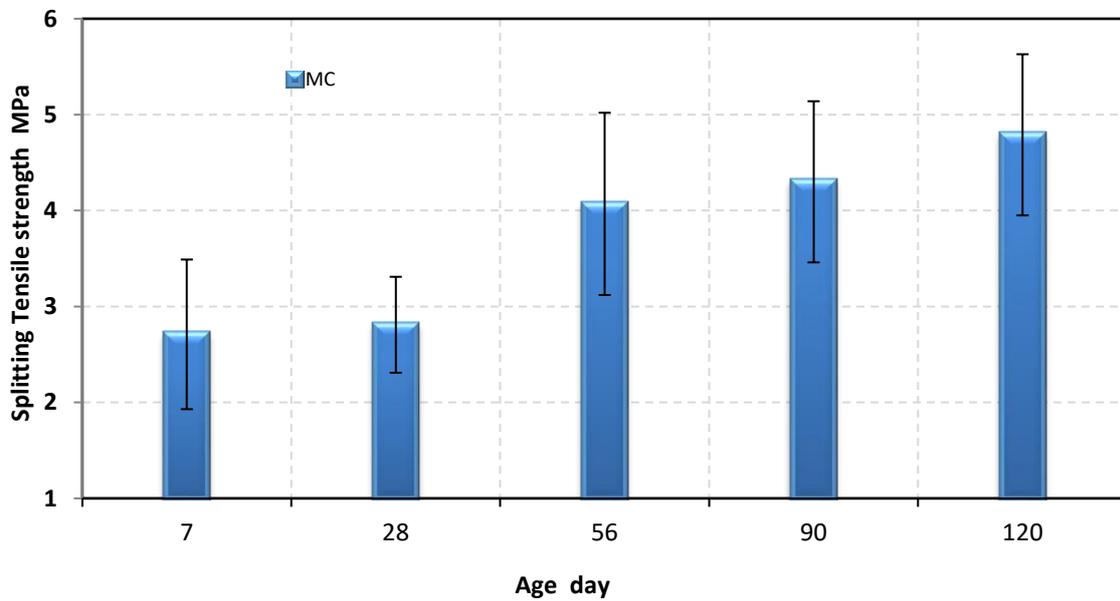
The splitting strength is a method to find tensile strength of (SCRC) indirectly and is considered one of the important properties of hardened concrete. The results for both treatment of rubber tyre particles by SBR solution and un-treated samples are presented in **Table 4.5**, which illustrates the changes in splitting strength at various curing age and type of exposure environment.

The results will be presented according to main factors affecting splitting strength as follows:

#### 4.3.2.1 Effect of Age for Normal Curing

**Figure 4-11** and **Table 4.5** illustrated the increase in splitting strength with ages for normal curing by tap water. The increase was 3.7%, 50.1%, 54.9% and 76.7% for 28, 56, 90, and 120 days as comparing with 7 days respectively. The particles of limestone powder could have acted to precipitate of C-S-H for that the cement hydration

increased. Generally, the interfacial transition zones improved and that led to improving splitting tensile strength with age and that agree with other researches (**Chen and Kwan, 2012**) (**Li and Kwan, 2015**).



**Figure 4-11** Effect age on Splitting Tensile Strength for SCC under tap water curing

**Table 4.5** Result of Splitting Tensile Strength of SCRC mixtures

Mixture symbol	Average of Splitting Tensile Strength MPa at									
	7 days		28 days		56 days		90 days		120 days	
	Curing Type									
	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution
<b>M C</b>	2.71	-	2.81	-	4.07	3.82	4.20	3.87	4.79	3.69
<b>M 4%</b>	2.62	-	2.69	-	3.95	3.76	4.29	3.86	4.38	3.59
<b>M 8%</b>	2.44	-	2.47	-	3.55	3.33	3.67	2.42	3.87	2.35
<b>M 12%</b>	1.80	-	2.04	-	2.60	2.36	2.66	2.40	2.79	2.25
<b>M16%</b>	1.75	-	1.91	-	2.71	2.34	2.44	2.27	2.43	2.18
<b>M1</b>	2.80	-	3.12	-	4.01	3.83	4.31	3.75	4.57	3.54
<b>M2</b>	2.53	-	2.74	-	3.75	3.67	3.82	3.49	3.92	3.33

- Curing in a tap water
- Saline solution is a mix of  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  ions solution curing at 28 days as mentioned in Chapter 3

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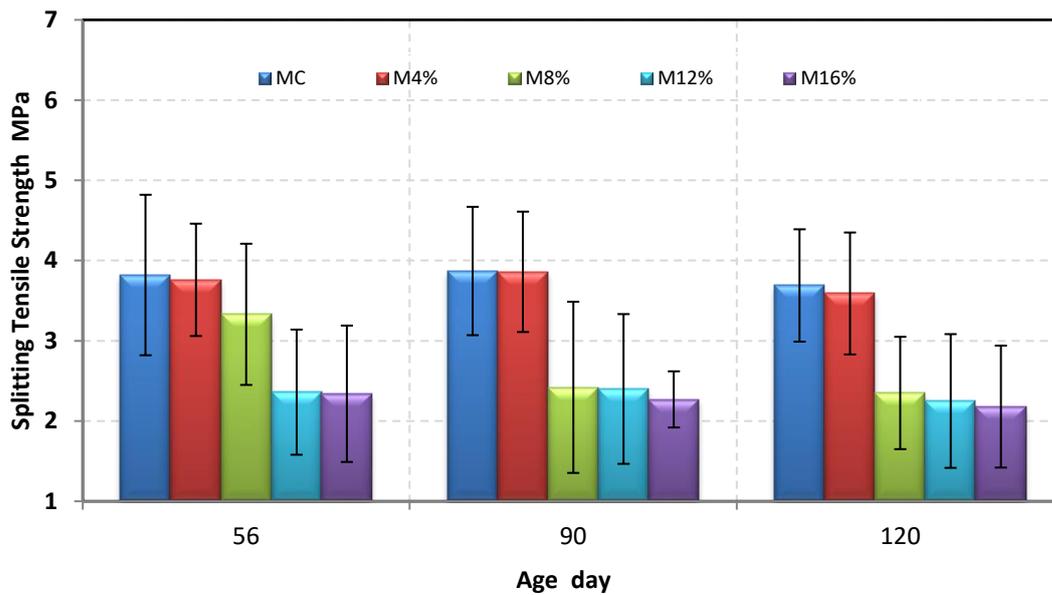
#### 4.3.2.2 Effect of Saline Solution Curing

The splitting tensile strength suffered from reduction in strength due to negative effect of saline curing as showed in **Table 4.5**. The reduction in splitting strength was 6.1%, 7.8%, and 22.9% for 56, 90, and 120 days as comparing with tap curing in the same ages respectively. This phenomenon is due to the increasing diffusion rate of the solution inside the sample and to the acceleration of the chemical reaction of degradation leading to a higher absorption rate of the solution for the same time of immersion and accelerated degradation reaction (**Robert et al., 2009**) (**Robert et al., 2013**).

Self-compacted concrete that exposed to ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) solution exhibited a degradation in splitting tensile strength as regarding to sample exposed to tap water as presented in **Figure 4-12**. While **Table 4.6** illustrates the reduction in splitting tensile strength for samples with rubber content (0, 4, 8, 12, and 16) % for age (56, 90, and 120 days) in addition to modified rubber by SBR (M1 and M2). The lower in splitting tensile strength for SCC is due to formation of expansive compounds such as ettringite and gypsum. The reaction between hydrated calcium aluminate and sulfate ions (external and internal) led to produce expansive compounds (**Neville, 2011**).

**Table 4.6** Deterioration percentage in splitting strength due to sulfate attack

Mixture symbol	Change in Splitting Tensile Strength % at		
	56 days	90 days	120 days
	For Curing Type (Saline Solution)		
<b>MC</b>	6.1	7.9	23.0
<b>M 4%</b>	4.8	10.0	18.0
<b>M 8%</b>	6.2	21.9	39.3
<b>M 12%</b>	15.4	2.8	10.4
<b>M16%</b>	13.7	7.0	10.3
<b>M1</b>	4.5	13.0	22.5
<b>M2</b>	2.0	8.6	15.1

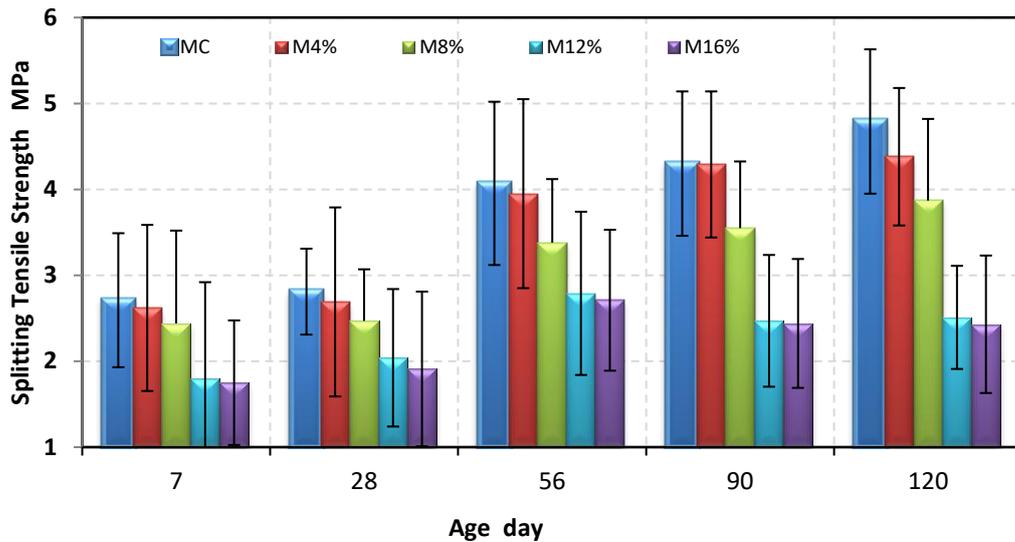


**Figure 4-12** Effect of rubber at different age on exposed ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) curing

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### 4.3.2.3 Effect of Percentage Replacement of Rubber Tyre

For the both exposure, tap water and saline solution environment, the splitting tensile strength decreased into the self-compacting concrete for mixes with higher percentage of rubber tyre replacement. These reductions were 3.3%, 9.9%, 33.5%, and 35.4% at 7 days, 4.2%, 12%, 27%, and 32% at 28 days, 2.9%, 12.7%, 31.4%, and 33.4% at 56 days, 2%, 27.7%, 42.4%, and 43.1% at 90 days, 8.5%, 19.2%, 47.5%, and 49.2% at 120 days for replacing tyre rubber with fine aggregate by 4%, 8%, 12%, and 16% respectively for tap water curing. While, the reductions in the splitting tensile strength were 1.5%, 12.8%, 38.2%, and 38.7% at 56 days, 0.2%, 37.4%, 37.9%, and 41.3% at 90 days, 2.7%, 36.3%, 39%, and 40.9% at 120 days for replacing tyre rubber with fine aggregate by 4%, 8%, 12%, and 16% respectively for saline solution curing as shown in **Figure 4-13**. This reduction in splitting tensile strength can be attributed to the fact that the waste rubber tyre particles associated to the decrease of modulus of elasticity (E) of recycled tyres. In addition to the poor adhesion in the interface region between cement paste and rubber could have been defected initiation from voids formed by the interaction of cement paste and crumb rubber (**Najim and Hall, 2012; Karunarathnaetal., 2021**).

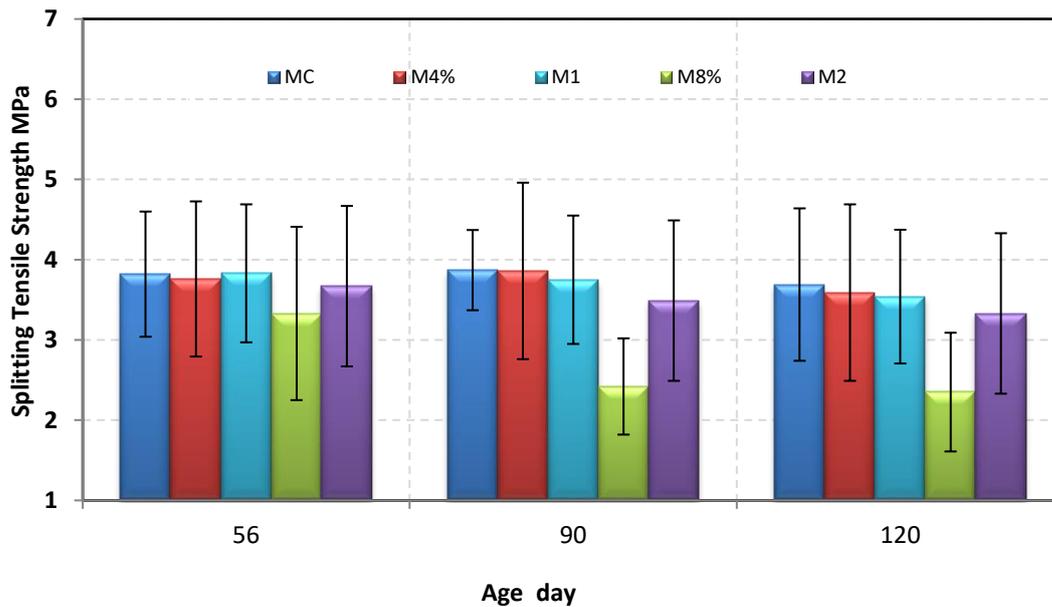


**Figure 4-13** Effect of rubber at deferent age of tap water curing

#### 4.3.2.4 Effect of Coating of Rubber Tyre Particles

The particles of rubber tyre when treated with SBR have noticeable effects on splitting tensile strength of self-compacting concrete as presented in **Table 4.5**, **Figure 4-14** and **Figure 4-15**. For tap water curing, the improve in strength was 6.8%, 15.9%, 1.5%, 2.6%, and 4.3% for 4% of replacing rubber and 3.6%, 10.9%, 5.6%, 23.2%, and 1.2% for 8% of replacing at 7, 28, 56, 90, and 120 days respectively as comparing with same percentage of replacing rubber without treated. SBR provided a high resistance to deterioration due to sulfate attack into the self-compacting concrete for mixtures with replacement 4% and 8% of rubber tyre. The increase in splitting strength was 1.8%, 2.3%, and 4.1% for 4% of replacing rubber and 10.2%, 44.2%, and 41.7% for 8% of replacing at 56, 90, and 120 days respectively as regarding to mixture with same percentage of replacing rubber without treated. SBR maybe help to increase the elastic modulus of concrete containing rubber and improvement of bonding

between the cement paste and rubber particles (Grinys et al., 2020). For that, the film generated by using SBR prevents the formation of micro cracking inside the concrete during the test of until elastic deformation because it is known in fracture mechanics that a hole at the crack tip can arrest the crack growth (a stop-hole effect) (Grinys et al., 2020). **Figure 4-14** Effect of rubber with SBR at different age of tap water curing



**Figure 4-15** Effect of rubber with SBR at different age of exposed  $\text{Cl}^-$  &  $\text{SO}_4^{2-}$  curing

#### 4.3.2.5 The Relationship between the Splitting Tensile Strength and Compressive strength of SCRC

A modelling of the empirical relationship between compressive strength and Splitting Tensile Strength of SCRC has been statistically predicted as presented in **Figure 4-16** and *Equation (4-3)*. The Figure illustrated the increase in compressive strength accompanied by an increase in splitting strength. The percentage Splitting Tensile Strength to compressive strength was about ( 1-/10-1/12).

$$f_{cu} = 0.4153 f_{spt}^{0.5821} \quad (4-3)$$

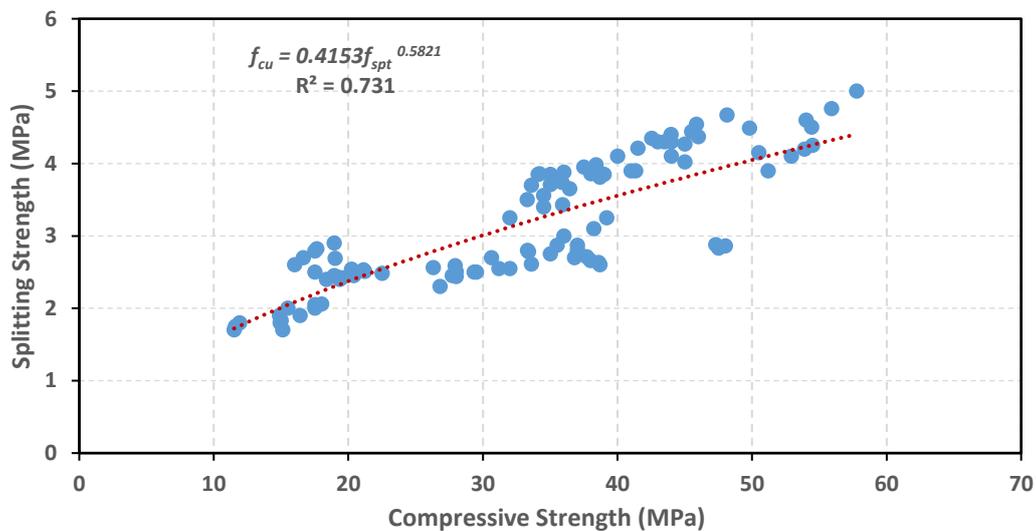
$$R^2 = 0.731$$

Where:

$f_{cu}$  = Compressive strength,

$f_{spt}$  = Splitting tensile strength, and

R = Coefficient for best-fit curve.



**Figure 4-16** Relationship between the Splitting Tensile Strength and compressive strength

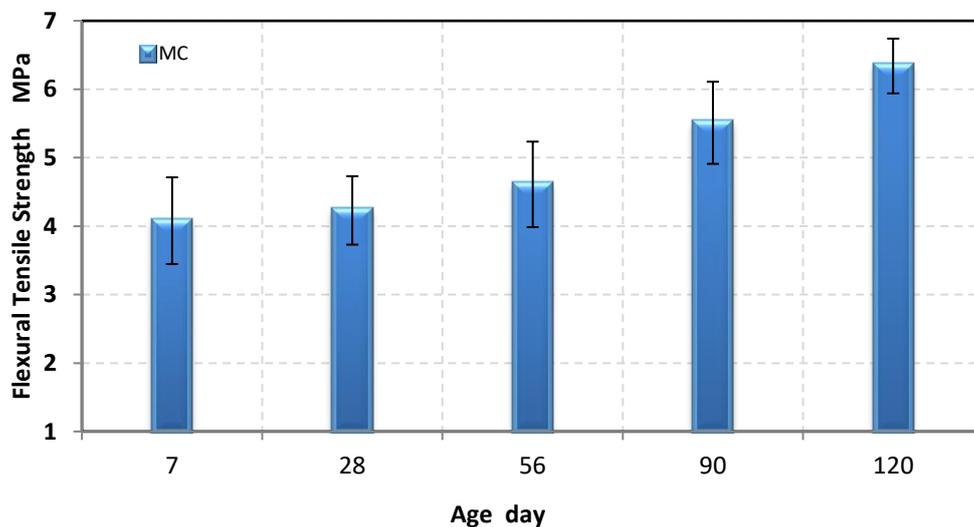
### 4.3.3 Flexural Tensile Strength

Flexural strength is one measure of the tensile strength of SCRC specimens by using simple prism in order to estimate indirect tensile strength of concrete. The treated (by SBR solution) and untreated specimens results for rubber tyre particles are presented in **Table 4.7**, that illustrates the flexural strength at different curing age and type of exposure environment conditions.

The results will be presented according to main factors affecting flexural strength as follows:

### 4.3.3.1 Effect of Age for Normal Curing

Flexural strength results for normal curing (tap water) illustrated an increase in their values with progress age as presented in **Figure 4-17**. The increase was 3.1%, 12.9%, 35% and 55.4% for 28, 56, 90, and 120 days as comparing with 7 days respectively. The improvement of paste matrix in addition to ITZ (interfacial transition zone) between matrix and aggregate denser led to enhance of flexural strength of SCC that having lime stone powder because of filling ability as mentioned in (**Liu and Yan, 2010**).



**Figure 4-17** Effect of age on flexural strength mix control exposed to tap water

**Table 4.7** Result of Flexural Tensile Strength of SCRC mixtures

Mixture symbol	Average of Flexural Tensile Strength Mpa at									
	7 days		28 days		56 days		90 days		120 days	
	Curing Type									
	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution
<b>M C</b>	4.08	-	4.23	-	4.61	4.27	5.51	5.27	6.34	5.54
<b>M 4%</b>	3.90	-	4.01	-	4.31	4.21	4.76	4.48	5.76	4.64
<b>M 8%</b>	3.94	-	3.72	-	4.08	3.93	4.48	4.07	4.68	4.25
<b>M 12%</b>	3.16	-	3.55	-	3.60	3.35	3.71	3.58	4.00	3.88
<b>M16%</b>	3.10	-	3.18	-	3.40	3.29	3.48	3.37	3.57	3.44
<b>M1</b>	4.08	-	4.07	-	4.43	4.32	3.82	4.60	3.93	5.09
<b>M2</b>	4.00	-	4.10	-	4.19	4.13	4.71	4.61	4.74	4.57

- Curing in a tap water

- Saline solution is a mix of  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  Ions solution curing at 28 days as mentioned in Chapter 3

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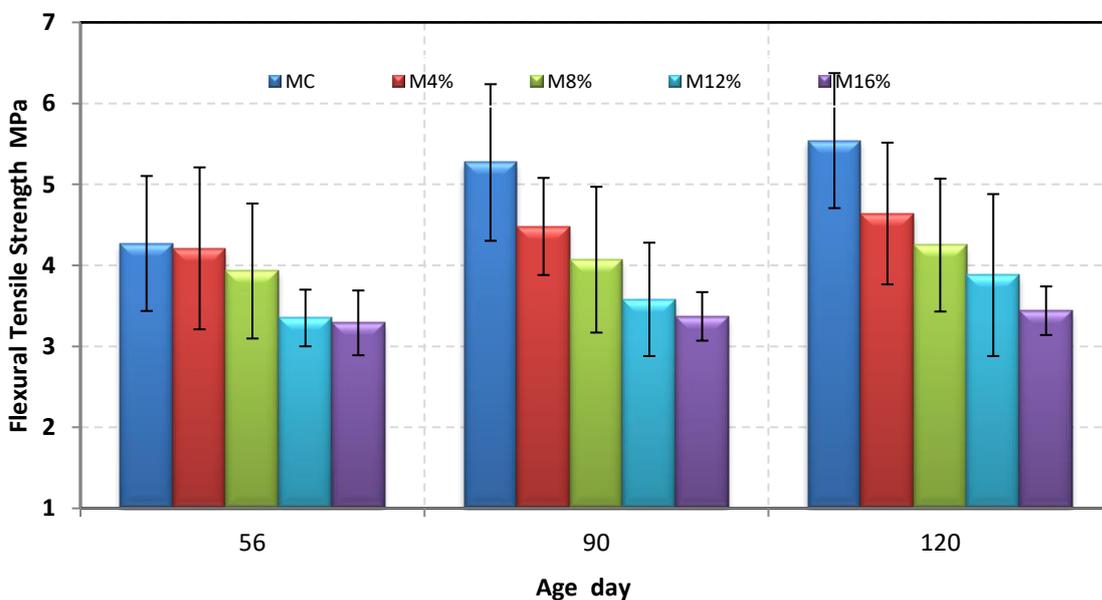
### 4.3.3.2 Effect Saline Solution Curing

**Table 4.8** presents the changes in flexural strength due to saline solution curing. Flexural strength showed a reduction due to the effect of saline curing. This reduction in flexural strength was 7.4%, 4.4%, and 12.6% for 56, 90, and 120 days as comparing with tap curing in the same ages respectively. The diffusion of the solution inside the sample led to accelerate in chemical reaction between the aggressive agent (sulfate and chloride) and cement products. In addition, the higher absorption of the solution for the same time of immersion accelerated the degradation reaction in microstructure of concrete (**Robert et al., 2009; Robert et al., 2013; Govalkar and Lal, 2020**).

