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The Effect of Adding Tires Wastes on the Properties of Lightweight Self – Compacting Concrete in Both Fresh and Hardened states

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بسم الله الرحمن الرحيم

(نَرْفَعُ دَرَجَاتٍ مَّن نَّشَاءُ ۗ
وَفَوْقَ كُلِّ ذِي عِلْمٍ عَلِيمٌ)

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سورة يوسف – الآية 76

<u>Supervisor Certification</u>

I certify that this thesis entitled **“The Effect of Adding Tire Wastes on the Properties of Lightweight Self –Compacting Concrete in Both Fresh and Hardened states.’’** was prepared by (**Hiba Mohammed Mehdy**) under My supervision at Civil Engineering department / University of Babylon in a partial fulfillment of the requirements for the Master degree of Science in Civil Engineering.

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Dedication

To my merciful God … The secret of my strength in this life …

To my lovely, beloved husband … The person who love me, support me, tolerate me and understanding me during a difficult period of our lives … I am grateful to you …

To my kids (Ali) & (Reem)… My little angels that I see hope in their smile …

To my Father … The person who support me all times …

To my Brilliant, respected Mather … The first supporter to me in all my life … There are no words to describe my thanks and appreciation to you …

To my favorite Sisters … I hope that I can be as good sister for them as they are good sisters for me …

To my wounded country (Iraq) … I hope all the peace for you …

To them I dedicated this work …

Hiba Mohammed

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Abstract

The consequences of rubber tire disposal on the environment and human health as well as the lack of available land for disposal will be lessened by the effective use of waste rubber tires.

This study's aim is to investigate how crumb rubber's size and content affect light weight self-compacting concrete's fresh, hardened, and durability characteristics. Various light weight self-compacting concrete mixtures were created with a constant water to binder ratio of 0.35 to address this problem.

At different Levels, crumb rubber was used in place of natural fine aggregates by volume. Six designated crumb rubber contents of 5%, 10%, 15%, 20%, and 25% have been designated as experimental, together with three different sized crumb rubbers (No. 18 (1mm), No. 5 (4.75mm), and mixed crumb rubber). There were 18 different light weight self-compacting rubberized concrete mixtures made in total. Slump flow diameter, T50 slump flow time, V-funnel flow time, and L-box height ratio and segregation resistance have been used to determine the workability characteristics of light weight self-compacting concrete mixtures.

The concrete made with No. 5 (4.75mm) crumb rubber had lower slump flow diameter values compared to that produced with No. 18 (1mm) crumb rubber. Similarly, No. 5 (4.75mm) crumb rubber had the longer slump flow time at every replacement level. The L-box height ratio was lowest in mixes made with No. 5 (4.75mm) crumb rubber, though, and there wasn't much of a distinction among concrete made with No. 18(1mm) and mixed crumb rubber either.

The compressive strength, splitting tensile strength, and modulus of elasticity of the hardened concretes have been tested. Testing samples'

sorptivity and water absorption were also done to see how long the concrete mixtures will last, the durability of concrete is affected by adding rubbers. The findings showed that using crumb rubber in the production of self-compacting concrete led to a systematic reduction in compressive strength and splitting tensile strength through the best results were obtained for mixtures with No.18 (1mm) crumb rubbers followed by the mixed crumb rubbers and No.5 (4.75mm) respectively.

The results showed that the light weight self-compacting concretes produced with No. 18 (1mm) crumb rubber gave the highest splitting tensile strength, while those produced with No. 5 (4.75mm) crumb rubber gave the lowest splitting tensile strength. Additionally, the use of coarse crumb rubber decreased the compressive strength of light weight self-compacting concrete more than the use of fine crumb rubber.

The control mixture without crumbed rubbers also yielded the maximum water absorption and sorpitivity , and as rubber content grew, they were seen to systematically decline regardless of its size. Similar is accurate of sorptivity, where the sorptivity height gradually fell with the addition of crumb rubber particles.