Flexural strength for self-compacted concrete containing rubber tyre when exposed to solution ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) showed a degradation as compared with same sample exposed to tap water as illustrated in **Figure 4-18** and **Table 4-8**. Whereas, **Table 4.9** exhibit the reduction in flexural strength (RFS) for samples with rubber content (0, 4, 8, 12, and 16) % for age (56, 90, and 120 days) in addition to modified rubber by SBR (M1 and M2). The formation of ettringite and gypsum (of expansive compounds) led to lower the flexural strength for self-compacted concrete. Hydrated calcium aluminate reaction with external and internal sulphate ions have ability to produce expansive compounds, which effect adversely on flexural strength (**Emiroglu et al., 2007**).

**Table 4.8** Deterioration percentage in Flexural Tensile Strength due to sulfate attack

Mixture symbol	Changes in Flexural Tensile Strength % at		
	56 days	90 days	120 days
	For Curing Type (Saline Solution)		
MC	7.4	4.4	12.6
M 4%	2.3	5.9	19.4
M 8%	3.7	9.2	9.2
M 12%	6.9	3.5	3.0
M16%	5.5	1.5	3.6
M1	2.5	4.6	4.8
M2	1.4	2.1	3.6



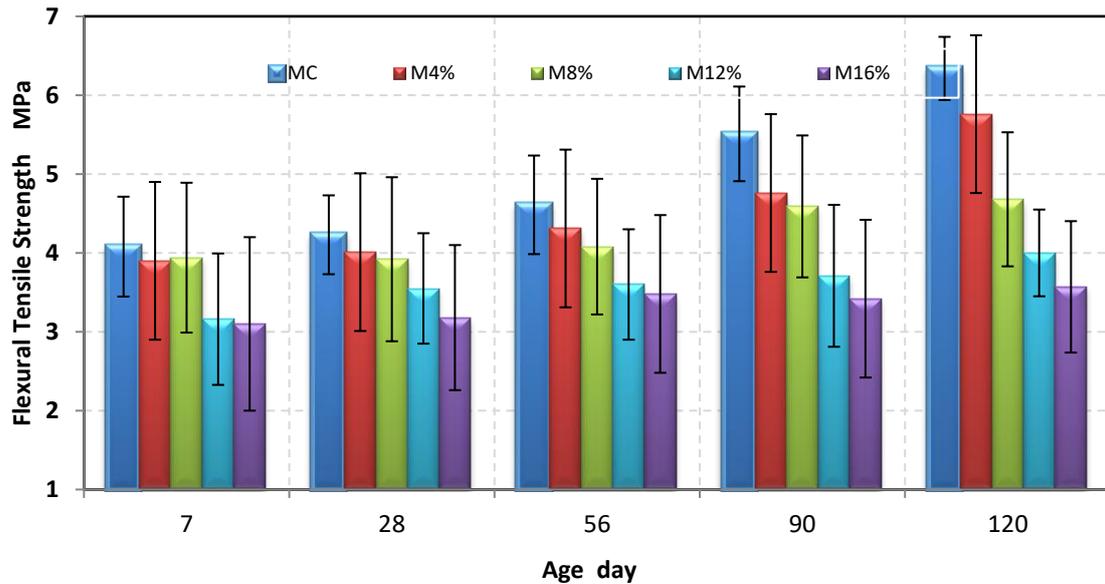
**Figure 4-18** Effect of rubber at different age on Flexural Tensile Strength by exposed (Cl<sup>-</sup>&SO<sub>4</sub><sup>2-</sup>) curing

### 4.3.3.3 Effect of Percentage Replacement of Rubber Tyre

Self-compacting concrete suffering from reduction in flexural strength for the both exposure, tap water and saline solution environment, for mixtures with different percentage replacement rubber tyre. The reductions in flexural strength were presented in **Table 4.9** and **Figure 4-19**. The self-compacted concrete with rubber tyre particles as fine aggregate associated with lowering in flexural strength due to the low modulus of elasticity of recycled tyres. On the other hand, the low adhesion between cement paste and rubber may be defected the interfacial transition zone (ITZ) by propagate voids formed by the interaction of cement paste and crumb rubber (Najim and Hall, 2012; Karunarathna et al., 2021).

**Table 4.9** Redaction in Flexural Strength (%) for SCRC

Redaction in Flexural Tensile Strength (%)								
Mixture symbol	7 days	28 days	56 days		90 days		120 days	
	Curing Type							
	Tap water	Tap water	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution
<b>M 4%</b>	4.4	5.2	6.5	1.4	13.6	15	9.1	16.2
<b>M 8%</b>	3.4	12.1	11.5	8	18.7	22.8	26.2	23.3
<b>M 12%</b>	22.5	16.1	21.9	21.5	32.7	32.1	36.9	30
<b>M16%</b>	24	24.8	24.5	23	37.9	36.1	43.7	37.9

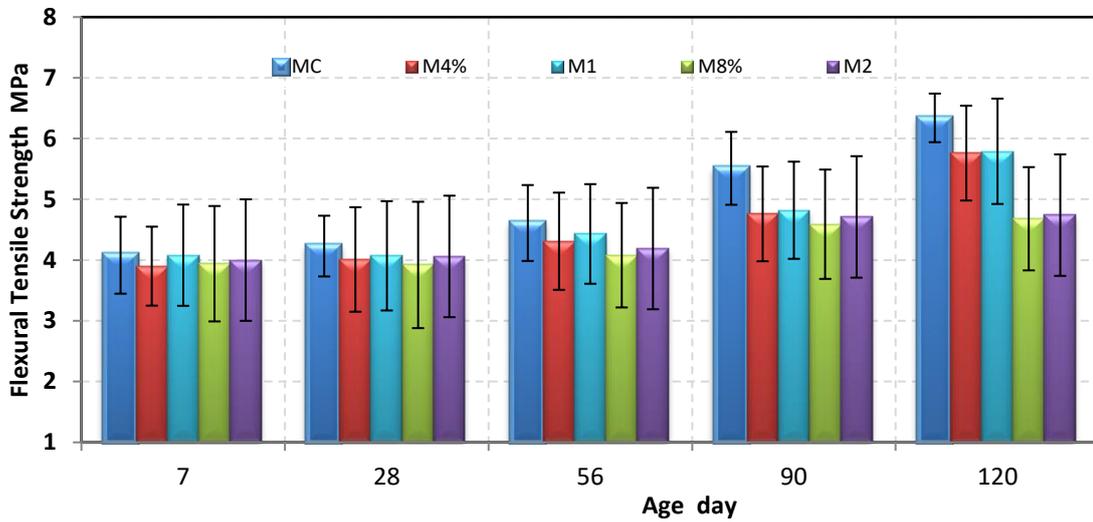


**Figure 4-19** Effect of rubber at different age of tap water curing on Flexural Tensile Strength

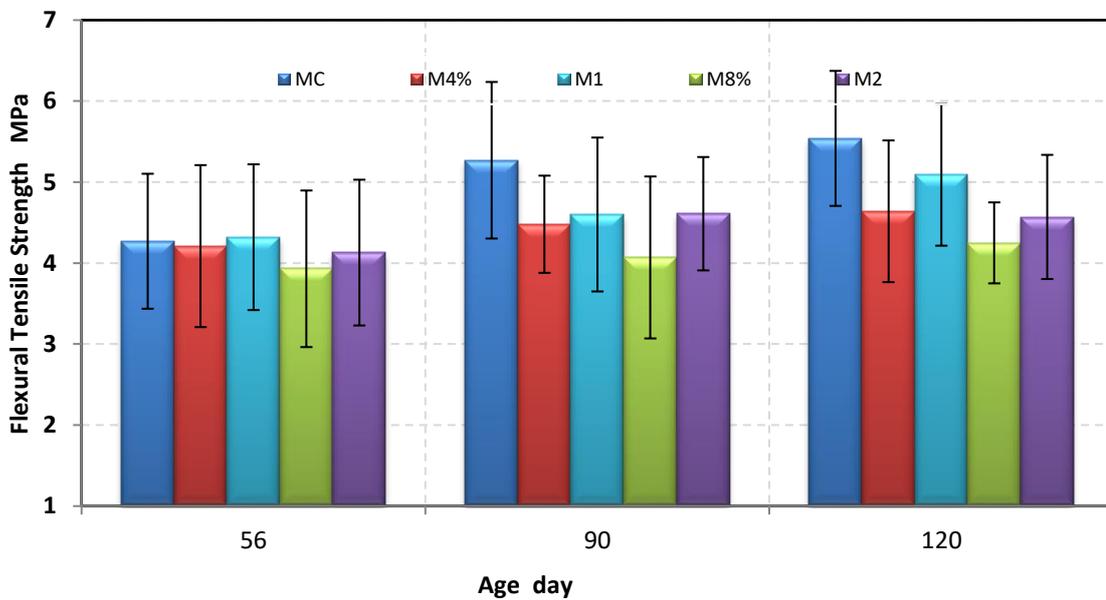
#### 4.3.3.4 Effect of Coating of Rubber Tyre Particles

The SBR have good effects on flexural strength of self-compacting concrete for treated particles of rubber tyre. **Figure 4-20**, **Figure 4-21**, and **Table 4.7** present the results of flexural strength For normal curing (tap water). The enhancement in flexural strength was 1.9%, 3.8%, 3.9%, 12.5%, and 18.7% for 4% of replacing rubber and 2%, 4%, 7.1%, 14.5%, and 25.2% for 8% of replacing at 7, 28, 56, 90, and 120 days respectively as comparing with same percentage of replacing rubber without treated. SBR gave a high resistance to degradation due to sulphate attack into the self-compacting concrete for mixtures with replacement 4% and 8% of rubber tyre. The increase in flexural strength was 1.2%, 8.1%, and 12.5% for 4% of replacing rubber and 3.3%, 12.6%, and 17.5% for 8% of replacing at 56, 90, and 120 days respectively as regarding to mixture with same percentage of replacing rubber without treated. The elastic modulus of concrete containing treated particles of rubber by utilizing SBR may be improved because of enhancing the bond between the cement paste and rubber particles (**Grinys et al., 2020**). The SBR was produced a film that have ability to

prevent the formation of micro cracking inside the concrete under the load (during the test) and withstand crack propagation by arresting the crack growth for that the flexural strength improved (Grinys et al., 2020).



**Figure 4-20** Effect of rubber with SBR at different age of tap water curing



**Figure 4-21** Effect of rubber with SBR at different age of exposed (Cl<sup>-</sup>&SO<sub>4</sub><sup>2-</sup>) solution curing

### 4.3.3.5 The Relationship between the Flexural Tensile Strength and Compressive strength

From the results of compressive strength and flexural strength of SCRC modelling of the empirical relationship between them has been statistically predicted as shown in **Figure 4-22** and *Equation (4-4)*. This Figure shows the increase in compressive strength accompanied by an increase in flexural strength. The percentage flexural strength to compressive strength was about (1/11).

$$f_{cu} = 0.051 f_{ct} + 2.5263 \quad (4-4)$$

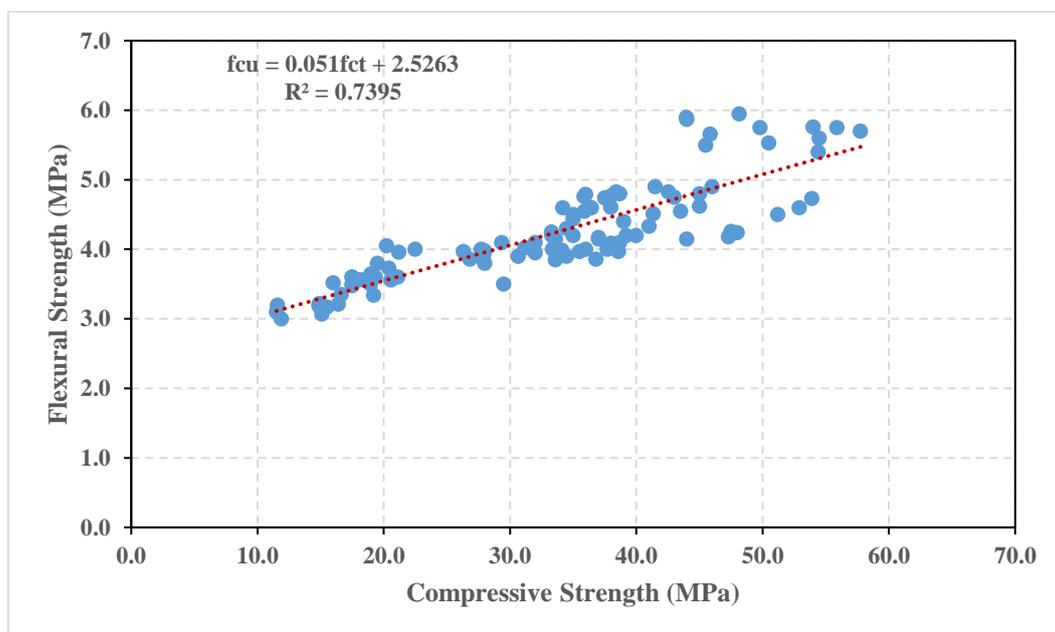
$$R^2 = 0.7395$$

Where:

$f_{cu}$  = Compressive strength,

$f_{ct}$  = Flexural strength, and

R = Coefficient for best-fit curve.



**Figure 4-22** Relationship between the flexural strength and compressive strength

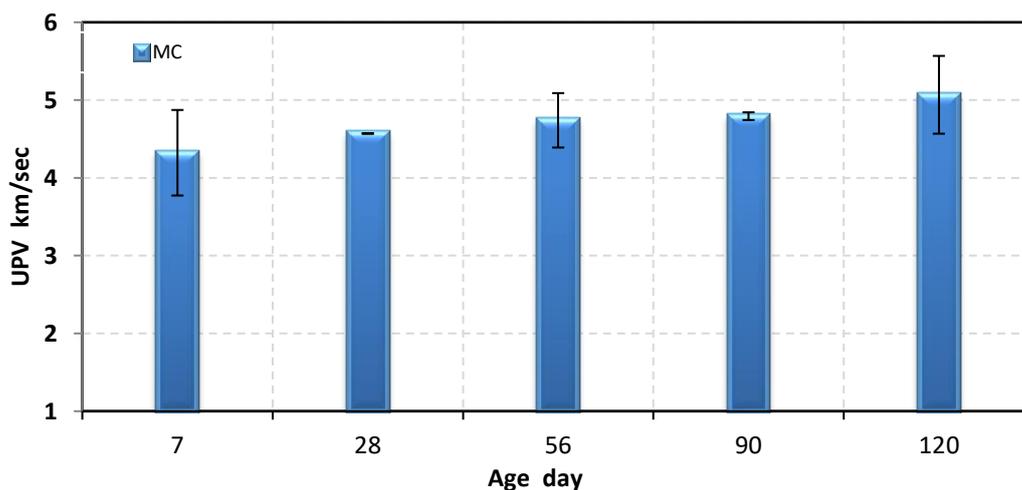
### 4.3.4 Ultrasonic Pulse Velocity Test

The ultrasonic pulse velocity test was conducted for hardened of SCRC carried out at 7, 28, 56, 90 and 120 days with different exposure or immersion in tap water or in saline solution of ( $\text{Cl}^-$  and  $\text{SO}_4^{2-}$ ). Treated rubber tyre particles by SBR solution and untreated samples results are presented in **Table 4.10** that illustrates values of ultrasonic pulse velocity test at various curing age and type of exposure environment.

The main observations from the ultrasonic pulse velocity test results are:

#### 4.3.4.1 Effect of Progress Age for Normal Curing

There is a clear increase in the ultrasonic pulse velocity with increase the curing age for the tap water curing of the control mixture as presented in **Figure 4-23**. The increase in ultrasonic pulse velocity results was 8%, 9.6%, 10.8%, and 17.2% for 28, 56, 90, and 120 days as comparing with 7 days respectively. The increase in velocity of ultrasonic pulse with age due to increase the density of concrete because of cement reaction led to produce more C-S-H and  $\text{Ca}(\text{OH})_2$  and improve the microstructure of concrete (Véronique et al., 2005).



**Figure 4-23** Effect of age on velocity of ultrasonic test for control mixture exposed to tap water

**Table 4.10** Result of Ultrasonic test(UPV) of SCRC mixtures

Mixture symbol	Average of Ultrasonic UPV km/sec at									
	7 days		28 days		56 days		90 days		120 days	
	Curing Type									
	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution
<b>M C</b>	4.323	-	4.670	-	4.740	4.707	4.793	4.740	5.068	4.902
<b>M 4%</b>	4.260	-	4.327	-	4.643	4.600	4.693	4.483	4.632	4.785
<b>M 8%</b>	4.033	-	4.187	-	4.343	4.191	4.247	4.250	4.566	4.534
<b>M 12%</b>	3.672	-	3.697	-	3.953	3.800	3.823	3.757	4.245	4.188
<b>M16%</b>	3.642	-	3.670	-	3.657	3.630	3.790	3.678	4.214	4.017
<b>M1</b>	4.523	-	4.640	-	4.785	4.712	4.866	4.785	4.863	4.785
<b>M2</b>	4.057	-	4.360	-	4.367	4.339	4.566	4.464	4.602	4.573

- Curing in a tap water
- Saline solution is a mix of Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup> Ions solution curing at 28 day as mentioned in Chapter 3

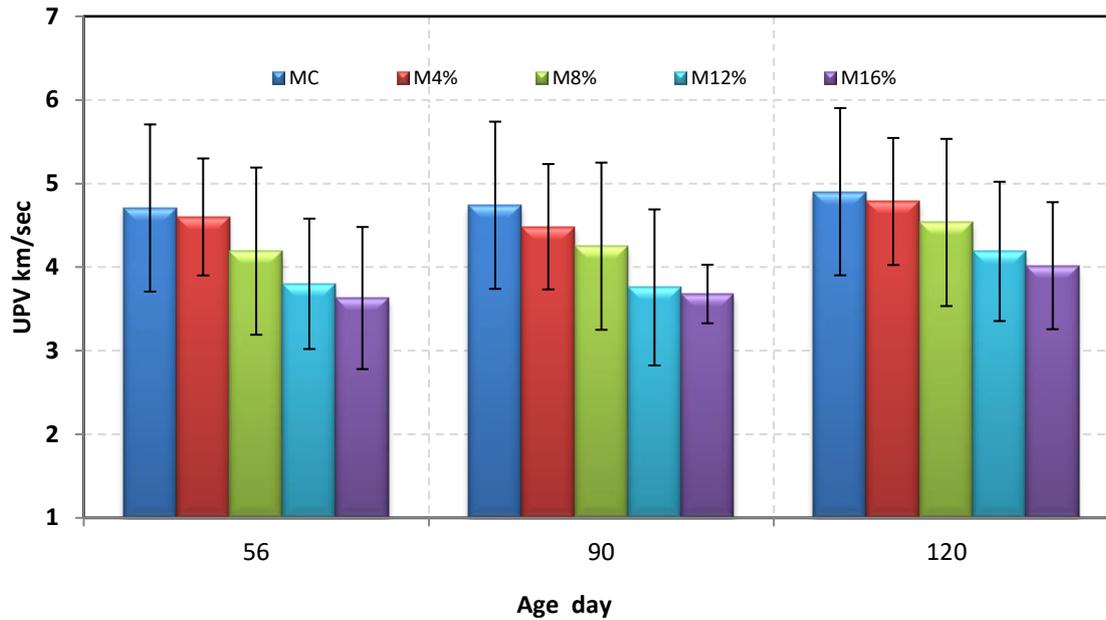
#### 4.3.4.2 Effect of Saline Solution Curing

The results of UPV reduced in the values under saline curing for self-compacted concrete as compared with tap water curing as showed in **Table 4.10**. The reduction in velocity was 0.7%, 1.1%, and 3.2% for 56, 90, and 120 days as comparing with tap curing in the same ages respectively. That reduction was slightly as comparing with the other mechanical properties and that may be because the voids of self-compacted concrete filled with saline solution, which the velocity of pulse ultrasonic increased in wet environment than the dry (**Hwang, 2012**).

Self-compacted Rubberised concrete when exposed to ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) solution exhibited a reduction in velocity of ultrasonic pulse as regarding to sample exposed to normal curing (tap water) as presented in **Figure 4-24**. **Table 4.11** showed the reduction in ultrasonic pulse test (UPV), for samples with rubber content at different percentage (0, 4, 8, 12, 16) % for age (56, 90, and 120 days) in addition to modified rubber by SBR (M1 and M2). The reduction in velocity of ultrasonic pulse was due to deterioration in structure of concrete because ettringite and gypsum formation. These materials are produced by the reaction between hydrated calcium aluminate and sulfate ions (external and internal) (**Neville, 2011**).

**Table 4.11** Deterioration percentage in Ultrasonic test due to sulfate attack

Mixture symbol	Change in Ultrasonic UPV % at		
	56 days	90 days	120 days
	For Curing Type (Saline Solution)		
MC	0.7	1.1	3.3
M 4%	0.9	4.5	3.3
M 8%	3.5	0.1	0.7
M 12%	3.9	2.0	1.3
M16%	0.7	3.0	4.7
M1	1.5	1.7	1.6
M2	0.6	2.2	0.6



**Figure 4-24** Effect of rubber tyre on Pulse velocity test at different age of curing exposed ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) solution

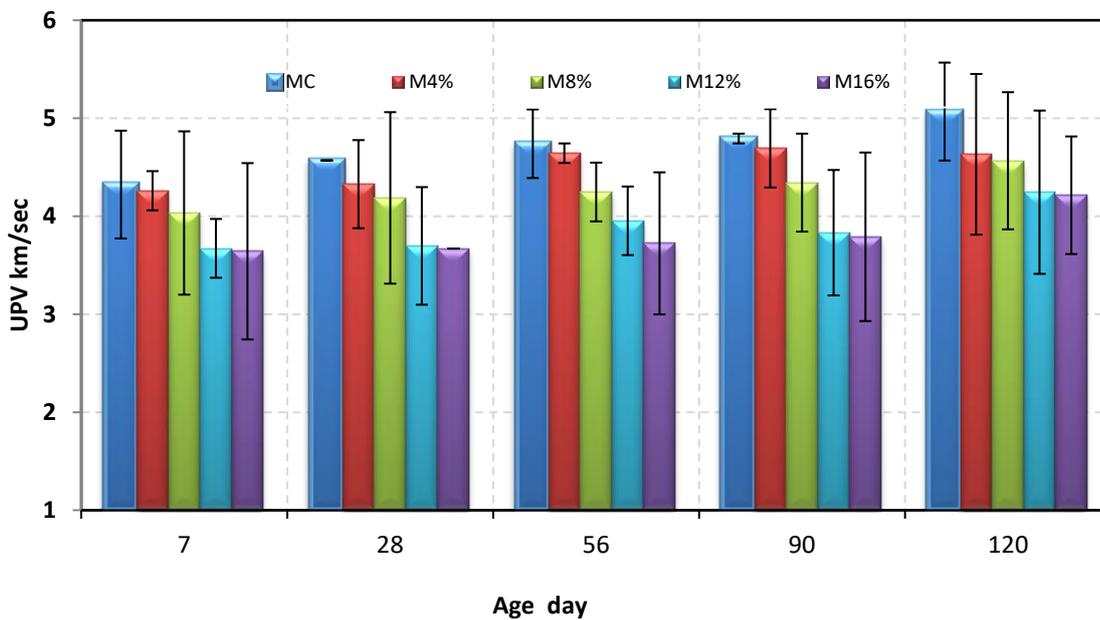
#### 4.3.4.3 Effect of Percentage Replacement of Rubber Tyre

UPV test results recorded a reduction as compressive strength decreases progressively into the self-compacting concrete for mixes with higher percentage replacement for (all exposure condition) as presented in **Table 4.12** and **Figure 4-25**.

The velocity of ultrasonic pulse reduced with increasing percent of utilizing tyre rubber in mixtures was due to lesser stiffness of the substitute material as compared to the surrounding fine aggregate. Generally, the packing of rubber tyre particles became more difficult with high content in addition to the voids are generated in the concrete. All the condition led to lowering the velocity of ultrasonic pulse and that agree with (Benazzouk et al., 2007) (Yung et al., 2013).

**Table 4.12** Reduction percentage in UPV (%) for SCRC

Redaction in UPV (%)								
Mixture symbol	7 days	28 days	56 days		90 days		120 days	
	Curing Type							
	Tap water	Tap water	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution
<b>M 4%</b>	1.5	7.3	2	2.3	2.1	5.4	8.6	2.4
<b>M 8%</b>	6.7	10.3	8.4	11	11.4	10.3	9.9	7.5
<b>M 12%</b>	15.1	20.8	16.6	19.3	20.1	22.4	16.2	14.6
<b>M16%</b>	15.8	21.4	22.8	22.9	20.9	20.7	16.9	18.1

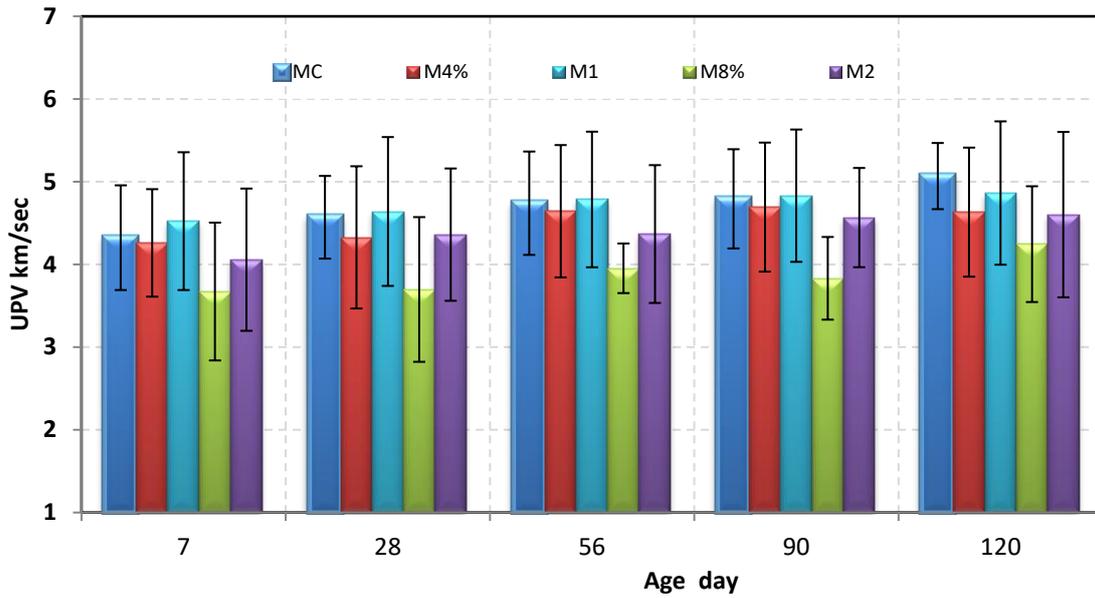


**Figure 4-25** Effect of rubber at deferent age on Pulse velocity test of tap water curing

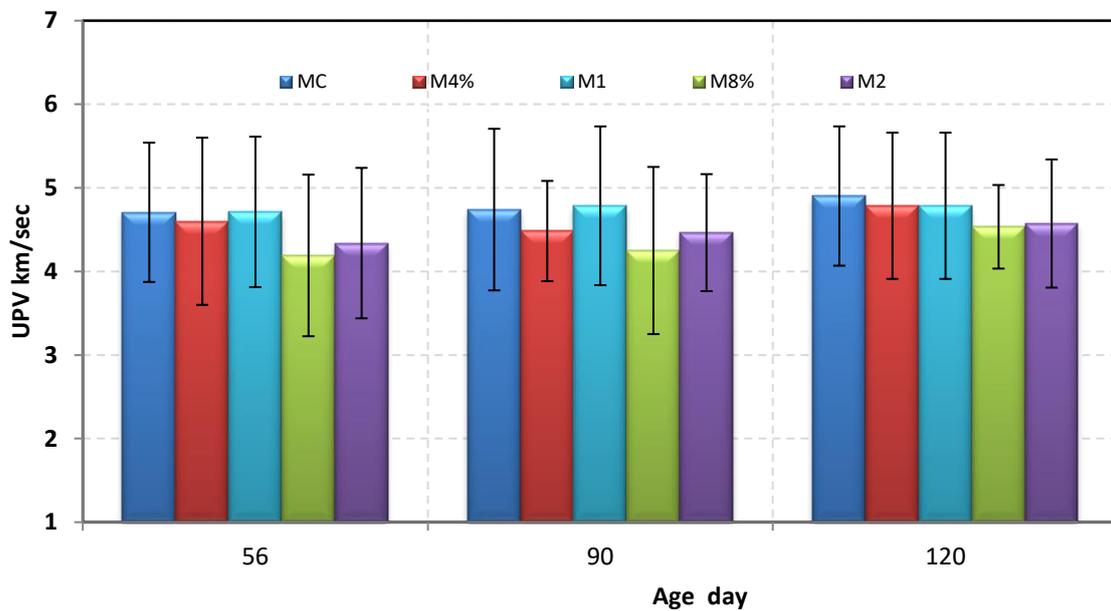
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#### 4.3.4.4 Effect of Coating of Rubber Tyre Particles

SBR solution have an noticeable impact on UPV when treatment of rubber tyre particles and resistance to deterioration due to sulfate attack into the self-compacting concrete for mixtures with replacement 4% and 8% rubber tyre as shown in **Table 4.10**, **Figure 4-26** and **Figure 4-27**. With normal curing (tap water), the improvement in UPV test was 4.6%, 0.6%, 1.5%, and 4% for 4% of replacing rubber and 6.2%, 6.6%, 7.9%, 4.7%, and 9.2% for 8% of replacing at 7, 28, 56, 90, and 120 days respectively as comparing with same percentage of replacing rubber without treated. SBR provided a high resistance to deterioration due to sulfate attack into the self-compacting concrete for mixtures with replacement 4% and 8% of rubber tyre. The increase in velocity of ultrasonic pulse test was 0.1%, 0.9%, and 2.4% for 4% of replacing rubber and 7.8%, 5.8%, and 6.7% for 8% of replacing at 56, 90, and 120 days respectively as regarding to mixture with same percentage of replacing rubber without treated. The SBR coat of the rubber particles could alter the mechanism of failure in sample due to enhance of bonding between the cement paste and rubber particle that enhancing the velocity of ultrasonic pulse of samples in mixtures M1 and M2 (**Ling et al., 2009**). By improving compressive strength of mixture with rubber aggregate modified with SBR led to enhance the microstructure and lowering the percent of voids for that, the velocity of ultrasonic pulse will be increased (**Audrius et al., 2020**).



**Figure 4-26** Effect of rubber with SBR at different age on pulse velocity test of tap water curing



**Figure 4-27** Effect of rubber with SBR at different age tyre on pulse velocity test of exposed (Cl<sup>-</sup>&SO<sub>4</sub><sup>2-</sup>) solution curing

**Table 4.13** classifies the quality of concrete based on the pulse velocity that is possible according to **(IS 13311: Part 1, 1992)**.

**Table 4.13:** Ultrasonic Pulse Velocity Ratings for Concrete Quality Grading

<b>Pulse velocity (m/s)</b>	<b>Quality Grade of Concrete</b>
> 4500	Excellent
3500-4500	Good
3000 – 3500	Medium
< 3000	Doubtful

According to **(IS 13311: Part 1, 1992)**, all SCRC were found to have good and excellent quality as shown in **Table 4.14**.

**Table 4.14** .The Effect Rubber of Self compacting concrete on Quality

Mixture symbol	Average of Ultrasonic UPV km/sec at									
	7 days		28 days		56 days		90 days		120 days	
	Curing Type									
	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution
<b>M C</b>	Good	-	Good	-	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
<b>M 4%</b>	Good	-	Good	-	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
<b>M 8%</b>	Good	-	Good	-	Good	Good	Good	Good	Excellent	Excellent
<b>M 12%</b>	Good	-	Good	-	Good	Good	Good	Good	Good	Good
<b>M16%</b>	Good	-	Good	-	Good	Good	Good	Good	Good	Good
<b>M1</b>	Good	-	Good	-	Good	Excellent	Excellent	Excellent	Excellent	Excellent
<b>M2</b>	Good	-	Good	-	Good	Good	Excellent	Excellent	Excellent	Excellent

#### 4.3.4.5 Predicting the Compressive Strength from UPV

As presented in the results of compressive strength and UPV for SCRC, an empirical relationship between them can be statistically predicted. **Figure 4-28** and **Equation (4-5)** illustrated the increase in compressive strength accompanied by an increase in speed of UPV test. The percentage UPV to compressive strength was about 5/10).

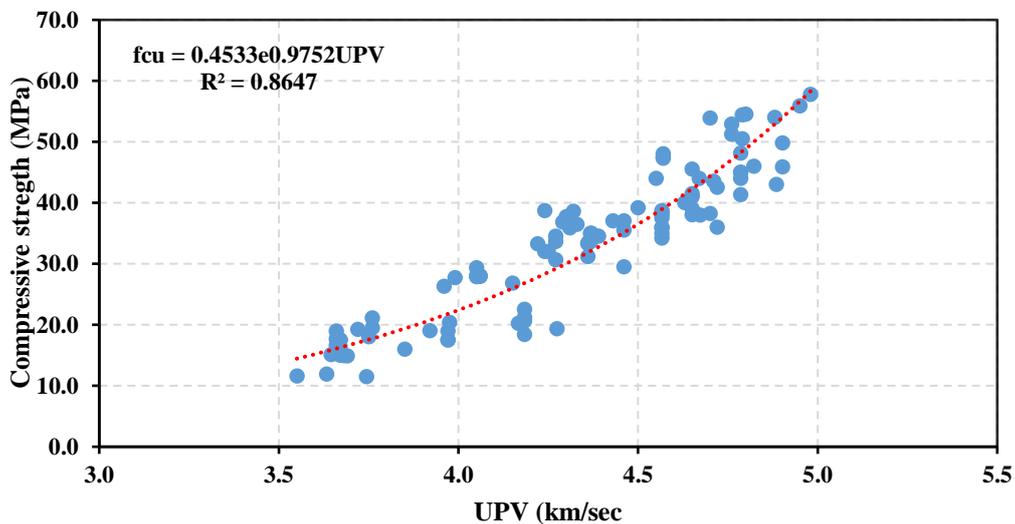
$$f_{cu} = 0.4533e^{0.9752UPV} \quad (4-5)$$

$$R^2 = 0.8647$$

Where:

X= Compressive strength,

R= Coefficient for best-fit curve.



**Figure 4-28** Relationship between the UPV and compressive strength

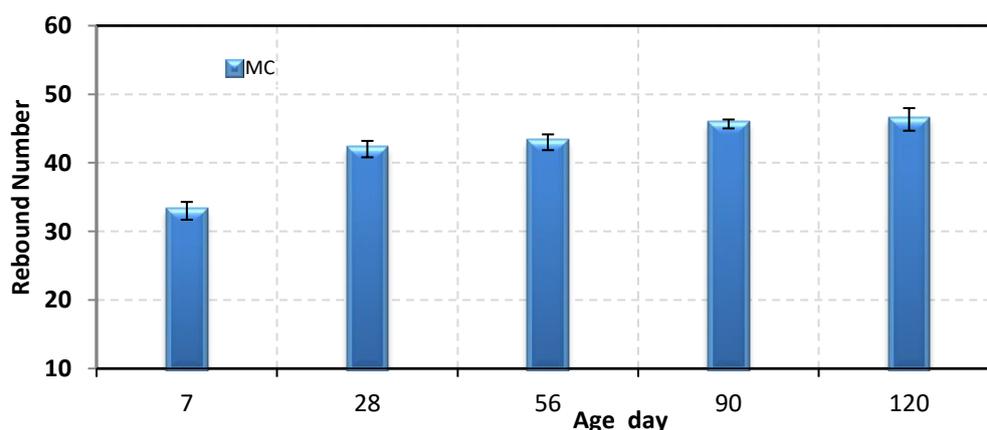
### 4.3.5 Schmidt Hammer Test

The test of Schmidt hammer gives an indication for some of the SCRC properties such as strength and hardness. Results of Schmidt hammer test (rebound number) including the test for specimens with utilizing rubber tyre as partial replacing of aggregate at different percentage and the results of test for treated rubber tyre particles by SBR solution and untreated samples at various curing age and type of exposure environment are presented in **Table 4.13**

Key observations from the Schmidt hammer results are in next sections:

#### 4.3.5.1 Effect of Age for Normal Curing

There is a significant increase in the Schmidt hammer results with age under tap water curing. The increase was 27.2%, 30.3%, 38.4% and 44.4% at 28, 56, 90, and 120 days as comparing with 7 days respectively. The increase in rebound number with progress age that refers to develop the surface and microstructure of concrete and lower the voids because of cement reaction led to produce more C-S-H and  $\text{Ca}(\text{OH})_2$  and improved of concrete density (**Dai et al., 2021**). Where the results of rebound number of Schmidt hammer test are presented in **Figure 4-29** and **Table 4.15**.



**Figure 4-29** Effect of age rebound number for Rebound number for control mixture exposed to tap water

**Table 4.15** Result of Schmidt hammer test (Rebound number) of SCRC mixtures

Mixture symbol	Average of Rebound number at									
	7 days		28 days		56 days		90 days		120 days	
	Curing Type									
	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution
<b>M C</b>	33	-	42	-	43	41	46	44	46	45
<b>M 4%</b>	34	-	36	-	40	39	41	39	44	42
<b>M 8%</b>	30	-	31	-	35	33	37	37	38	36
<b>M 12%</b>	21	-	24	-	25	24	26	25	28	27
<b>M16%</b>	20	-	22	-	24	23	25	24	62	25
<b>M1</b>	35	-	36	-	40	39	41	40	42	41
<b>M2</b>	30	-	35	-	35	34	37	36	38	37

- Curing in a tap water
- Saline solution is a mix of  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  Ions solution curing at 28 day as mentioned in Chapter 3

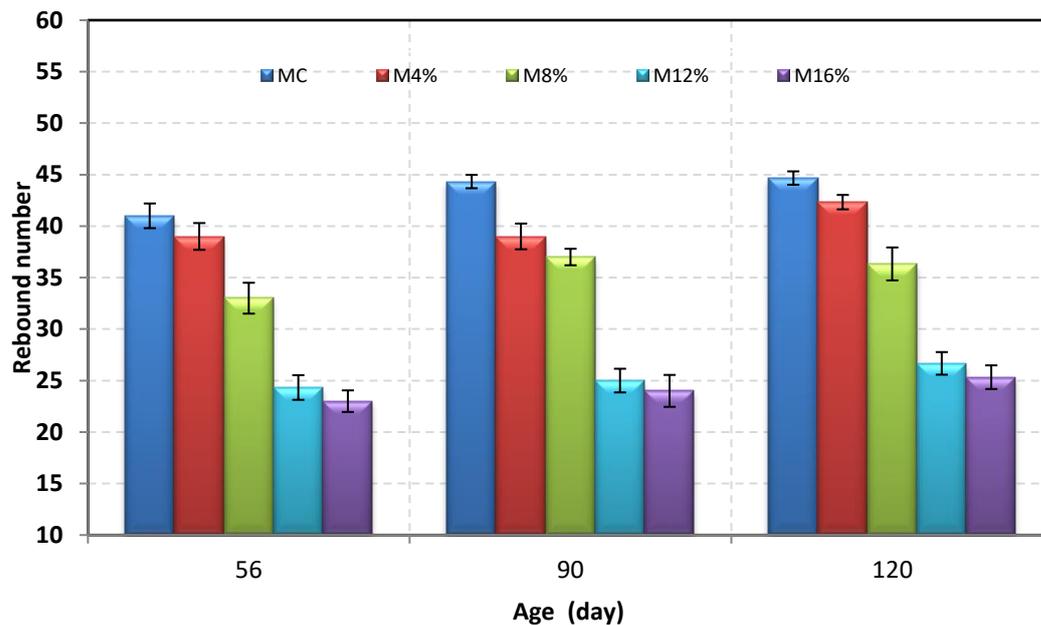
### 4.3.5.2 Effect of Saline Solution Curing

The saline curing for self-compacted concrete suffered from decrease in rebound number of Schmidt hammer test as compared with tap water curing. The reduction in rebound number was 4.7%, 2.9%, and 3.6% for 56, 90, and 120 days as comparing with tap curing at the same ages respectively as showed in **Table 4.15**. As compressive strength, the rebound number of Schmidt hammer tested a reduction when exposed to saline solution of chloride and sulfate (**Govalkar & Lal, 2020**).

When self-compacted concrete was exposed to ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) solution exhibited a lowering in rebound number as regarding to sample exposed to normal curing (tap water) are presented in **Figure 4-30**. **Table 4.16** showed the reduction in rebound number (RN) for samples with rubber content at different percentage (0, 4, 8, 12, 16) % for age (56, 90, and 120 days) in addition to modified rubber by SBR (M1 and M2). The reduction in rebound number was conformable with the other mechanical tests (compressive, splitting and flexural strength) due to formation of expansive compounds (ettringite and gypsum) resulting the reaction between external sulfate ions (in saline solution) and internal sulfate ions in concrete components with hydrated calcium aluminate (**Neville, 2011**).