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List of Abbreviations

Abbreviation	Description
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
CCR	No.5 crumb rubber
Dmax.	Largest diameter of the flow spread (mm)
Dperp	Diameter of the flow spread at right angle to Dmax. (mm).
E	Modulus of elasticity
EFNARC	European Federation of National Trade Association
Fc	Compressive Strength
FCR	No.18 crumb rubber
fst	Splitting Tensile Strength
H1	Vertical distance at the begging of the horizontal section of the L-Box to the concrete surface after barriers
H2	Vertical distance at the end of the horizontal section to the concrete surface (mm).
W/C	Water to cement ratio
W/C+P	Water to cement + powder ratio
LWC	Lightweight concrete
LWAC	Lightweight aggregate concrete
LWSCC	Lightweight self-compacting concrete
LSP	Limestone powder
LECA	Lightweight expanded clay aggregate
MOE	Modulus of Elasticity
SP	Superplasticizer
MCR	Mixed No.18 CR and No.5 CR
NCC	Normal Compacting Concrete
RC	Rubberized concrete
RLWSCC	Rubberized Light Weight Self Compacting Concrete
ITZ	interfacial transition zone
xL	Variation in length at x age %
L_x	Device reading of sample at x age(mm)
L_i	First device reading of sample(mm)
G	The length of nominal gage(mm).
P	Highest applied load in test of splitting(N).
D	The cylinder’s diameter(mm).

L	The cylinder’s length(mm).
S_2	Stress equivalent to forty percent of the ultimate load (Mpa)
S_1	Longitudinal strain-related stress (5*10^-5) (Mpa)
e_2	Longitudinal strain resulting from S2 stress

1.1 General Overview

The difficulties related to non-biodegradable waste management raise the danger of environmental and health issues since millions of worn rubber tires are discarded yearly. Over the past several years, the building industry has been compelled to use this material combined with cement-based products due to the material's accessibility and vast manufacturing volume. Due to its promising properties, including enhanced ductility, damping ratio, and vibration resistance, recycling used tire rubber as a partial replacement of natural stones in concrete is a topic of intense research. Conversely, the rubber aggregator reduces the mechanical characteristics and workability of the resulting concrete mixtures **(Alzubi et al ., 2022)** . SCC could be employed in some crowded reinforcement regions because it is able to flow through places where vibrating technologies cannot be employed. This is thought to be the primary benefit of SCC over the conventional one **(Aslani,2018)**. By combining fine materials like silica fume, limestone powder, GGBFS, and fly ash, SCC's stability and workability could be improved **(Şahmaran,2006)**. Self-compacting concrete lowers vibrating disturbance, boosts efficiency, gives designers more choice when designing column-beam intersections (**Beigi et al., 2013)** and leads to the reduction of construction time and cost as well as the reduction of noise in construction sites **(Asteris et al., 2019).**

With the development of concrete technologies, numerous efforts were made over the years to create new, high-performance substances that possess the advantages and traits of self-compacting concrete and light concrete. A novel type of concrete called lightweight self-compacting concrete, which combines the benefits of self-compacting concrete with lightweight concrete, was already created. By substituting light weight aggregate with normal weight aggregate in self-compacting concrete, lightweight self-compact concrete is created. According **to ACI 213 (2014)**, Concrete used for structural lightweight construction should have a high density ranged between 1120 and 1920 kg / m^3. The majority of concrete's weight comes from aggregates, which typically make up around 60percent of the material's volume **(Topçu et al., 2010)** As a result, concrete's density and thermal conductivity can be reduced because to lightweight aggregates's porous structure. Due to the voids in light weight aggregate, the utilization of light weight self compact concrete provides a variety of benefits, including less self-weight, a quicker construction time, lower construction costs, the elimination of machine vibration disturbances, and greater heat and sound insulation **(Grabois et al., 2016)**. Given that the construction industry currently faces a skills gap and hiring challenges for the next generation of competent professionals **(Kim et al., 2010)** Lightweight self-compacting concrete, which requires less labor, could provide a quick fix for these issues. Light weight self-compacting concrete concrete, which is excellent for producing precast modules, can also be utilized to encourage the mechanization or even automation of construction industry processes. The construction processes are now simpler thanks to the on-site assembly of precast building component pieces.