**Table 4.16** Deterioration percentage in Rebound number due to sulfate attack

Mixture symbol	Change in Rebound number % at		
	56 days	90 days	120 days
	For Curing Type (Saline Solution)		
<b>MC</b>	4.7	2.9	3.6
<b>M 4%</b>	2.5	4.9	3.1
<b>M 8%</b>	4.3	0.9	3.4
<b>M 12%</b>	2.7	5.1	3.0
<b>M16%</b>	4.2	4.0	3.8
<b>M1</b>	2.5	4.0	3.1
<b>M2</b>	2.8	3.6	3.5



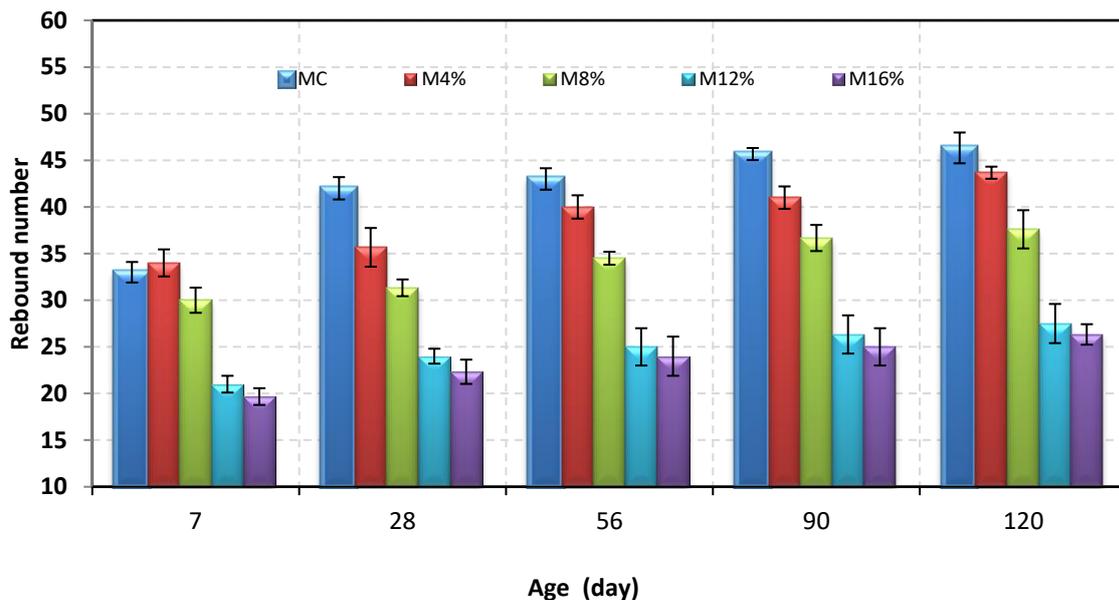
**Figure 4-30** Effect of rubber tyre on rebound number at different age of curing exposed ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) solution

#### 4.3.5.3 Effect of Percentage Replacement of Rubber Tyre

With utilizing rubber tyre as fine aggregate for the both exposure, tap water and saline solution environment, the rebound number for schmidt hammer test presented a decrease into the self-compacting concrete. These reductions are shown in **Table 4.17** and **Figure 4-31**. The Rebound number reduction with increasing percent of utilizing tyre rubber in mixtures was due to significant different between the modulus of elasticity for rubber aggregates and hardened cement paste. In addition, the poor adhesion in the interface region between cement paste and recycled rubber could have been defected initiation from voids formed by the interaction of cement paste and crumb rubber molecules especially in un-treatment samples (**Khalid and Matthew, 2012**).

**Table 4.17** Redaction in rebound number (%) for SCRC

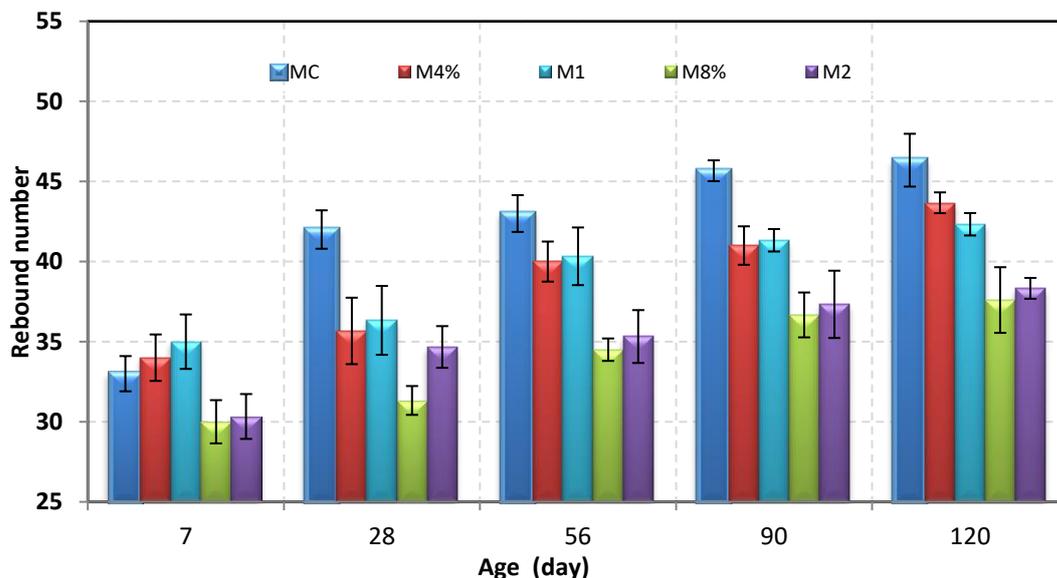
Redaction in Rebound Number (%)								
Mixture symbol	7 days	28 days	56 days		90 days		120 days	
	Curing Type							
	Tap water	Tap water	Tap water	Saline Solution	Tap water	Saline Solution	Tap water	Saline Solution
<b>M 4%</b>	3	15.1	7	4.9	10.2	12	5.7	5.2
<b>M 8%</b>	9.1	25.4	19.8	19.5	19.7	16.5	18.8	18.7
<b>M 12%</b>	36.4	42.9	41.9	40.7	42.3	43.6	40.6	40.3
<b>M16%</b>	40.4	46.8	44.2	43.9	45.3	45.9	43.2	43.3

**Figure 4-31** Effect of rubber at deferent age on Rebound number of tap water curing

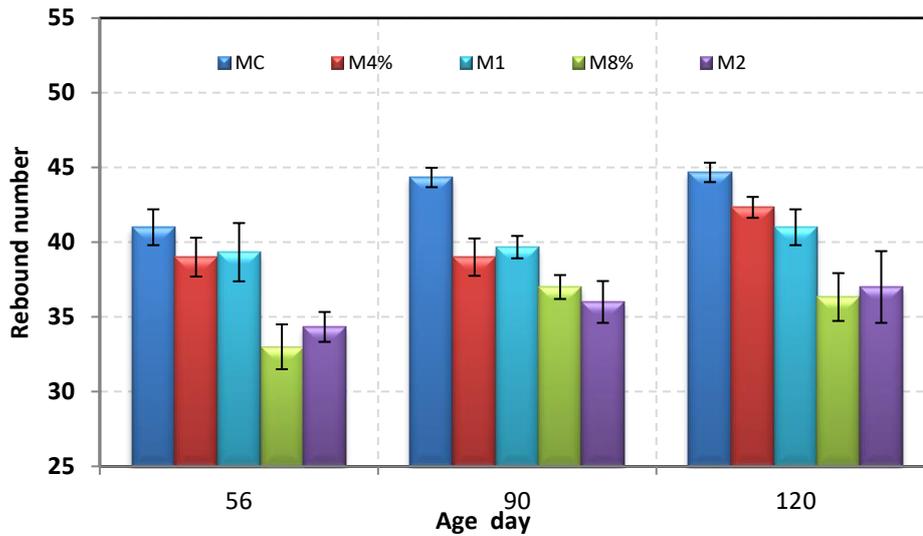
#### 4.3.5.4 Effect of Coating of Rubber Tyre Particles

Treatment of rubber tyre particles by using SBR has a positive influence on the Rebound number and withstand to deterioration due to sulfate attack into the self-compacting concrete for mixtures with replacement 4% and 8% rubber tyre as shown

in Table 4.15 and Figure 4-32 and Figure 4-33. With tap water curing, the improvement in rebound number was 6.1%, 7.5%, 9.3%, 10.6%, and 12.1% for 4% of replacing rubber and 8.6%, 10.2%, 11.6%, 13.4%, and 14.3% for 8% of replacing at 7, 28, 56, 90, and 120 days respectively as comparing with same percentage of replacing rubber without treated. SBR provided a high resistance to deterioration due to sulfate attack into the self-compacting concrete for mixtures with replacement 4% and 8% of rubber tyre. The increase in rebound number was 0.8%, 1.7%, and 3.1% for 4% of replacing rubber and 1.8%, 2.7%, and 4.7% for 8% of replacing at 56, 90, and 120 days respectively as regarding to mixture with same percentage of replacing untreated rubber tyre particles. The SBR coat of the rubber particles could modify the mechanism of failure in sample due to enhance of bonding between the cement paste and rubber particle that improve the rebound number of samples in mixtures M1 and M2. Rebound number results was depending on compressive strength results for that, SBR admixtures which, in turn strengthens the bonding characteristics between cement paste and the surface of rubber aggregates by ‘bridging the gaps (Grinys et al., 2020).



**Figure 4-32** Effect of rubber with SBR at different age on Rebound number of tap water curing



**Figure 4-33** Effect of rubber with SBR at different age tyre on Rebound of exposed ( $\text{Cl}^-$ - $\text{SO}_4^{2-}$ ) solution curing

#### 4.3.5.5 Predicting the Compressive Strength from Rebound Number

A relationship can be predicted (modelling of the empirical) between the results of compressive strength and rebound number for SCRC from the results obtained in this work. As presented in **Figure 4-34** and **Equation (4-6)** the increase in compressive strength is accompanied by an increase in rebound number. The percentage rebound number to compressive strength was about ( 9/10).

$$f_{cu} = 0.0768 RN^{1.7107} \quad (4-6)$$

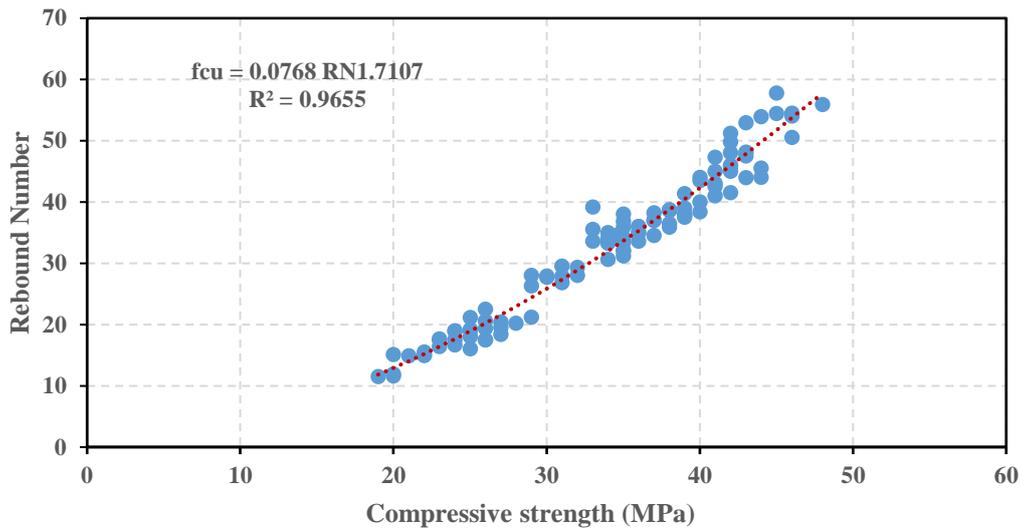
$$R^2 = 0.9655$$

Where:

$f_{cu}$  = Compressive strength,

RN = Rebound Number, and

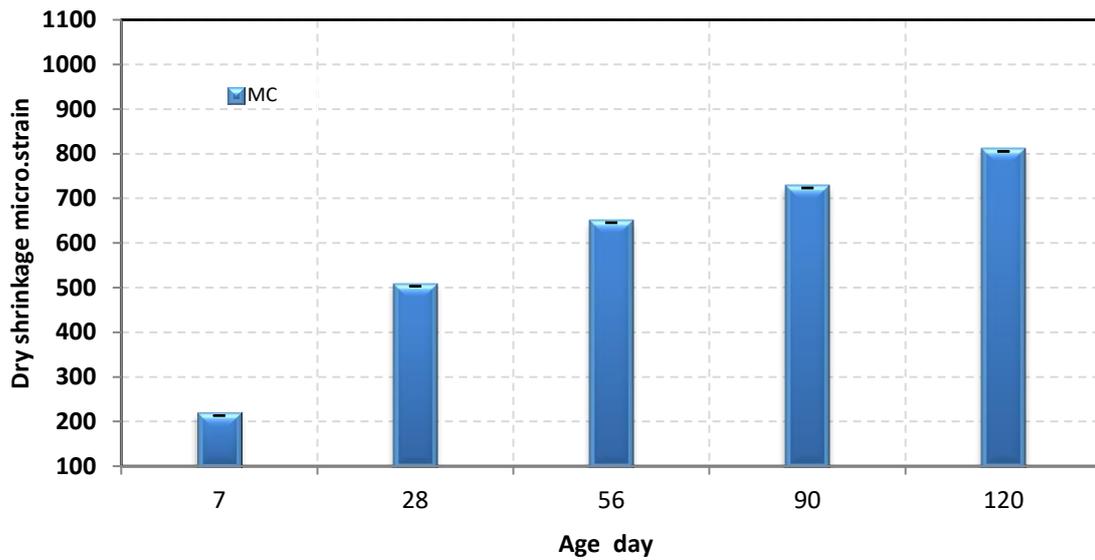
R = Coefficient for best-fit curve.



**Figure 4-34** Relationship between the rebound number and compressive strength

#### 4.3.6 Drying Shrinkage

The drying shrinkage test results for various self-compacted Rubberised concrete mixes containing rubber tyre as fine aggregate up to 120 days are shown in **Table 4.18**. For control mixture, the drying shrinkage progressed with increasing age after curing in tap water for 7 days as illustrated in **Figure 4-35**. The increase in drying shrinkage was 135.9%, 202.6%, 239%, and 277.5% for 28, 56, 90, and 120 days as comparing with 7 days. The rate of increase in shrinkage for self-compacted concrete reduced with time especially after age of 56 days. This behaviour of drying shrinkage was clear and conformable with other researchers (**Bouhamou et al., 2013**) (**Gesoglu et al., 2015**) (**Abdalmid et al., 2019**).



**Figure 4-35** Dry shrinkage development with age for control mix

**Table 4.18** Result of drying shrinkage of SCRC mixtures

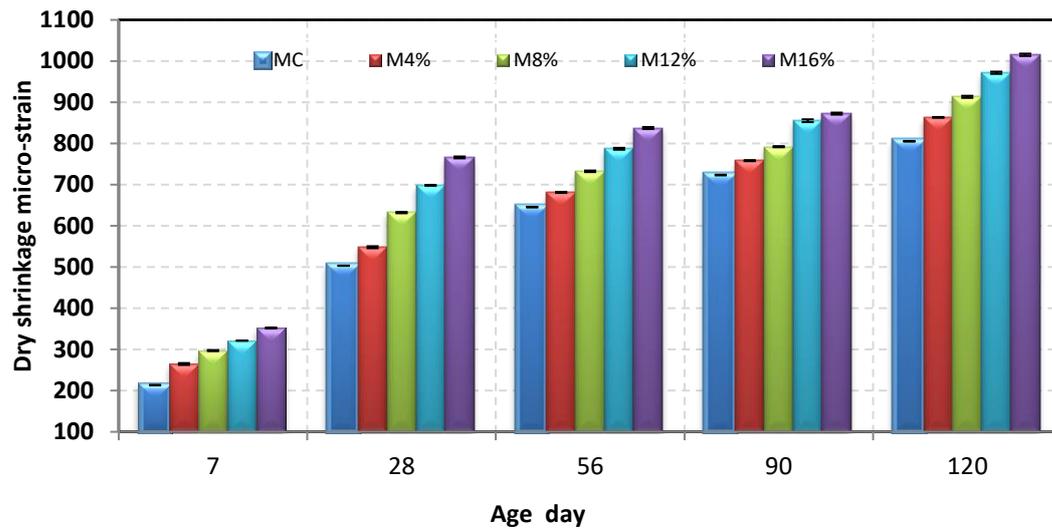
Mixture symbol	Average of dry shrinkage (micro strain)				
	7 days	28 days	56day	90day	120day
	Curing in tap water				
<b>MC</b>	213.33	503.18	645.53	723.34	805.25
<b>M 4%</b>	264.67	548.23	681.37	758.32	863.32
<b>M 8%</b>	297.22	632.19	732.42	792.18	913.20
<b>M 12%</b>	321.35	698.38	787.15	855.25	971.63
<b>M16%</b>	352.16	766.21	837.57	872.48	1015.22
<b>M1</b>	242.56	513.29	623.47	703.12	818.16
<b>M2</b>	273.45	604.73	686.91	748.52	867.09

With utilizing tyre rubber as partial replacement of sand, the drying shrinkage increased with increasing percent of replacement as presented in **Figure 4-36**. The increase in shrinkage strain was 24.1%, 9%, 5.6%, 4.8%, and 7.2% for 4% of rubber and 39.3%, 25.6%, 13.5%, 9.5%, and 13.4% at 8% of rubber and 50.6%, 38.8%, 21.9%, 18.2%, and 20.7% at 12% of rubber, and 65.1%,

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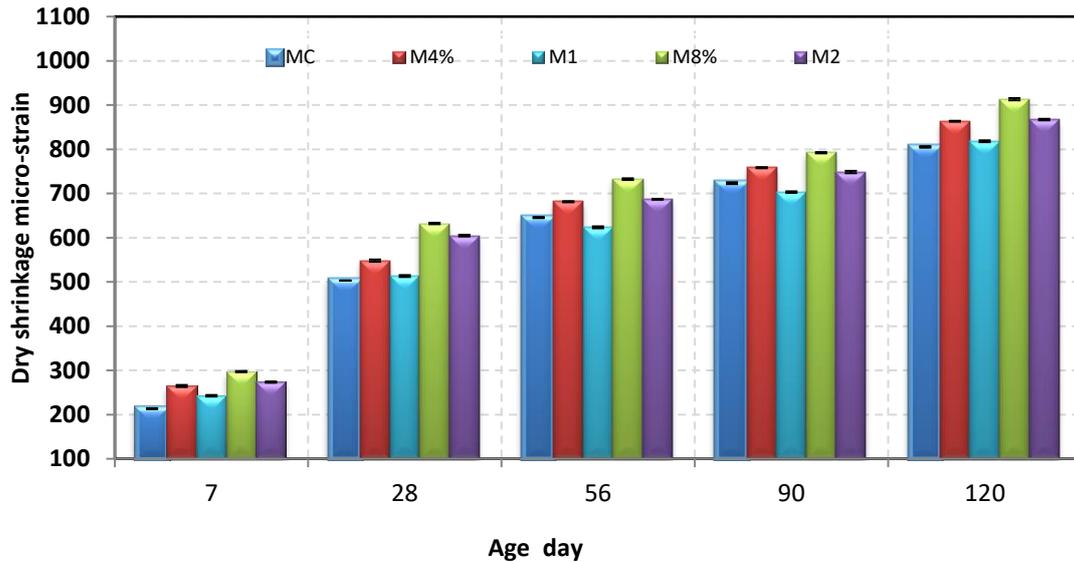
52.3%, 29.7%, 20.6%, and 26.1% for 16% of rubber at 7, 28, 56, 90, and 120 days respectively as comparing with control mixture. The tyre rubber content led to change the moisture diffusion in material and restrain rubber particles effect. The rubber stiffness was lesser than the cement paste (and natural sand) for that the shrinkage could increase (**Roziere et al., 2007**). From the literature, it is known that drying shrinkage of self-compacted concrete increases with increase of porosity. For that, addition of rubber had a significant impact of lowering drying shrinkage as mention by (**ayfun and Ilker, 2010**). **Sukontasukkul and Tiamlom, 2012** observed that, with increasing the replacement percentage of rubber instead of fine aggregate leads to greater shrinkage percent in the mixture due to the lack of natural sand causes a higher decrease of internal restraints and that agreed upon by many researchers (**Kang, and Jiang 2008; Bravo and Brito, 2012; Yung, et al., 2013**).

Higher drying shrinkage of SCC with rubber can be attributed to the effect of increase of the air content (porosity) for these mixtures in comparison to the mixture without rubber. Increasing porosity means more pores (micro and macro) that can lead to an increase in the number and width of the paths of water migration from the concrete to the atmosphere, which in turn results in high shrinkage. High deformability (low stiffness) of the rubber increase the drying shrinkage as regarding to natural sand particles. The low stiffness of the rubber particles provides less restraining against the drying induced deformation when used in the concrete mix. Thus, causing high shrinkage strains for the rubberised concrete in comparison to the sand particles, which provide high restraining effect, hence less drying shrinkage strains (**Khaleel et al., 2017**).



**Figure 4-36** Effect of rubber tyre on dry shrinkage at different age

As shown in **Table 4.18** and **Figure 4-37** utilizing SBR has a positive effect on decrease the drying shrinkage of SCC. The reduction in shrinkage strain was 8.4%, 6.4%, 8.5%, 7.3%, and 5.2% for M1 mixture as comparing with M4% for 7, 28, 56, 90, and 120 days respectively. While, the reduction was 9%, 5%, 6.7%, 5.8%, and 5.3% for M2 mixture as comparing with M8% for 7, 28, 56, 90, and 120 days respectively.



**Figure 4-37** Effect of rubber tyre modified with SBR on dry shrinkage of different age

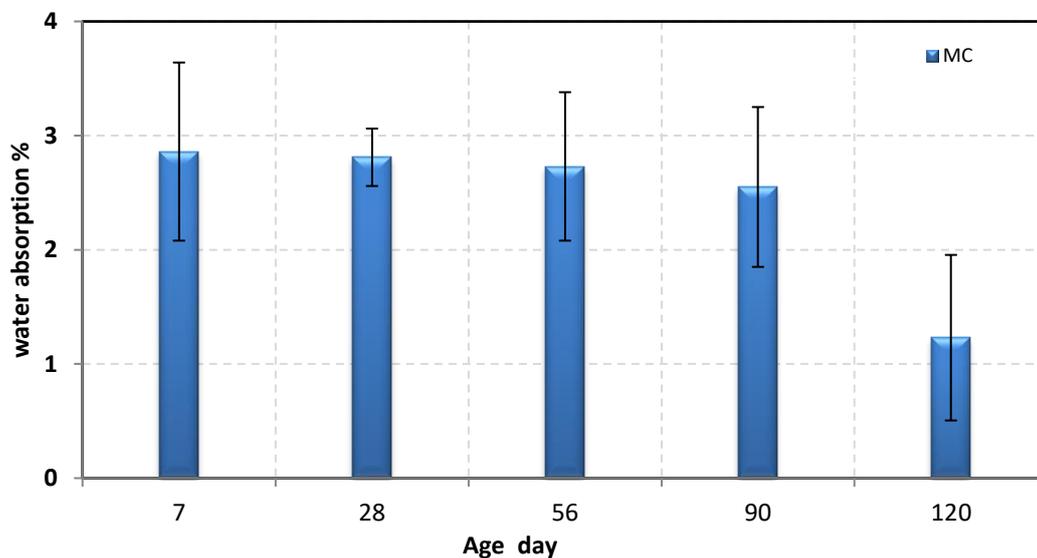
The mechanical properties of self-compacted concrete improved led to enhance the microstructure of concrete. For that, with utilizing SBR for medication the SCC with rubber particles properties by coated with thin film, the drying shrinkage worked to reduce the percent of porosity as well (Turatsinze et al., 2007). This attribute may be due to bridging the interfacial crack between cement paste and fine aggregate and more arrested of hardened concrete against shrinkage strain (Li et al., 2016).

#### 4.4 Durability

The durability of SCRC considers one of the most important relevant issues. For examining the durability of self-compacted concrete containing rubber as partial replacing fine aggregate (treated with SBR and untreated) different tests were conducted. Water absorption, surface absorption (conducted at 7, 28, 56, 90, and 120 days), and chloride migration coefficient, chloride penetration, and chloride concentration (conducted at age as shown in chapter 3) depending on the test.

#### 4.4.1 Water Absorption

**Table 4.19** and **Figure 4-38** illustrate the total water absorption percentage for self-compacted concrete with different percentage of rubber. Based on the experimental results of test for control mix, water absorption lowered with progressing the age. The reduction was 1.7%, 4.5%, 10.8%, and 57% for 28, 56, 90, and 120 days as comparing with water absorption at 7 days respectively. The reduction in water absorption of self-compacted concrete with age refers to improve the microstructure of concrete. The cement hydration products (C-S-H and  $\text{Ca}(\text{OH})_2$ ) led to fill the voids in addition to the particles of lime stone powder could have acted to precipitate of C-S-H for that the cement hydration increased. Generally, the interfacial transition zones improved and that led to reduce the percent of porosity and water absorption (**Chen and Kwan, 2012**) (**Li and Kwan, 2015**).

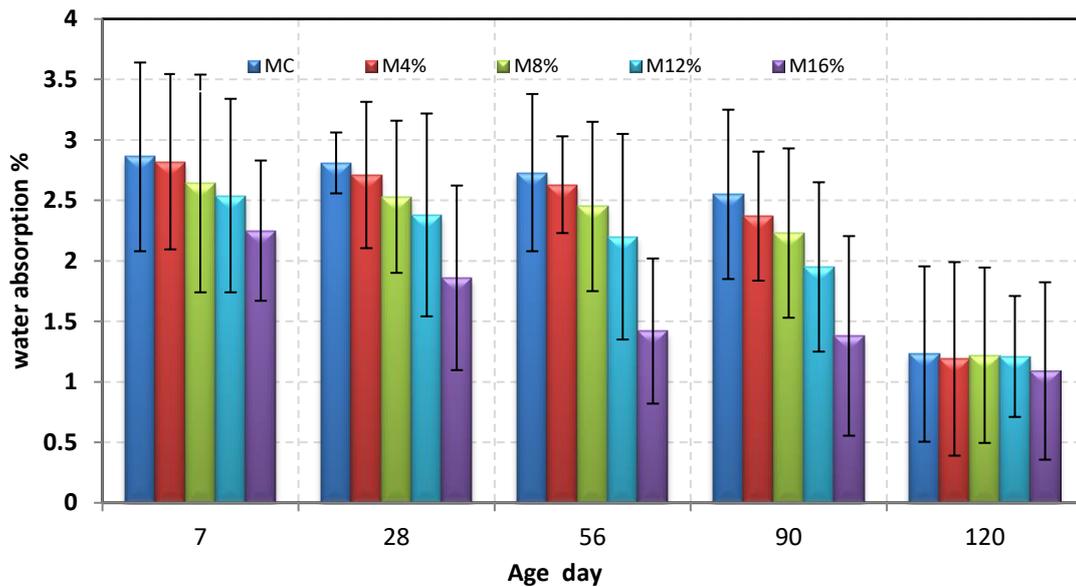


**Figure 4-38** Water absorption percentage for SCC mixtures

**Table 4.19** Result of water Absorption of SCRC mixtures

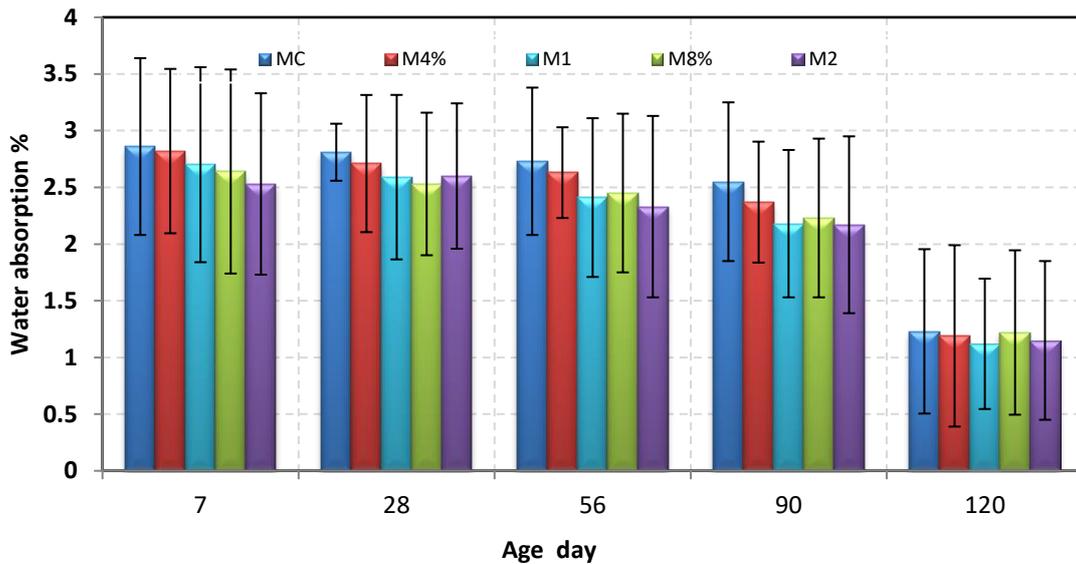
Mixture symbol	Average of water absorption %				
	7 days	28 days	56day	90day	120day
	Curing in tap water				
MC	2.86	2.81	2.73	2.55	1.23
M 4%	2.82	2.71	2.63	2.37	1.19
M 8%	2.64	2.53	2.45	2.23	1.22
M 12%	2.54	2.38	2.20	1.95	1.21
M16%	2.25	1.86	1.42	1.38	1.09
M1	2.70	2.59	2.41	2.18	1.12
M2	2.53	2.60	2.33	2.17	1.15

Utilizing rubber as fine aggregate in SCC led to reduce the water absorption as shown in **Table 4.19** and **Figure 4-39**. The lower was 3.9%, 6.7%, 15.9%, and 57.8% at 4% of rubber and 4.1%, 3.1%, 15.5%, and 53.7% at 8% of rubber and 6.3%, 13.3%, 23.2%, and 52.4% for 12% of rubber and 17.3%, 36.8%, 38.6%, and 51.5% at 16% of rubber at 28, 56, 90, and 120 days as regarding to 7 days respectively. The water absorption indicates that the reduction as comparing to control mixture refer to the less affinity of water to rubber than to sand (**Marques et al., 2008**). On the other hand, by increasing the rubber content in mixture leads to a rise the content of incorporated air and lowering values of capillary water absorption (**Pedro et al., 2013**). Rubber particles incorporation in matrix led to restrict water absorption of the composite. Generally, the reduction in water absorption is tends to lowering porosity due to filling the voids by rubber particles (**Fadiel et al., 2014**).



**Figure 4-39** Effect of replacement rubber on water absorption of SCRC

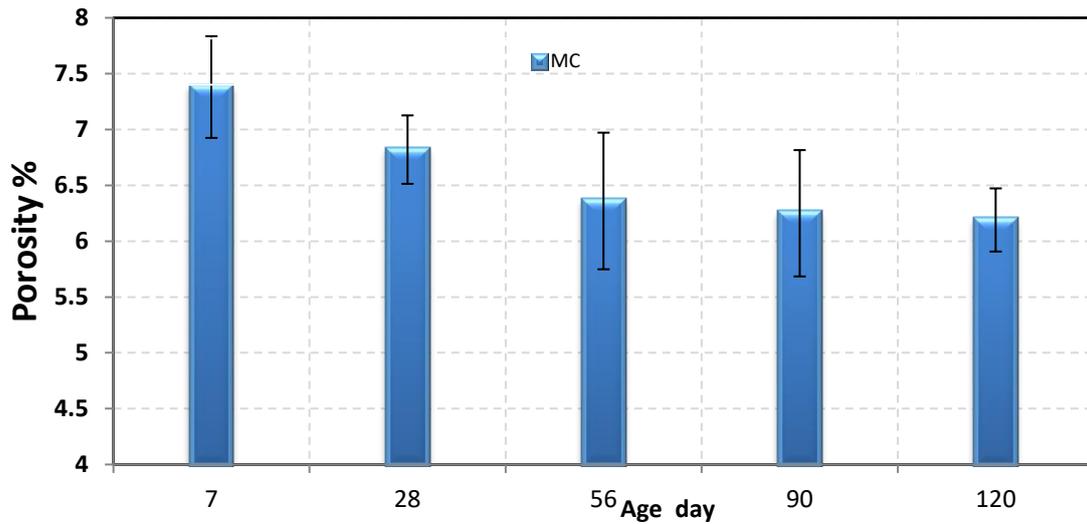
The results refers to modified rubber by using SBR has a significant effect on water absorption property. The self-compacted concrete containing treated rubber showed a reduction in water absorption as comparing with same mixture without treated. The reducing was 4.3%, 4.4%, 8.4%, 8%, and 5.9% at 7, 28, 56, 90, and 120 days for 4% of treated rubber as comparing with same mixtures without treated by SBR. While, the reduction was 4.2%. 1.9%, 4.9%, 2.9%, and 5.7% at 7, 28, 56, 90, and 120 days for 8% of treated rubber as comparing with same mixtures without treated by this material as shown in **Figure 4-40**. SBR have ability to filling the smaller voids of the rubber particles and formed a monolithic film that cover the rubber and lowering the water absorption (**Yao and Ge, 2012**). In addition, the crumb rubber particles have an open capillary porosity, for that SBR has a positive influence on self-compacted concrete porosity and improve the durability (**Grinys et al., 2020**).



**Figure 4-40** Effect of rubber with SBR on water absorption of SCRC

#### 4.4.2 Porosity

The porosity results for self-compacted Rubberised concrete are illustrated in **Table 4.20** and **Figure 4-41**. Depending on the results of the experimental work, the percentage of porosity for control mixture (MC) lowered with age. The reduction was 7.5%, 13.8%, 15.3%, and 16.1% for 28, 56, 90, and 120 days as comparing with porosity at 7 days respectively. The reduction in porosity of self-compacted concrete with age due to enhance the microstructure of concrete.  $\text{Ca(OH)}_2$  products from cement hydration could fill the voids in cooperation with C-S-H due to increase the cement hydration. The improving ITZ of self-compacted concrete led to reduce percent of porosity (**Li and Kwan, 2015**).



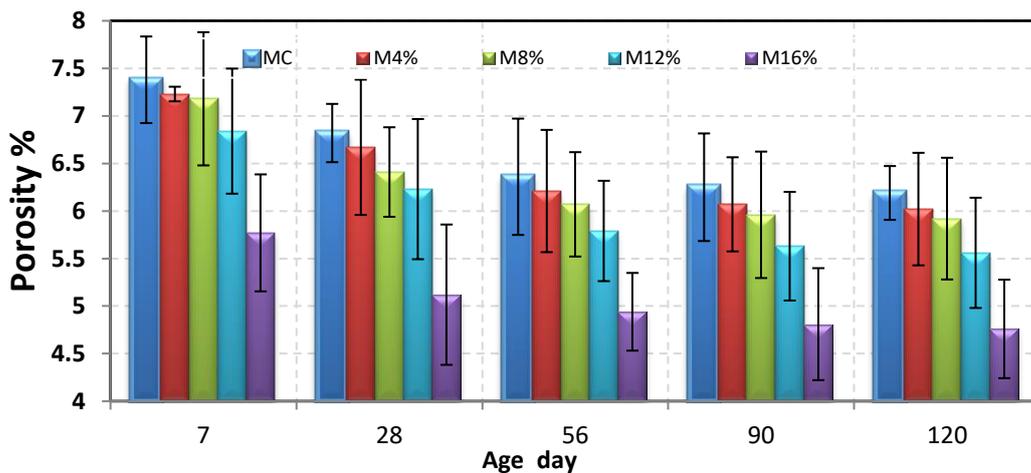
**Figure 4-41** Porosity percentage for SCC mixtures

**Table 4.20** Result of porosity of SCRC mixtures

Mixture symbol	Average of porosity%				
	7 days	28 days	56day	90day	120day
	Curing in tap water				
MC	7.38	6.82	6.36	6.25	6.19
M 4%	7.23	6.67	6.21	6.07	6.02
M 8%	7.18	6.41	6.07	5.96	5.92
M 12%	6.84	6.23	5.79	5.63	5.56
M16%	5.77	5.12	4.94	4.81	4.76
M1	6.84	6.37	5.93	5.66	5.59
M2	6.73	6.14	5.87	5.70	5.67

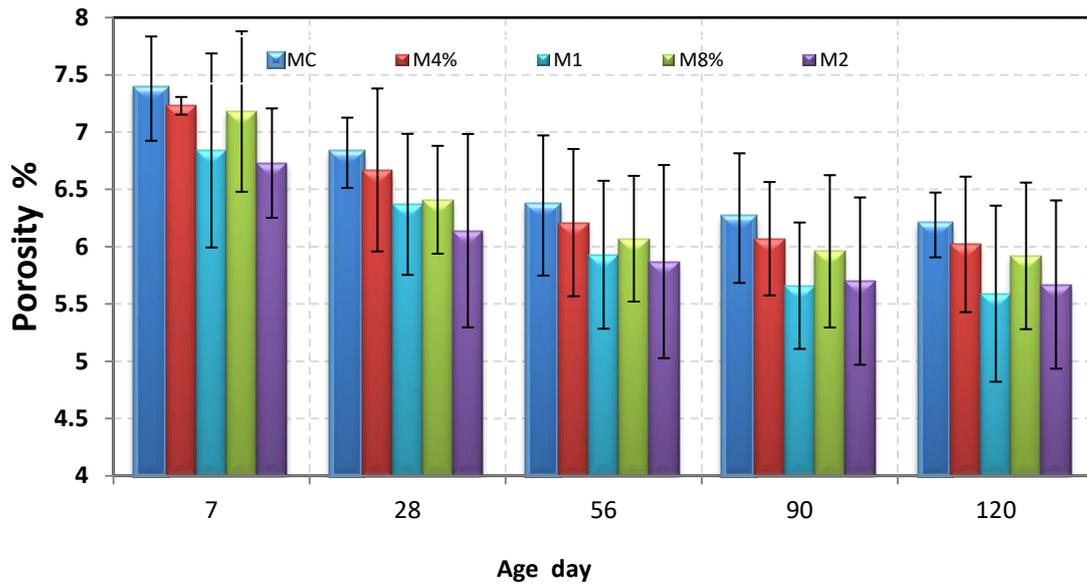
The porosity of SCC with tyre rubber as fine aggregate showed a reduction as presented in **Table 4.20** and **Figure 4-42**. The reduction was 2%, 2.2%, 2.3%, 2.9%, and 2.7% at 4% of rubber and 2.7%, 6%, 4.5%, 4.6%, and 4.3% at 8% of rubber and 7.3%, 8.6%, 8.9%, 9.9%, and 10.2% at 12% of rubber, and 21.8%, 25%, 22.3%, 23%, and 23.1% at 16% of

rubber at 7, 28, 56, 90, and 120 days as comparing with control mixture respectively. The reduction in percent of porosity of SCC was because of the smaller particle size of tyre rubber as comparing with natural aggregate. The rubber particles made a packing for the large voids and cutting the capillary voids (Segre et al., 2004) (Marques et al., 2008) (Ganesan et al., 2012) (Ling, 2012).



**Figure 4-42** Effect of replacement rubber on porosity of SCRC

When treated tyre rubber particles with SBR a significant reduction in porosity of SCC was recorded as regarding to the same mixture without treated as presented in **Figure 4-43**. The reduction was 5.4%, 4.4%, 4.5%, 6.7%, and 7.1% at 7, 28, 56, 90, and 120 days for 4% of treated rubber as comparing with same mixtures without treated. While, the redaction was 6.2%. 4.2%, 3.3%, 4.3%, and 4.2% at 7, 28, 56, 90, and 120 days for 8% of treated rubber as comparing with same mixtures without treated. By coating tyre rubber particles with SBR a monolithic film cover the rubber and led to lower the porosity of SCC. In addition to the ability of SBR to fill, the small voids in rubber particles itself (Yao and Ge, 2012).

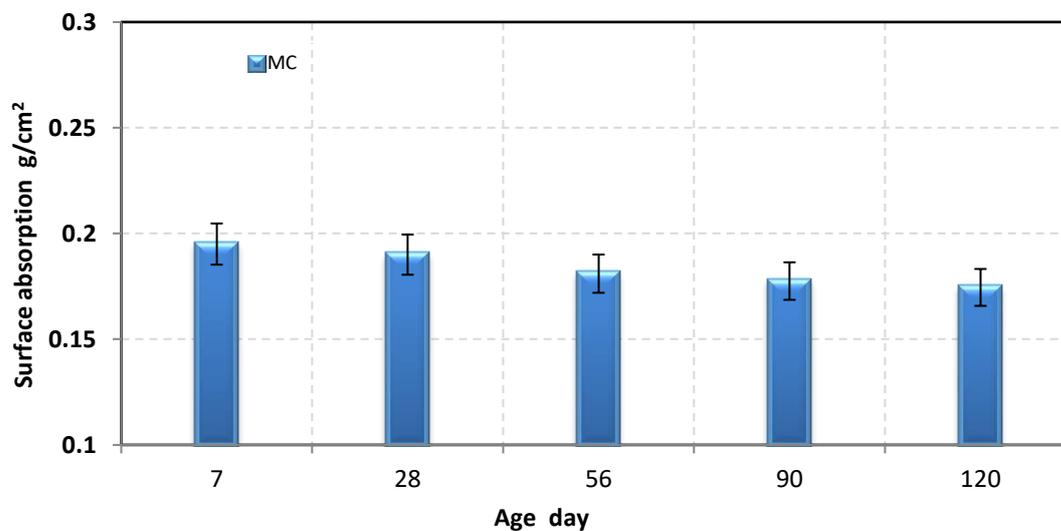


**Figure 4-43** Effect of rubber with SBR on porosity of SCRC

#### 4.4.3 Surface Absorption

Surface absorption test conducted at different curing ages (7, 28, 56, 90, and 120 days) for self-compacted concrete, with and without rubber for treated and untreated rubber. **Figure 4-44** and **Table 4.21** were shown the reference mixture (MC) presenting a reduction for the surface water absorption test with age. The reduction was 2.5%, 7.2%, 8.7%, and 10.2% at 28, 56, 90, and 120 days as comparing with 7 days. As water absorption, the surface water absorption enhanced the self-compacted concrete with age due to microstructure improvement and lowering the porosity of concrete.  $\text{Ca(OH)}_2$  fill the voids as well as precipitation of C-S-H due to increase the cement hydration (**Chen and Kwan, 2012; Li and Kwan,**

2015).