One of the most promise light weight aggregate is light expanded clay (LECA) which is produced under different products names. Some nations, including the "UK, Iran, Portugal, Finland, Germany, Italy, Denmark, and Switzerland", produce LECA using a method that is essentially the same, whereas "Sweden, China, Poland, and Russia brand" it as "Keramzite." South Africa marketed it as "Argex," while Spain called it "liapour." Whichever the case, LECA is produced using a special plastic clay with minimal to no lime. The clay is heated to extremely high temperatures—

roughly 1100–1300 C where it is dried, heated, and burned in rotating kilns **(Alexander et al., 1999)**. As the organic chemicals burn off, the pellets expand (or bloat), creating porous, light-weight ceramic pellets with a high crushing resistance composition. Gas is created inside the pellets after heating and is trapped there until cooling (Fig. 1.1). The volume of an LECA pellet can increase by 5 to 6 times **(Ozguven et al., 2012).** Because of the kiln's circular movement, LECA is round. There are holes of different sizes, most of which are connected, inside LECA particles (Fig. 1.2). Various varieties have various geometries and structures. It all hinges on the manufacturing method, which involved raising the temperature throughout sintering to produce continuous pores and increase overall porosity. Porosity and pore size decreased as temp was raised just above pyro-plasticity range **(Ayati Bamdad et al ., 2018)**.

Fig. (1.1) The flowchart of LECA production.

LECA is a versatile material with numerous applications. It has a wide range of applications in the construction industry, including "the manufacture of lightweight blocks, concrete, and precast or in-cast structural elements like panels and partitions". It may be used in "lightweight, heat-insulating tiles, thermal proofing plaster, noise-canceling plaster, and thermally and sound-resistant flooring and roofing". Because of its "high shear strength and low weight", LECA is used as a lightweight fill in constructions to relieve pressure on structures and decrease settling **(Rashad, A. M., 2018).**

When LECA is cracked apart, it reveals vesicular texture in the form of spherical pellets **(Priyanga et al ., 2017)**. LECA typically has dark brown, reddish, brown-red, or gray colors. There are various colors in yellow or black. These color variations may be related to the various chemical compositions of LECA and its manufacturing processes. It is a "harmless, inert substance that has a natural pH value of nearly 7, is non-combustible, non-biodegradable, and resistant to harsh circumstances". Due to its" great acoustic resistance, it also offers good thermal insulation, fire resistance, and soundproofing properties". From 0.1 to 25 mm, LECA can come in a variety of sizes that are suited for both fine and coarse aggregate. According to **Matthew R. Hall (2010)**, LECA has a wide range of loose bulk densities that vary from 250 to 710 kg/m3, primarily depending on its size.

Fig. (1.2) Different grain sizes of LECA.

The exponential rise in population and transportation growth is driving up tire manufacture for automobiles. Waste tires that are no longer in use produce a significant amount of rubber waste**. Raffoul et al., (2018)** stated that the globe produced more than 2.9 billion tires annually in 2017, it was claimed that tire waste is almost proportionate to tire production. A sizable portion of this number is solely dumped untreated in landfills. Land is used up significantly when tires are disposed of in landfills. There is an urgent need to properly and environmentally dispose of used tires. As was already indicated, one of these solutions to this problem and to enhance some undesirable concrete qualities is to utilize recycled tire rubber in place of aggregate in concrete.

Fig. (1.3) Waste rubber tires (AL Fayez et al ., 2020).