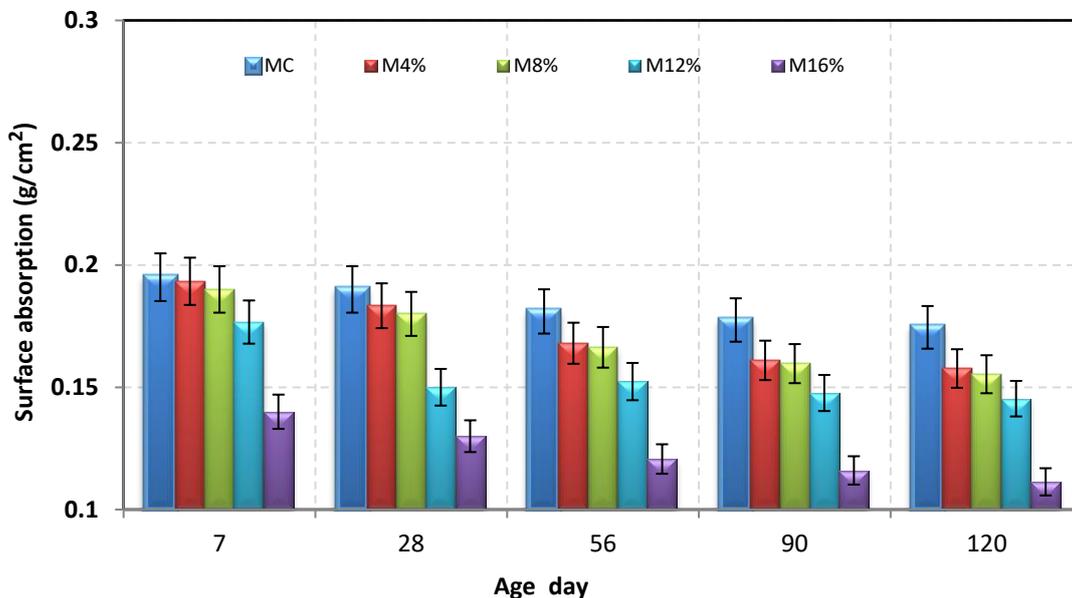
**Figure 4-44** Surface absorption (g/cm<sup>2</sup>) for SCC mixtures

**Table 4.21** Result of Surface Absorption of SCRC mixtures

Mixture symbol	Average of surface absorption (g/cm <sup>2</sup> )				
	7 days	28 days	56day	90day	120day
	Curing in tap water				
<b>MC</b>	0.195	0.190	0.181	0.178	0.175
<b>M 4%</b>	0.193	0.183	0.168	0.161	0.158
<b>M 8%</b>	0.190	0.180	0.166	0.160	0.155
<b>M 12%</b>	0.177	0.150	0.152	0.148	0.145
<b>M16%</b>	0.140	0.130	0.121	0.116	0.111
<b>M1</b>	0.180	0.170	0.158	0.159	0.155
<b>M2</b>	0.183	0.168	0.153	0.156	0.149

When utilizing tyre rubber particles as a fine aggregate replacement in self-compacted concrete at different percentage, the surface absorption presented a reduction in these values. As shown in **Figure 4-45**, the

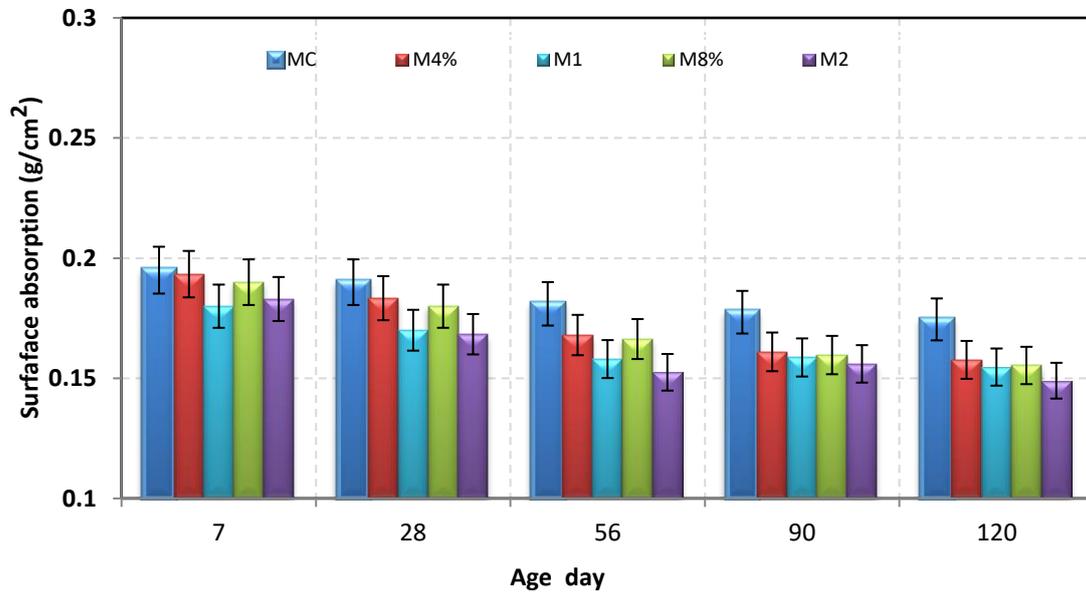
reduction was 1%, 3.6%, 7.1%, 9.5%, and 9.7% at 4% of rubber and 2.5%, 5.2%, 8.2%, 10.1%, and 11.4% at 8% of rubber and 9.2%, 21%, 16%, 16.8%, and 17.1% for 12% of rubber and 28.2%, 31.5%, 33.1%, 34.8%, and 36.5% at 16% of rubber at 7, 28, 56, 90, and 120 days as comparing with control mixture respectively. The surface absorption reduction was due to its finer sizes of rubber as comparing with natural sand, the acting as a filler material and filling the pores created by the rubber and, hence, lowering of the surface absorption (Kelechi et al., 2022).



**Figure 4-45** Effect of replacement rubber on surface absorption of SCRC

The rubber when treated with SBR, the properties of self-compacted concrete improved. **Table 4.21** and **Figure 4-46** showed the reduction in surface absorption. The lower was 6.7%, 7.1%, 5.9%, 1.2%, and 1.6% at 7, 28, 56, 90, and 120 days for 4% of treated rubber as comparing with same mixtures without treated. While, the reduction was 3.6%, 6.6%, 7.8%, 2.5%, and 3.8% at 7, 28, 56, 90, and 120 days for 8% of treated rubber as comparing with same mixtures without treated. The filling ability

of SBR to smaller voids of rubber particles led to lowering the surface absorption by coated it with monolithic film (Yao and Ge, 2012).



**Figure 4-46** Effect of rubber with SBR on surface absorption of SCRC

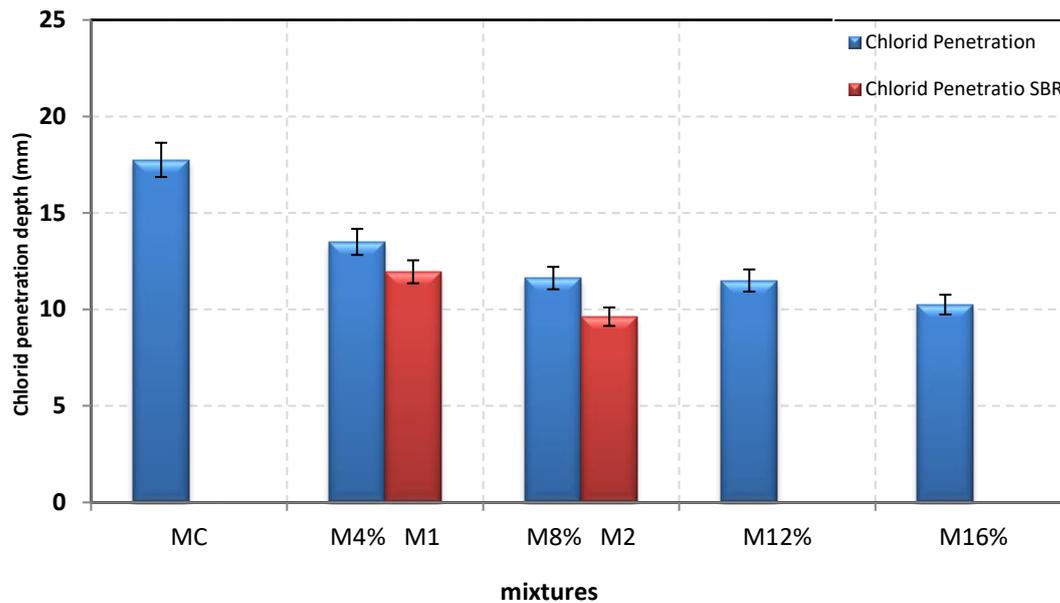
#### 4.4.4 Chloride Penetration Depth

The sample was subjected to specific environmental condition (drying and wetting cycles used), while the other faces were covered by coating of water-proofing based. These specimens were addressed to the ions of chloride saline solution of (NaCl, Na<sub>2</sub>SO<sub>4</sub>, CaCl<sub>2</sub>.2H<sub>2</sub>O) within a periodical of **wetting and drying two week for 120 days** in total. The test are based on depth of chloride penetration ion ,  $x_d$  which is tested by spraying silver nitrate (AgNO<sub>3</sub>) solution of a specific concentration of 0.1 N on the splitting short prism and measured the chloride penetration ( $x_d$ ) as a result of a reaction for both Cl<sup>-</sup> with Ag<sup>+</sup> to find chloride penetration depth for prism.

The chloride penetration depth ( $x_d$ ) for self-compacted Rubberised concrete are showed in **Table 4.22** and **Figure 4-47**. Chloride penetration depth decreased with increasing tyre rubber content in mixtures. The reduction was 24%, 34.5%, 35.2%, 42.2%, for M4%, M8%, M12%, and M16% as comparing with control mixture (MC) respectively at 120 days. **Thomas et al., 2016** explained the chloride penetration depth decreases with increasing content of rubber in mixture and that agree with (**Oikonomou and Mavridou, 2009; Ganesan et al., 2012**). Microstructure improved with utilizing tyre rubber against the penetration of fluid into concrete by presence the rubber that leads to enhance the durability of self-compacted concrete. The reduction in chloride penetration depth ( $x_d$ ) in SCRC compared to the  $x_d$  for a control mixture results from an increase in resistance of rubber tyre particle to penetrate water and salty solution in the concrete mass (**Yung W.H et al., 2013**).

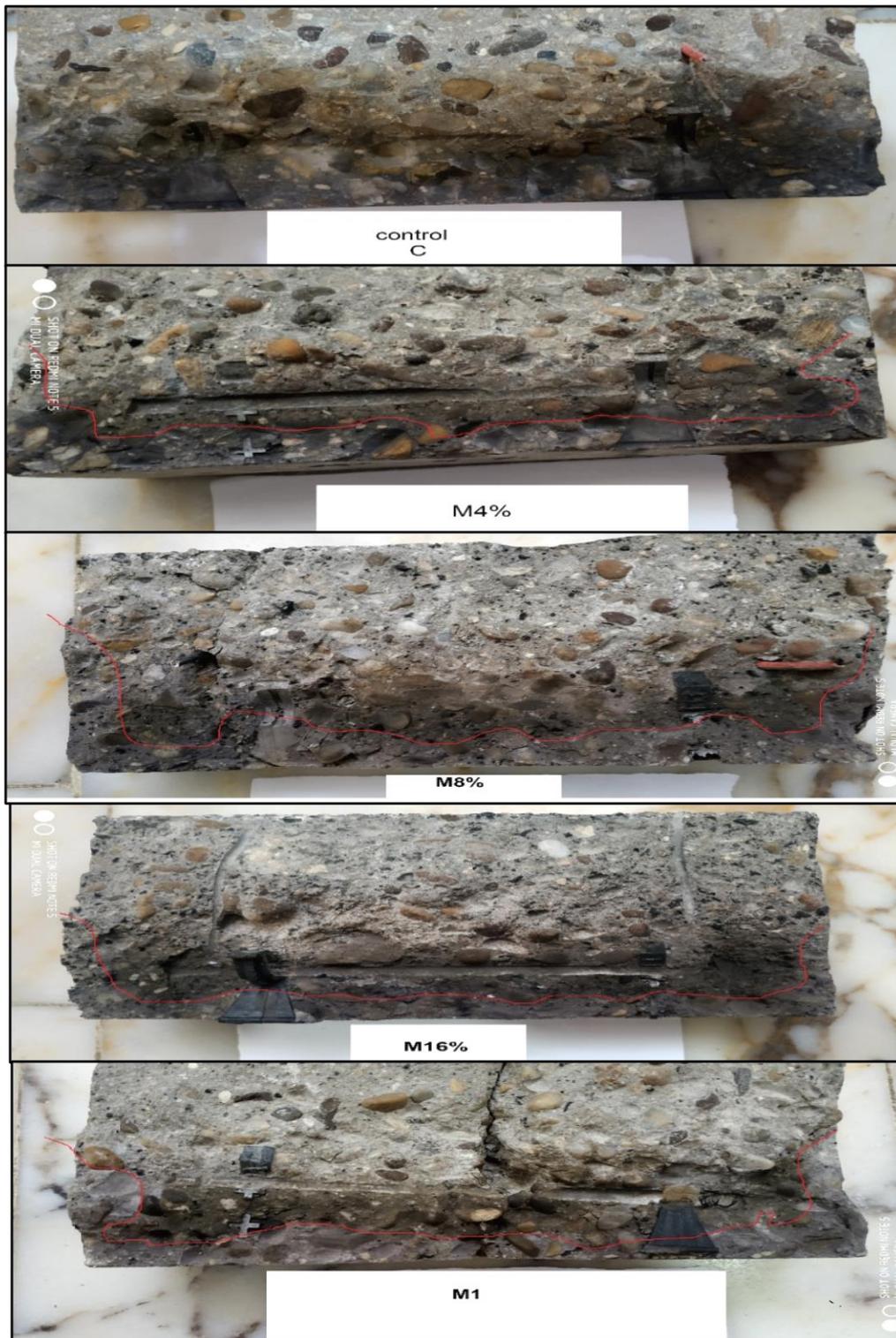
**Table 4.22** Result of chloride penetration depth for SCRC mixtures

Mixture	Chloride Penetration Depth (mm) at Point ( $x_p$ )						
	$X_{d1}$	$X_{d2}$	$X_{d3}$	$X_{d4}$	$X_{d5}$	$X_{d6}$	average
<b>MC</b>	17.4	19.0	18.5	17.5	16.3	15.5	17.8
<b>M 4%</b>	13.3	14.5	13.5	13.0	13.0	12.5	13.5
<b>M 8%</b>	11.9	10.5	11.5	11.5	13.5	12.8	11.6
<b>M 12%</b>	11.6	13.0	11.0	10.0	12.3	11.5	11.5
<b>M16%</b>	10.4	10.0	9.8	10.5	11.3	10.5	10.3
<b>M1</b>	12.25	11.5	12.25	11.75	11.5	12.5	11.95
<b>M2</b>	9.5	9.5	9.5	9.75	9.25	10.25	9.62



**Figure 4-47** Effect of replacement tyre rubber on chloride penetration depth

Self-compacted Rubberised concrete modified by utilizing SBR have a significant effect on chloride penetration depth. When tyre rubber particles treated with SBR the chloride penetration reduced as shown in **Table 4.22** and **Figure 4-47** and **Figure 4-48**. The reduction was 23.2% for M1 mixture as comparing M4% and 16.1% for M2 as comparing with M8%. This improvement in durability (lowering chloride penetration depth) could be attribute to morphology of SBR that ability to enhance the properties of rubber particle and maybe lower the porosity of microstructure of concrete with presence of tyre rubber particles (**Corinaldesi et al., 2011**).



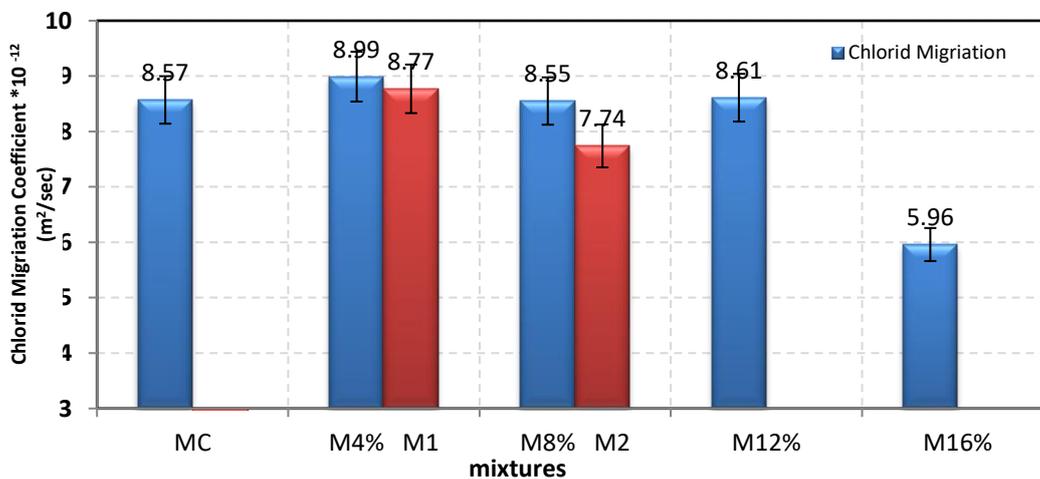
**Figure 4-48** Effect of chloride penetration on SCRC mixture

#### 4.4.5 Chloride Migration

The migration of chloride test was performed with short concrete cylinders at the 28 days age. The migration of chloride penetration is fast-tracked by applying an electrical circle on two distinct solutions, NaCl and NaOH according to **NT Build 492:1999**. The first face of the specimens was addressed to 10% of NaCl solution and the second face is exposed to sodium hydroxide solution of 0.3% of NaOH as shown in **Figure 4-49**. These samples of SCRC were exposed to two solutions and electrical circle with (DC) of 30Voltage for 24 hrs. This test is based on depth of chloride penetration ion, which is tested by spraying silver nitrate ( $\text{AgNO}_3$ ) solution of a specific concentration of 0.1 N on the split cylinder sample. The chloride penetration depth in short cylinder can be employed to find  $D_{\text{nssm}}$ . The chloride migration coefficient test conducted by calculate  $D_{\text{nssm}}$ , for self-compacted concrete containing tyre rubber as a sand replacing with treated and untreated rubber particles. **Table 4.23, Figure 4-49** showed the result  $D_{\text{nssm}}$  values **at 28 days**. The result presented a reduction in chloride migration coefficient with increasing rubber tyre content in the self-compacted concrete mixtures. The reduction too clear at high percent of utilizing rubber which was reach to 30.4% as comparing with control mix without rubber (MC). This phenomenon can be attribute is consistent with the low water absorption and surface absorption as mentioned perilously (**Onuaguluchi and Panesar, 2014**). **Bravo and de, (2012)** explained the effect of rubber size on chloride migration test, the  $D_{\text{nssm}}$  increased with increasing particle size of rubber. The reduction in chloride penetration depth ( $x_d$ ) in SCRC compared to the  $x_d$  for a control mixture results from an increase in resistance of rubber tyre particle to penetrate water and salty solution in the concrete mass (**Yung W.H et al., 2013**).

**Table 4.23** Result of chloride migration coefficient test ( $D_{nssm}$ ) for SCRC mixtures

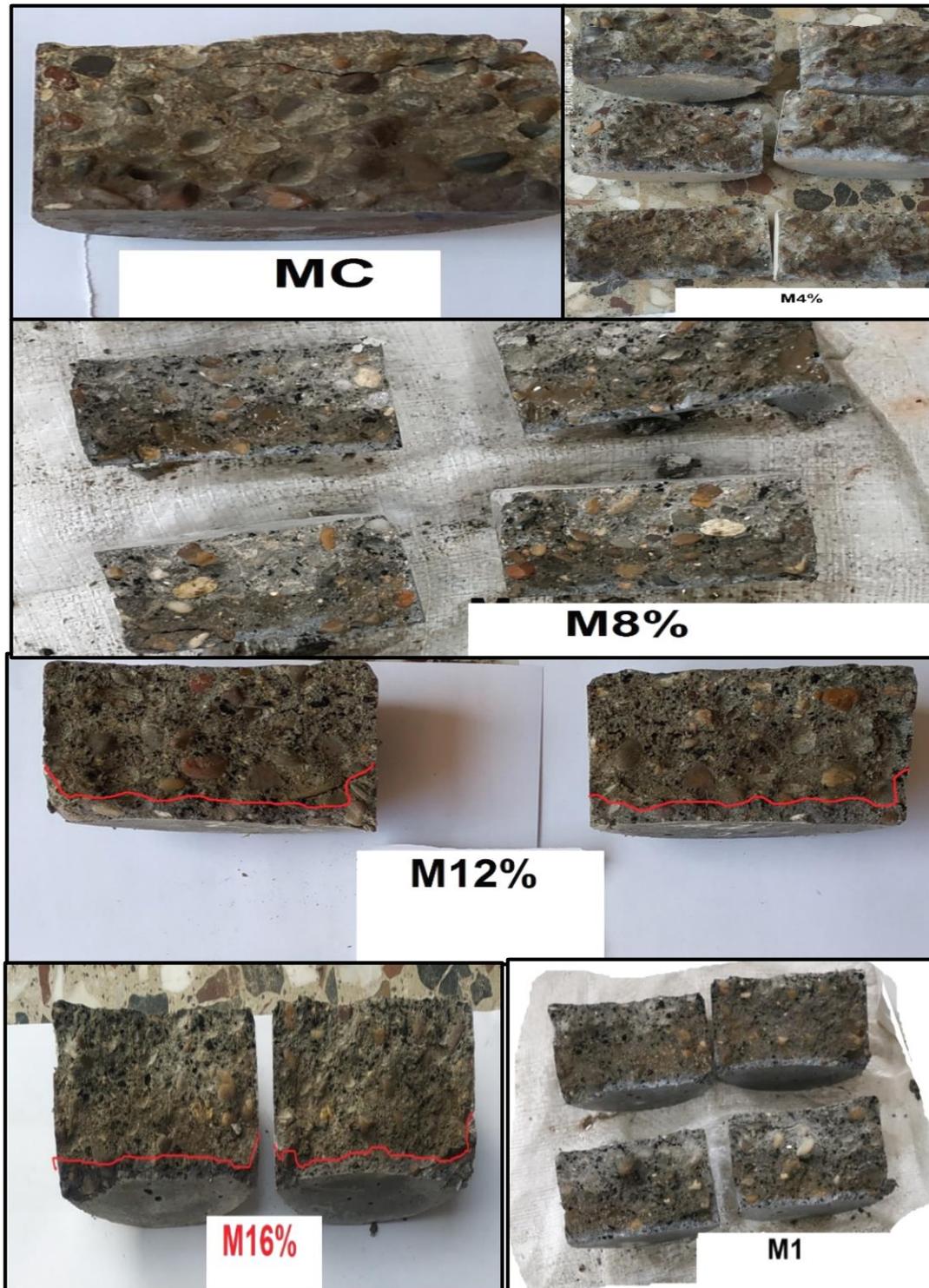
Mixture symbol	Chloride Migration Coefficient ( $D_{nssm}$ ) * $10^{-12}$ ( $m^2/sec$ )
MC	8.57
M 4%	8.99
M 8%	8.55
M 12%	8.61
M16%	5.96
M1	8.77
M2	7.74



**Figure 4-49** Effect of replacement tyre rubber on chloride migration coefficient

When SBR used to modify the self-compacted concrete by treated the tyre rubber particles, the chloride migration coefficient recorded an enhancement.  $D_{nssm}$  showed a reduction for sample of SCRC treated with SBR as illustrated in **Table 4.23** and **Figure 4-49** and **Figure 4-50**. The reduction was 2.4% for M1 mixture as comparing M4% and 9.5% for M2 as regarding to M8%. **Oikonomou and Mavridou (2009)** explained that the chloride migration coefficient decreased when amount of rubber was

increased in mixture, while the higher reduction happened in  $D_{nssm}$  value by treated rubber with bitumen emulsion.