The construction industry may advantage from waste tire qualities that, unless handled improperly, could threaten the ecology. Numerous studies have been conducted on concrete that contains varied amounts of scrap rubber from old tires in place of natural aggregate **(Girskas et al., 2017)**. When natural coarse and/or fine aggregate is partially replaced, the properties of the concrete produced are drastically altered. Findings demonstrate that when rubber is regularly added to concrete, the substance's compressive, flexural, and elastic properties are reduced in comparison to plain concrete **(Thomas et al.,2016)**. The poor interactions between the rubber surface and paste is mostly caused by the hydrophobic characteristics of rubber particles and their significant external irregularity **(Youssf et al., 2017)**. According to a microstructural examination, tire rubber particles' behavior as a soft aggregate may be connected to a large decline in capacity, according to **(Taha et al., 2008)**. When rubber is used as an aggregate, the rubber's content, particle size, and properties, in addition to the mix's variables and ratios, all affect how strong the concrete becomes. **(Benazzouk et al ., 2003)**.

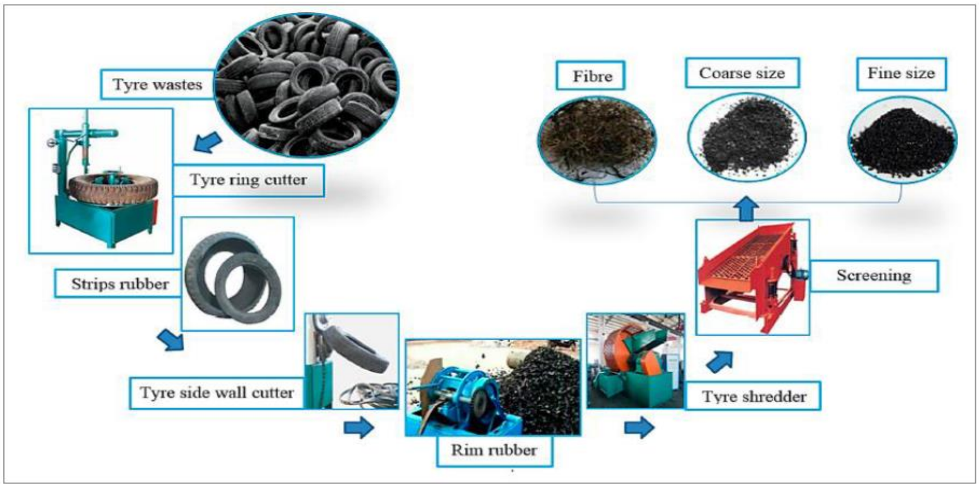

Fig. (1.4) Flow chart of waste rubber tires from waste into concrete (Mhaya, A.M. et al .2021).

1.3 Significance of the Research

The consequences of rubber tire disposal on the environment and human health as well as the lack of available land for disposal will be lessened by the effective use of waste rubber tires. According to the literature review, we find that there is avery little researches dealing with rubberized lightweight self-compact concrete in hardened, fresh and durability behavior. So, this thesis investigates the addition of rubber to the LWSCC in both hardened and fresh state, although we didn't find enough data for comparing the results.

1.2 Objectives and Experimentations of the Present Study

This study's goal is to investigate how rubber waste affects the properties of light weight, self-compacting concrete mixtures. The primary objective of this research is to determine the percentages of rubber in the mixture in order to identify potential improvements to the capabilities of the light weight self-compacting concrete. Waste rubber is the least expensive aggregate for concrete when compared to sand and other natural materials. Even so, the amount of tire rubber needs to be monitored carefully because too much of it could weaken the concrete.

1.4 Thesis’s Outline

This thesis is divided into five chapters, beginning with chapter one and ending with chapter five:

Introduction in the First Chapter: This chapter provides some historical context for scc, LWCA, and rubber. Along with the research overview, it also discusses the significance of the research, the aims, and the difficulties.

Literature Review in the Second Chapter: This chapter examines a number of studies, analyses, and scientific papers on the impact of adding rubber on light weight self-compact concrete that have been written by reputable academics and researchers.

Experimental Part in the Third Chapter: This chapter describes the fundamental characteristics of the utilized materials, concrete preparation, concrete specimens, equipment, and specimen testing.

Experimental Results and Discussion in the Fourth Chapter: This chapter discusses and presents the results of carried out tests and the effect of adding rubber particle with different percentages on LWSCC samples.