**Figure 4-50** Effect of chloride migration coefficient on SCRC mixture

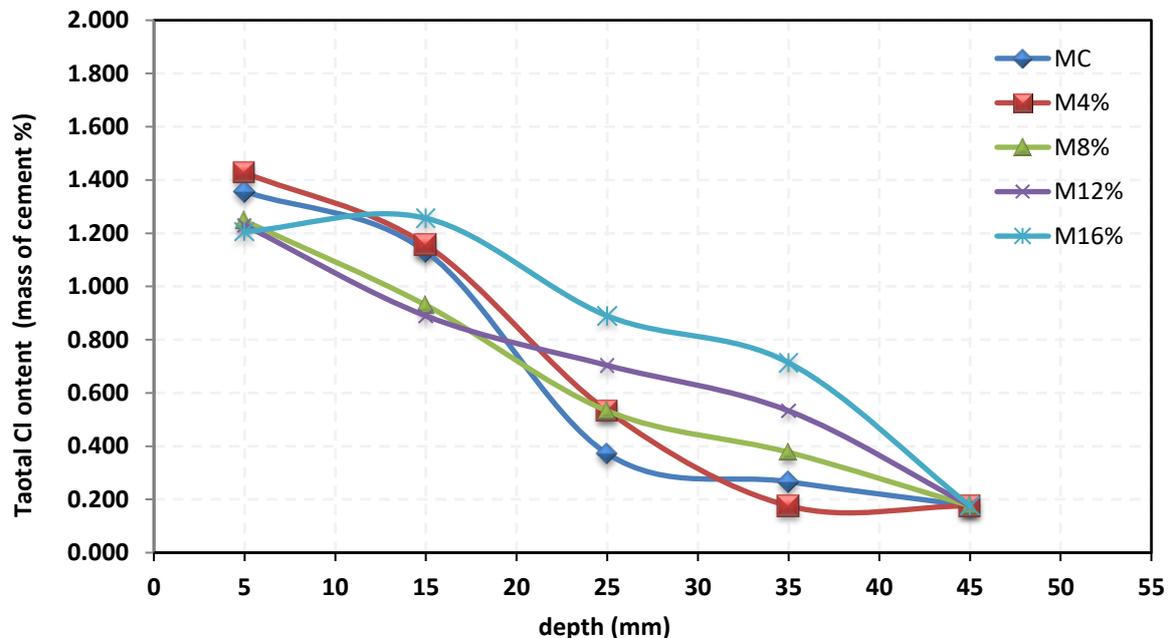
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#### 4.4.6 Chloride Concentration with Concrete Depth

The chloride concentration test is conducted by measuring **Cl<sup>-</sup> concentration** with depth for self-compacted concrete containing tyre rubber as a sand replacing with treated and untreated rubber particles. **Table 4.24** and **Figure 4-51** are presented the result **Cl<sup>-</sup> concentration** values at the end of exposure to saline solution (120 days). The results illustrated the chloride concentrations decreased with increasing depth and they varied according to the type of concrete and the strength of the self – compacting concrete due to replacement the sand by tyre rubber particle or treatment these particles. The result presented the reduction in chloride concentration with increasing depth (5, 15, 25, 35 and 45) mm and increasing rubber tyre content in the self-compacted concrete mixtures. The reduction at 5mm depth was 4.9%, 8.2%, 9.4%, 11.2% for M4%,M8%,M12%,M16% respectively as comparing with control mixture without rubber mixture(MC) and, 0.5%, 17.7%, 21.4%, 31.5% for M4%, M8%, M12%, M16% respectively as comparing with control mix without rubber (MC) at 15mm .This phenomenon can be attributed the consistent with the low water absorption and surface absorption as mentioned perilously. When the wetting and dry cycles with saline solution tak place .This mechanism lead to accumulation of chlorides in the surface zone and may also give rise to concentration peak inside the concrete which tends to progress to progress interior over time. ( **Costa A et at., 1999**)

**Table 4.24** Result of chloride concentration test

Depth (mm)	Chloride concentration(Cl <sup>-</sup> ) by mass of cement (%) for mixture						
	MC	M4%	M8%	M12%	M16%	M1	M2
5	1.357	1.427	1.246	1.230	1.206	1.270	1.231
15	1.131	1.125	0.930	0.889	0.786	0.804	1.010
25	0.372	0.533	0.533	0.704	0.889	0.357	0.985
35	0.266	0.375	0.377	0.533	0.714	0.251	0.628
45	0.176	0.176	0.176	0.176	0.176	0.176	0.377

**Figure 4-51** Total chloride concentration profile of mixtures at 120 days

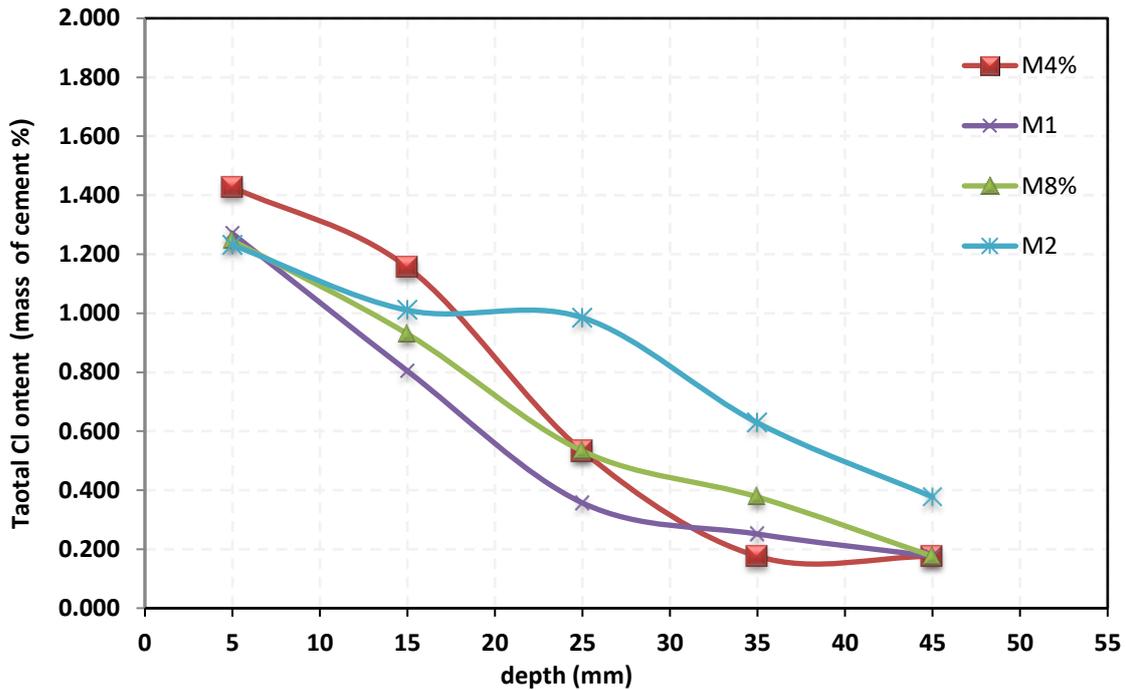
When SBR used to treat the tyre rubber particles, the chloride concentration recorded an enhancement. The reduction in chloride concentration for samples of SCRC treated with SBR are illustrated in **Table 4.24** and **Figure 4-52** and **Figure 4-53**. The reduction was 11%,28.5%,33%,33.05%,for M1 mixture at (5,15,25,35,45)mm respectively as comparing with M4%.The rubber gives a quality of

resistance to moisture penetration due to its low absorbability compared to sand, the highest absorption capacity and it is a carrier medium for moisture (Onuaguluchi and Panesar, 2014).

**Table 4.25** Result of  $D_a$ ,  $C_s$  Coefficient

Factor	Mixtures						
	MC	M4%	M8%	M12%	M16%	M1	M2
<b><math>D_a</math></b> (*10 <sup>-11</sup> )(m <sup>2</sup> /s)	2.80	2.00	1.90	1.80	4.00	1.60	1.85
<b><math>C_s</math></b> (by mass of cement %)	0.75	3.02	2.01	2.01	2.01	2.51	2.51
<b><math>C_i</math></b> (by mass of cement %)	0.176	0.176	0.176	0.176	0.176	0.176	0.176

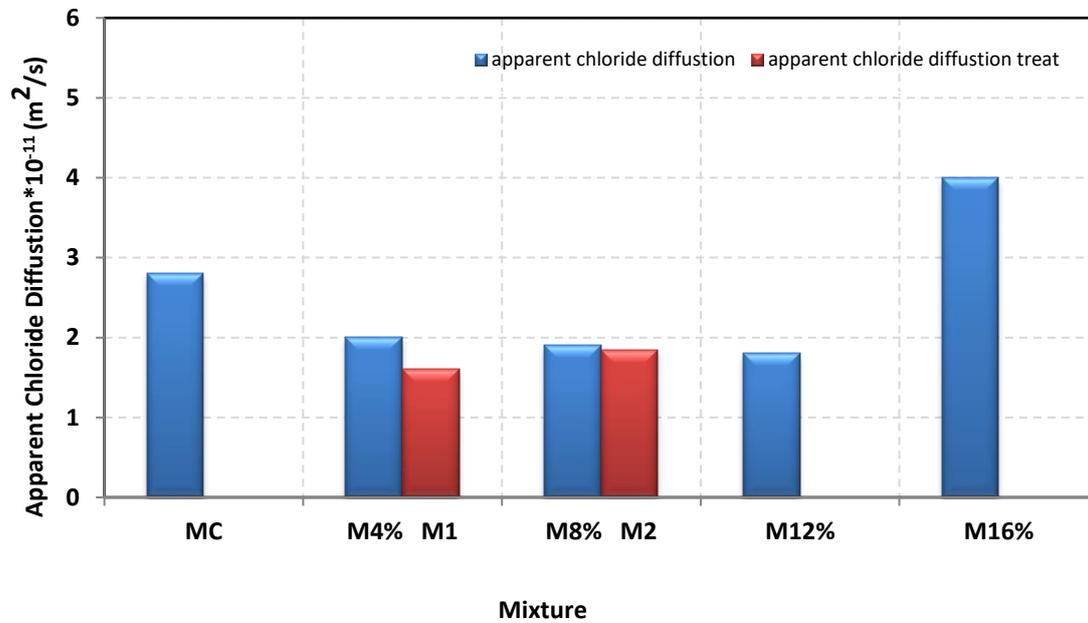
\* $C_i$ : Initial chloride concentration



**Figure 4-52** Total chloride concentration profile of mixes with treated rubber SBR at 120 days

Chloride represents chlorides and the extent of chlorides gathering on the concrete surface. The result diffusion chloride coefficient, **Da** and surface chloride concentration, **Cs** values at 120 days were presented in **Table 4.25** and (the calculations of **Da** and **Cs** are illustrated in **Appendix –A2**. The test scale for the values of **Cs** ( the accumulation of chlorides on the concrete surface ) and **Da** ( rate of diffusion of chloride into concrete) were computed as mentioned in the chapter three in the paragraph (3.8.5).The both factors, **Da**, **Cs** are reflect to penetration and concentration of chloride in concrete that exposed to chloride environmental conditions. The results showed the **Da** decreased with increasing content of rubber in mixture and with the depth of specimen. The rubber gives a quality of resistance to moisture penetration due to its low absorbability compared to sand, the highest absorption capacity and it is a carrier medium for moisture. The profiles were mainly influenced by two transport

mechanisms: diffusion and capillary suction of chloride solution in concrete (Bernal et al., 2016).



**Figure 4-53** Apparent Chloride Diffusion  $\times 10^{-11}$  ( $\text{m}^2/\text{s}$ ) with total mixes use in SCRC

# CHAPTER FIVE

## Chapter Five

### Conclusions and Recommendations

#### 5.1 Conclusion

According to the experimental results obtainable in the previous chapters, the impact of partially substituting sand by the crumb rubber tyre on the characteristics of SCC was investigated. Self-compacting rubberised concretes samples were tested under different environment test programme. The main points can be concluded from the experimental results as follows:

1. The rheological properties of fresh concrete (V-funnel, T500 ) tests increasing with increasing replacement of rubber for the mix in SCC (MC, M4%, M8%, M12%, M16%) and the (slump flow, sieve segregation, L-box ) tests decrease with increasing replacement of rubber for the mix in SCC ( MC, M4%, M8%, M12%, M16%)
2. The rheological properties of fresh concrete (V-funnel, T500 and mixes modify with SBR (M4%, M8%)) tests amplified with the increasing rubber tyre content in mixes of SCC and the (slump flow, sieve segregation, L-box and mixes modify with SBR (M4%, M8%)) tests decrease with increasing replacement of rubber percentage.
3. Mechanical characteristics which including compressive and flexural strength and splitting strength, non destructive tests, schmidt hammer, ultrasonic pulse velocity and drying shrinkage for self-compacting rubberised concrete were a curing in tap water and saline solution as follows:

## a- Tap water curing

- Compressive strength, flexural strength and splitting strength decrease for increasing present of replacing rubber tyre particles by sand for M4%, M8%, M12%, M16% as comparing with control mixture, MC about 60% at late age.
- Improve M1, M2 respectively as comparing with mix without SBR.
- Schmidt hammer test the reduction in rebound number (40-45) % for MC, M4%,M8%,M12%,M16% and 9% ,17% for M1,M2 as comparing with control mixture, On the other hand, There is improvement in rebound number for mixtures M1,M2 about 8.6%,12% respectively as comparing with mix without SBR,M4% and M 8%.
- Ultrasonic pulse velocity reduced about (19-20)% for M4%,M8%,M12%,M16% and 4%,9.2 for M1,M2 respectively as comparing with control mixture at different ages, While, the treatment the rubber particles in mixtures M1and M2 improved UPV about 4%,2.5% respectively as comparing with mix without SBR, M4% and M 8%.
- Drying shrinkage strain increased about (20-25)% and 2.5% for M4%,M8%,M12%,M16% and M1,M2 respectively as comparing with control mixtures. The shrinkage strain of M1and M2 was lesser than shrinkage values of mixtures without SBR, M4% and M 8% about (5-7) % respectively.

**b- Saline solution curing**

- Compressive strength, decrease for increasing present of replacing tyre for M4%, M8%, M12%, M16% and M1, M2 respectively as comparing with control mixture about 10% at late age. In addition, the strength of mixture M1, M2 more the strength of mixture with mix without SBR, M4% and M8%.
- Flexural strength and splitting strength reduced about 9-10 % for M4%, M8%, M12%, M16% and M1, M2 about 20% respectively as comparing with control mixture at late age. Moreover, there is improvement in strength of mixture M1, M2 about (11%) as comparing with mix without SBR, M4% and M8%.
- Schmidt hammer test and ultrasonic pulse velocity test decrease for increasing present of replacing tyre for M4%, M8%, M12%, M16% respectively as comparing with control mixture and 2-3% for M1,M2 as comparing with mix without SBR.

**4- Durability**

- Water absorption, porosity, surface absorption of SCRC samples, are influenced by the replacement percentage of rubber, decrease surface absorption with increase percentage rubber compare with control concrete mixture. The mixture M1 and M2 gave more resistance to water absorption surface absorption and lesser porosity comparing with control mix and comparing the mixture without SBR.
- The replacing sand by tyre rubber particles significantly enhances the resistance of chloride ions and water penetration in self-compacting rubberised concrete by preventing or lowering the diffusion of water and  $Cl^-$  ions in these samples of concrete And

the mixtures, M1 and M2 were more resistance to aggressive ions ( $\text{Cl}^-$ ) comparing with control mix and comparing the mix without SBR M4% and M8%.

- The utilization of waste tyres rubber slightly improved the chloride migration coefficient of self-compacting rubberised concrete by resisting the penetration of  $\text{Cl}^-$  ions.

## 5.2 Recommendation and Further Studies

The following are some suggestions for future study research:

- 1- More experimental work is required to investigate the sulfate resistance of SCC containing different types of rubber.
- 2- An investigation is required to study the corrosion resisting characteristics of steel reinforced SCC partial replacement by fine aggregate, which is exposed to ( $\text{Cl}^-$  &  $\text{SO}_4^{2-}$ ) solution.
- 3- Thermal and dynamic properties for self-compacted concrete with different size of rubber aggregate.
- 4- Studying the behavior of different sustainable rubberised self-compacted concrete members (beams, columns, etc.).
- 5- Additional investigating for examine the properties of SCC with high percentage of rubber with different type of curing employing Scanning Electronic Microscope (SEM).

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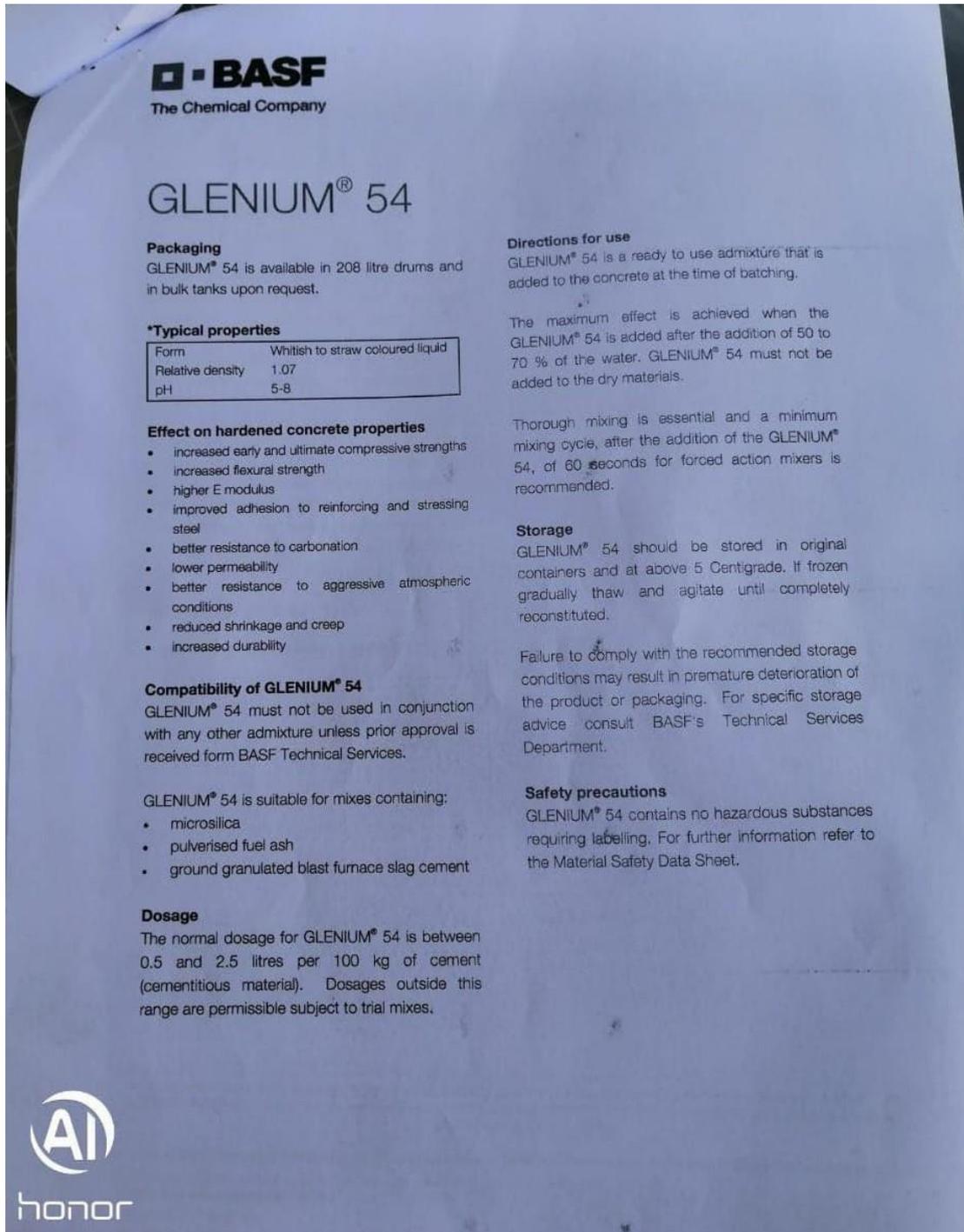
Construction and Architecture of the Slovak Academy of Sciences,  
Slovak Republic, April.

# **APPENDIXS**

# Appendixes

## Appendix A1: Material Datasheets

### 1. Datasheet of Superplasticiser Provided by the Manufacturer



**BASF**  
The Chemical Company

## GLENIUM® 54

**Packaging**  
GLENIUM® 54 is available in 208 litre drums and in bulk tanks upon request.

**\*Typical properties**

Form	Whitish to straw coloured liquid
Relative density	1.07
pH	5-8

**Effect on hardened concrete properties**

- increased early and ultimate compressive strengths
- increased flexural strength
- higher E modulus
- improved adhesion to reinforcing and stressing steel
- better resistance to carbonation
- lower permeability
- better resistance to aggressive atmospheric conditions
- reduced shrinkage and creep
- increased durability

**Compatibility of GLENIUM® 54**  
GLENIUM® 54 must not be used in conjunction with any other admixture unless prior approval is received from BASF Technical Services.

GLENIUM® 54 is suitable for mixes containing:

- microsilica
- pulverised fuel ash
- ground granulated blast furnace slag cement

**Dosage**  
The normal dosage for GLENIUM® 54 is between 0.5 and 2.5 litres per 100 kg of cement (cementitious material). Dosages outside this range are permissible subject to trial mixes.

**Directions for use**  
GLENIUM® 54 is a ready to use admixture that is added to the concrete at the time of batching.

The maximum effect is achieved when the GLENIUM® 54 is added after the addition of 50 to 70 % of the water. GLENIUM® 54 must not be added to the dry materials.

Thorough mixing is essential and a minimum mixing cycle, after the addition of the GLENIUM® 54, of 60 seconds for forced action mixers is recommended.

**Storage**  
GLENIUM® 54 should be stored in original containers and at above 5 Centigrade. If frozen gradually thaw and agitate until completely reconstituted.

Failure to comply with the recommended storage conditions may result in premature deterioration of the product or packaging. For specific storage advice consult BASF's Technical Services Department.

**Safety precautions**  
GLENIUM® 54 contains no hazardous substances requiring labelling. For further information refer to the Material Safety Data Sheet.

**AI**  
honor

## 2- Datasheet of Cempatch SBR by the Company

# Cempatch SBR100

Liquid polymer bonding agent for cement containing mixes



### DESCRIPTION

Cempatch SBR100 is a one component styrene butadiene rubber latex bonding agent. Cempatch SBR100 is designed to improve the physical properties of cement mixes and slurries.

### APPLICATIONS

Cempatch SBR100 is ideally designed for use in the following applications:

- » Bonding of new to old concrete when used as a slurry coat.
- » To produce various traditional cement/sand adhesive mortars such as block mortar, plaster/render and tile adhesive.
- » To produce a mechanical key prior to rendering of various plaster mixes on concrete, brick and block surfaces.

### ADVANTAGES

- » Successfully increases the bonding/adhesion of cement mixes.
- » Effective plasticiser giving improved workability and cohesion.
- » Improved mechanical and physical properties by increasing tensile, flexural and adhesive strengths.
- » Good freeze/thaw resistance.
- » Chloride free.

### STANDARDS

Cempatch SBR100 complies with:

- » ASTM C1059-99, Type 1, when tested in accordance with test method ASTM C1042.
- » ASTM C932, for bond strength.
- » ASTM C1438, for compressive strength.

### METHOD OF USE

#### SUBSTRATE PREPARATION

The substrate should be sound, clean and free from contamination. Surface laitance should be removed by acid etching. Exposed steel reinforcements should be grit blasted or wired brushed to a bright finish to insure it is clean of all surface contaminations.

For patch repair, cut back the edges of the repair areas to a minimum of 10 mm depth to avoid thin repair thicknesses. Presoak substrates with water prior to commencing the repair.

### TECHNICAL PROPERTIES @ 25°C:

Colour:	White
Specific gravity:	Around 1.0
Slant shear strength: ASTM C1042-99 Type I (dry)	≥ 5.0 MPa
Tensile bond strength: ASTM C932	≥ 1200 KPa (wet condition)

### MIXING

In general, Cempatch SBR100 should be added and mixed with the clean water prior to dry materials for better dispersion.

#### 1) As a bonding agent slurry:

The recommended mix to produce slurry consistency can be achieved by mixing 1 Cempatch SBR100 : 2 OPC cement by volume.

#### 2) As a bonding and waterproofing additive for site mixed cement/sand adhesive mortar:

The following table shows the mix design proposed to improve the adhesion of traditional cement/sand mortars such as block mortar, plaster/render and tile adhesive.

Component	QTY by Volume
Cement	3
Sand	6
Water*	1-3
Cempatch SBR100	1

\*Based on type of sand and humidity.

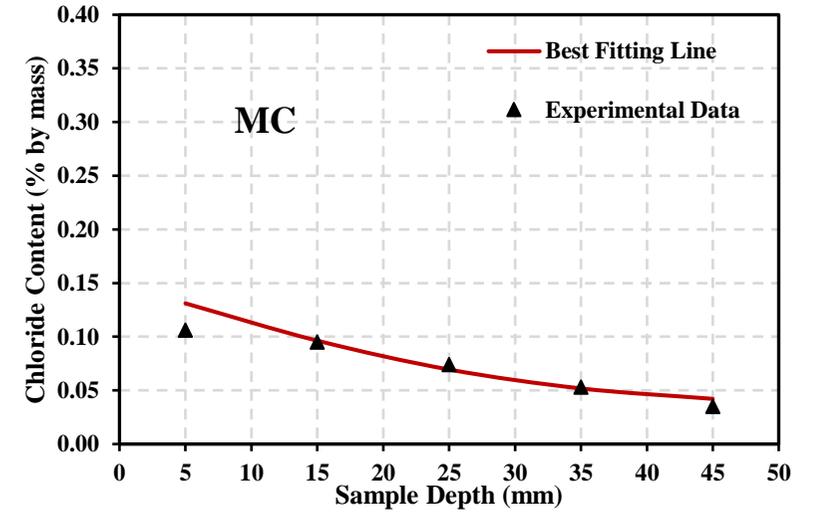
### APPLICATION

#### 1) As a bonding agent slurry:

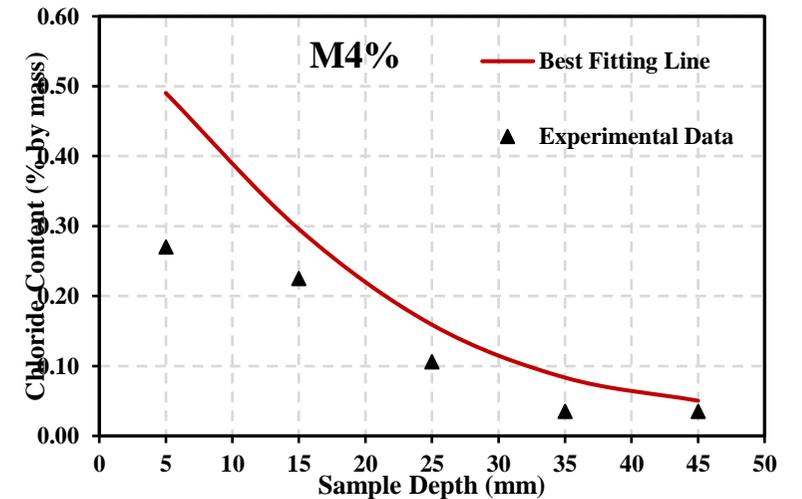
Use a stiff brush to apply a thick coat to presoaked surfaces. Application of the subsequent render, mortar or screed should take place while the bond coat is still wet (tacky). DO NOT apply on dry bond coats. (If bond coat dries before subsequent application, roughen the dry coat before applying a further coat of Cempatch SBR100 slurry.)

## Appendix A2: Computing Da & Cs

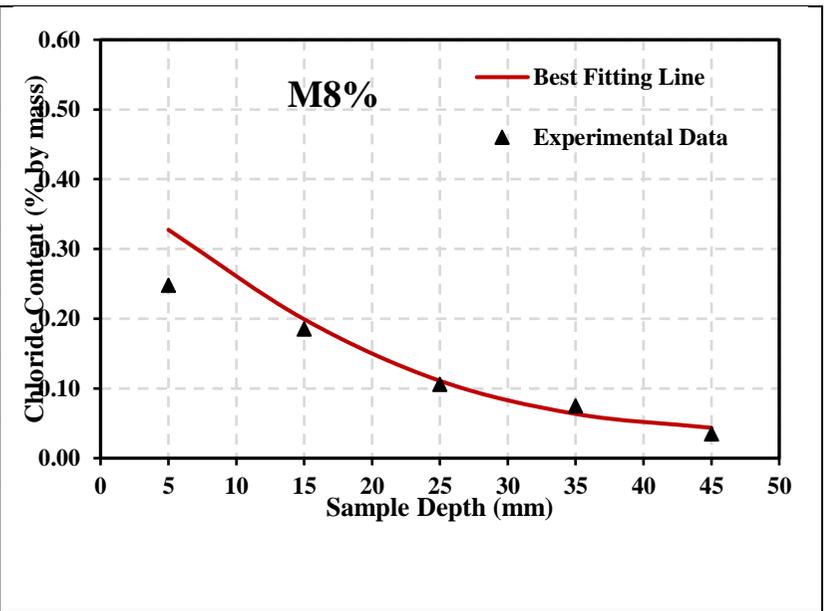
Mixture	MC				
Da	2.8E-11				
Cs	0.15	Depth	Cl <sup>-</sup>	Estimate from Eq. (3-16)	(Pred-Exper.) <sup>2</sup>
Ci	0.035	5	0.106	0.131	
		15	0.095	0.096	0.0006298
		25	0.074	0.069	1.8615E-06
		35	0.053	0.052	2.078E-05
		45	0.035	0.042	1.3675E-06
				<b>Summation</b>	<b>0.00070436</b>



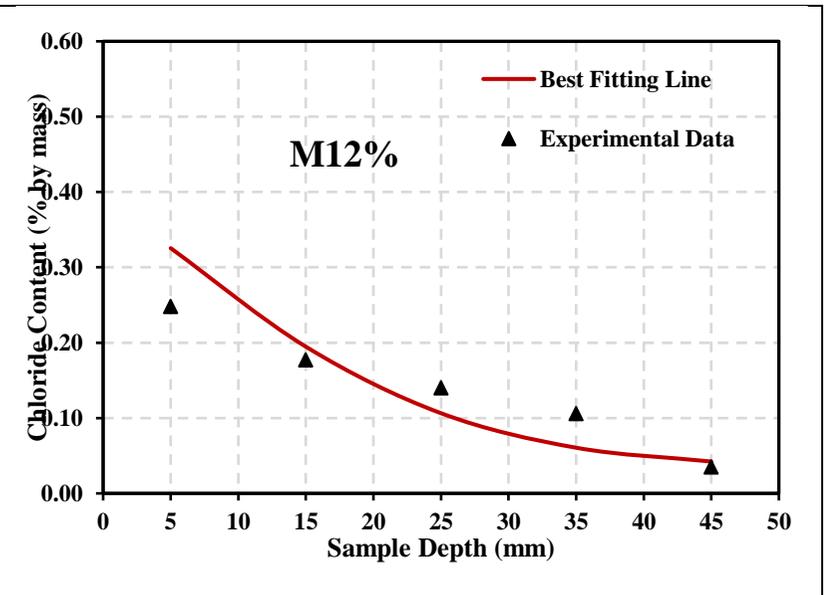
Mixture	M4%				
Da	2.0E-11				
Cs	0.6	Depth	Cl <sup>-</sup>	Estimate from Eq. (3-16)	(Pred-Exper.) <sup>2</sup>
Ci	0.035	5	0.270	0.490	
		15	0.225	0.296	0.00499595
		25	0.106	0.159	0.00281632
		35	0.035	0.083	0.00234323
		45	0.035	0.050	0.00023488
				<b>Summation</b>	<b>0.00982915</b>



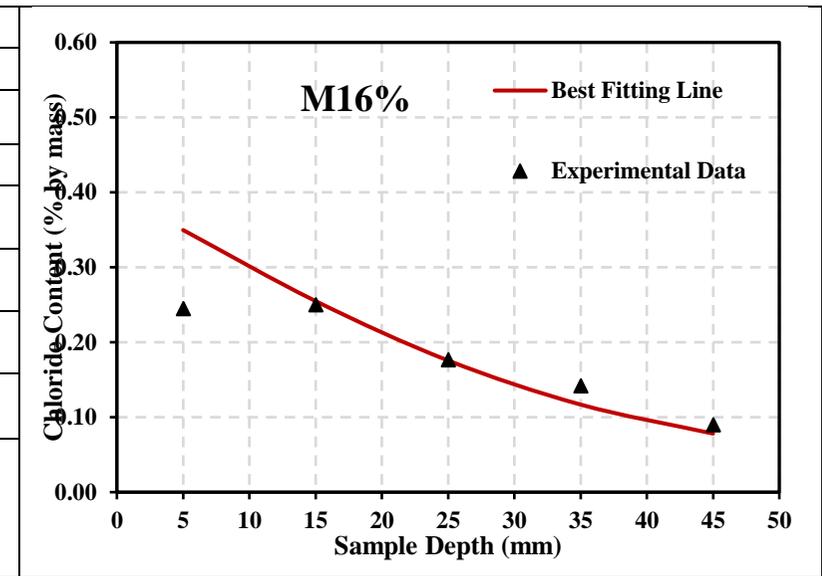
Mixture	M8 %				
Da	1.90E-11				
Cs	0.4	Depth	Cl <sup>-</sup>	Estimate from Eq. (3- 16)	(Pred-Exper.) <sup>2</sup>
Ci	0.035	5	0.248	0.327	0.0002013
		15	0.185	0.199	0.0000237
		25	0.106	0.111	0.0001342
		35	0.075	0.063	0.0000728
		45	0.035	0.044	0.0000000
				<b>Summation</b>	<b>0.0000864</b>



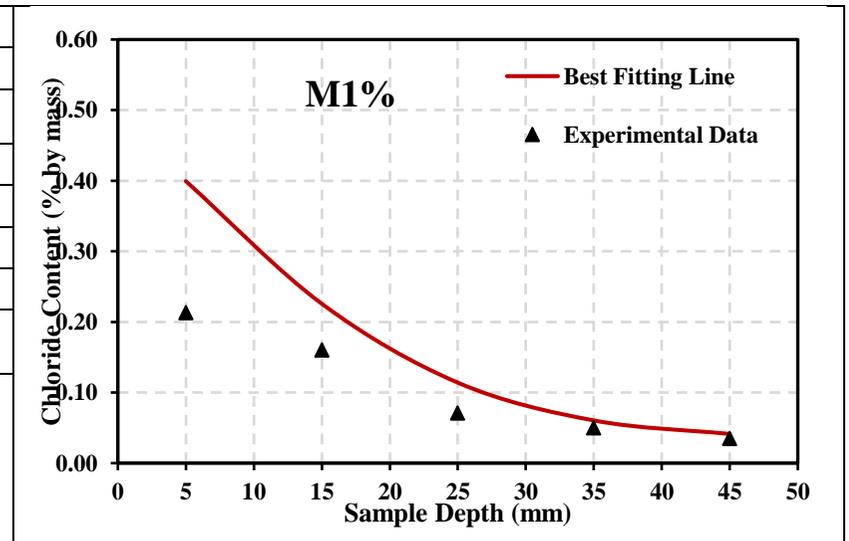
Mixture	M12%				
Da	1.8E-11				
Cs	0.4	Depth	Cl <sup>-</sup>	Estimate from Eq. (3-16)	(Pred-Exper.) <sup>2</sup>
Ci	0.035	5	0.248	0.325	0.0060004
		15	0.177	0.195	0.0003129
		25	0.140	0.106	0.0011279
		35	0.106	0.061	0.0020643
		45	0.035	0.042	0.0000525
				<b>Summation</b>	<b>0.00955795</b>



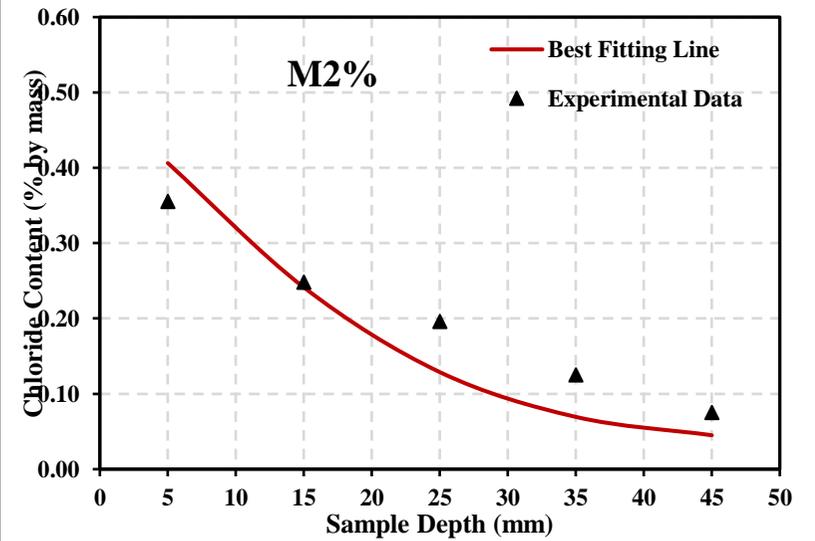
Mixture	M16%				
Da	4.00E-11				
Cs	0.4	Depth	Cl <sup>-</sup>	Estimate from Eq. (3-16)	(Pred-Exper.) <sup>2</sup>
Ci	0.035	5	0.245	0.325	0.0109605
		15	0.250	0.255	0.000241
		25	0.177	0.176	0.0000018
		35	0.142	0.117	0.0006323
		45	0.090	0.078	0.0001408
				Summation	0.0117595



Mixture	M1%				
Da	1.6E-11				
Cs	0.5	Depth	Cl <sup>-</sup>	Estimate from Eq. (3-16)	(Pred-Exper.) <sup>2</sup>
Ci	0.035	5	0.213	0.399	0.03475224
		15	0.160	0.226	0.00432325
		25	0.071	0.114	0.00184941
		35	0.050	0.060	0.00010857
		45	0.035	0.041	0.0000394
				Summation	0.04107282



Mixture	M2%				
Da	1.85E-11				
Cs	0.5	Depth	Cl <sup>-</sup>	Estimate from Eq. (3-16)	(Pred-Exper.) <sup>2</sup>
Ci	0.035	5	0.355	0.406	0.00263217
		15	0.241	0.241	4.4204E-05
		25	0.196	0.129	0.0045103
		35	0.125	0.069	0.00309331
		45	0.075	0.045	0.00089771
				Summation	0.01117769



## الخلاصة

يعتبر تراكم النفايات في جميع أنحاء العالم مشكلة كبيرة، خصوصاً في المناطق ذات الكثافة السكانية العالية. ونظراً لأن هذه النفايات خاملة بطبيعتها، يتم الاحتفاظ بها في مناطق طمر أو يتم التخلص منها بشكل غير قانوني. وباستخدام مواد النفايات هذه بطريقة أكثر صداقة للبيئة، يمكن أن يخفّي التأثير البيئي السلبي لها. يعد مادة المطاط للإطارات التالفة أحد الأمثلة على تلك النفايات. ويشكل مخزونات الإطارات مشكلة صحية وبيئية عالمية رئيسية، حيث يمكن أن تبدأ عملية حرق الإطارات بسرعة، وتستمر لفترة طويلة، وبالتالي تلوث الأرض والهواء. وتساهم إعادة التدوير في تقليل الإطارات التي يتم تخزينها. إن استخدام مطاط الإطارات كمجموع في صناعة الخرسانة المستدامة هو موضوع جدير بالبحث.

تجريبياً، تم استبدال الإطارات المطاطية الفتات جزئياً بالركام الناعم. كانت نسب الاستبدال (4%، 8%، 12%، 16%) بكتلة الركام الناعم وكذلك الخليط المرجعي (MC) من ناحية أخرى، تم تعديل نسبتيين آخرين من الإطارات المطاطية الفتات (4%، 8%) باستخدام SBR في الخلطات. تم تقسيم جميع العينات الخرسانية إلى مجموعتين بعد 28 يوماً من العلاج. المجموعة الأولى مغمورة جزئياً بمحلول ملحي ( $Cl^-$  &  $SO_4^{2-}$ ) بينما تم غمر المجموعة الثانية في ماء الاعتيادي للمقارنة. في وقت مبكر، يتم تقييم الخصائص الانسيابية لاختبارات SCRC الجديدة (slump test، T500، L-box، sieve segregation، V-funnel). قوة الانضغاط والانقسام والانتشاء ومطرقة شميدت وسرعة النبض بالموجات فوق الصوتية والتحقيقات في انكماش التجفيف لجميع أنواع الخرسانة المدمجة ذاتياً (SCRC) عند عمر (7, 28, 56, 90, 120) يوماً لتقييم استبدال الرمل بالمطاط إطار على الخواص الفيزيائية والميكانيكية لـ SCRC لمجموعتين. كما تم التحقق من امتصاص الماء والمسامية وامتصاص السطح وعمق تغلغل الكلوريد وانتقال الكلوريد واختبار تركيز الكلوريد لتقييم متانة هذه الأنواع من الخرسانة. تهدف نتائج هذه الدراسة إلى خفض مؤشرات الخواص الجديدة، slump test، L-box، sieve segregation، حيث يزيد محتوى الإطارات المطاطية الفتات في خليط SCRC. بينما تضخمت اختبارات V-funnel و T500 مع زيادة محتوى الإطارات المطاطية في مخاليط SCRC، فقد وجد أيضاً أن المخاليط المعالجة

SBR و (M1, M2) زاد وقت الاختبارات V-funnel T500، اما slump test، L-box، sieve segregation، ارتفع بمقدار قليل مقارنة مع نفس الخليط في ماء الصنبور، وقد تم اعتبار الخصائص المتصلبة لـ SCRC، وقوة الانضغاط، وقوة الانتشاء والانقسام، ومطرقة شميدت، وسرعة النبض بالموجات فوق الصوتية، واختبارات انكماش التجفيف، أن استخدام نسبة

الإطارات المطاطية الفتات في هذه الخلطات لها تأثير انخفاض الخصائص الميكانيكية مع زيادة نسبة الاستبدال ، وجد أيضاً أن الخليط المعالجة بـ SBR قد حسنت هذه الخصائص باستخدام الإطار المطاطي الفتات في خليط SCRC مقارنةً بنفس الخليط في ماء الصنبور. أظهرت النتائج أنه تحت تأثير محلول ملحي ، فإن معدل التحسن في كانت الخواص الميكانيكية للعينات أبطأ مع تقدم العمر للعينات مقارنة بمعدل التحسن في الخصائص الميكانيكية للعينات المعالجة في ماء الصنبور. النسبة المئوية للانخفاض في مقاومة الانضغاط وقوة الشد الانشقاقية وقوة الانتشاء ومطرقة شميدت وسرعة النبض فوق الصوتي (UPV) للمخاليط ، 4% ، 8% ، 12% ، 16% MC، عند عمر 56،90،120 يوماً ، بالإضافة إلى مزيجين من العلاج باستخدام تراوحت SBR للعينات المعرضة لمحلول (-SO<sub>4</sub> & Cl-) بين 6% ، 6.1% ، 5.3% ، 4.3% ، 4.7% . تقاس على التوالي بالنسبة للعينات المعالجة في ماء الصنبور. بينما خصائص المتانة لـ SCRC وامتصاص الماء والمسامية وامتصاص السطح وانتقال الكلوريد وعمق تغلغل الكلوريد ، تحسن تركيز الكلوريد هذه الخواص باستخدام الإطارات المطاطية الفتات في خليط SCRC مقارنة بخليط التحكم مثل امتصاص الماء عند 28 يوم 3.7% ، 6% ، 9% ، 15% ، 4% ، 8% ، 12% ، M16 على التوالي. المسامية عند 28 يوم 2.7% ، 6% ، 4.5% ، 4.6% ، 4% ، 8% ، 12% ، M16 على التوالي. تم تحسين عمق نفاذ الكلوريد 24% ، 34.5% ، 35.2% ، 42.2% ، 4% ، 8% ، 12% ، و 16% M بالمقارنة مع خليط التحكم (MC) على التوالي في 120 يوم.



جمهورية العراق  
وزارة التعليم العالي والبحث العلمي  
جامعة بابل  
كلية الهندسة  
قسم الهندسة المدنية

## أداء الخرسانة المطاطية – ذاتية الرص المعرضة الى ظروف بيئية قاسية

رسالة

مقدمه إلى كلية الهندسة / جامعة بابل  
وهي جزء من متطلبات الحصول على درجة الماجستير في الهندسة/ الهندسة  
المدنية/ مواد انشائية

من قبل

إيهاب عبود حسن عزوز

بإشراف

ا.د. عباس سالم عباس الاميري

2022 م

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