Conclusions and Recommendations in the Fifth Chapter: The main conclusions and suggested recommendations from the study are included in this chapter.

2.1 background

The literature that is relevant to this investigation is included in this section. The history of self-compacting concrete, lightweight concrete, lightweight self-compacting concrete, tire waste, rubberized concrete, and rubberized light weight self-compacting concrete is covered in this.

2.2 Self -Compacting Concrete

A type of concrete that can be produced without the effort of compacting in form work is called self-compacting concrete (SCC). To be settled without even any segregation or bleeding and to maintain a sufficient cohesion, it relies on its own weight.

SCC was initially offered to Japanese scholars at Tokyo University in the late 1980s. This new type of concrete was created in response to issues with inadequate compaction caused by a shortage of experienced Japanese workmen **(Okamura and Ouchi ,2003).**

The following are some of the benefits of SCC: (1) a substantial decrease in the number of workers needed and the loud sounds from mechanical vibration; (2) an improvement in surface finish compared to conventional concrete; (3) a decrease in formwork damage from mechanical vibration; (4) an extension of the forms' life; (5) protection of bar configurations reinforcement; and (6) a strong bond among concrete and pre-stressed strands (**Hwang and Hung (2005)).**

2.3 Fresh Properties of Self-Compacting Concrete

Any SCC must possess the three crucial workability traits of filling ability, passing ability, and segregation resistance.

2.3.1 Filling ability (excellent deformability): Under its own weight, SCC can flow and fill the formwork **(EFNARC, 2005)**.

2.3.2 Passing ability: SCC may pass through congested places as heavy reinforcement without it being blocked. The flow is obstructed and interlocked as a result of blockage, which is the non-uniform distribution of local aggregate inside the matrix in the vicinity of obstruction **(ACI237R-07, 2007)**.

2.3.3 Segregation Resistance: Segregation resistance, also known as concrete stability, is just the ability of fresh concrete to maintain its homogeneity throughout and after placing without splitting into individual components. Dynamic stability and static stability are both crucial stability characteristics. The first is stability throughout casting, whereas the second is concrete resistance to bleeding, segregation, and surface settling after casting whilst concrete has been in a plastic state. Viscosity regulates the segregation resistance. Making sure a concrete mix has an acceptable viscosity may prevent separation and/or bleeding **(Al-Abduljabbar, 2008)**.

Table (2.1) shows the SCC workability test techniques in accordance with the **(EFNARC, 2002),** while Tables (2.2) gives the criteria of acceptance according to **(EFNARC, 2005)**.

Table (2.1) List of fresh properties testing methods for SCC, EFNARC, (2005).

Methods	Property
1. Slump-flow by Abrams cone	Filling ability
2. T50cm slump-flow	Filling ability
3. J – ring	Passing ability
4. V- funnel	Filling ability
5. V- funnel at 5min.	Segregation resistance
6. L- Box	Passing ability
7. U – box	Passing ability
8. Fill- box	Passing ability
GTM screen stability test	Segregation resistance
10. Orimet	Filling ability

Table (2.2) Criteria of acceptance of self-compacting concrete tests according to EFNARC (2002).

Slump flow classes	Slump flow diameter (mm)	
SF_1	550-650	
SF_2	660-750	
SF_3	760-850	
Viscosity classes	$T_{50\,cm}$ (S)	V- funnel time (s)
VS_1/VF_1	≤ 2	≤ 8
VS_2/VF_2	> 2	9-25
Passing ability classes		
PA_1	≥ 0.8 with two rebar	
PA_2	≥ 0.8 with three rebar	

2.4 Mechanism for Attaining Self-Compactability of Concrete

The self-compactability could be obtained, as seen in Figure (2.1), by reducing the water/powder ratio, which provides segregation resistance, limiting the amount of coarse aggregate, that provides flowability and segregation resistance, utilizing mineral admixtures, which provides high flowability, and using superplasticizers, that provides high flowability**(Al-bayati, 2017)**.

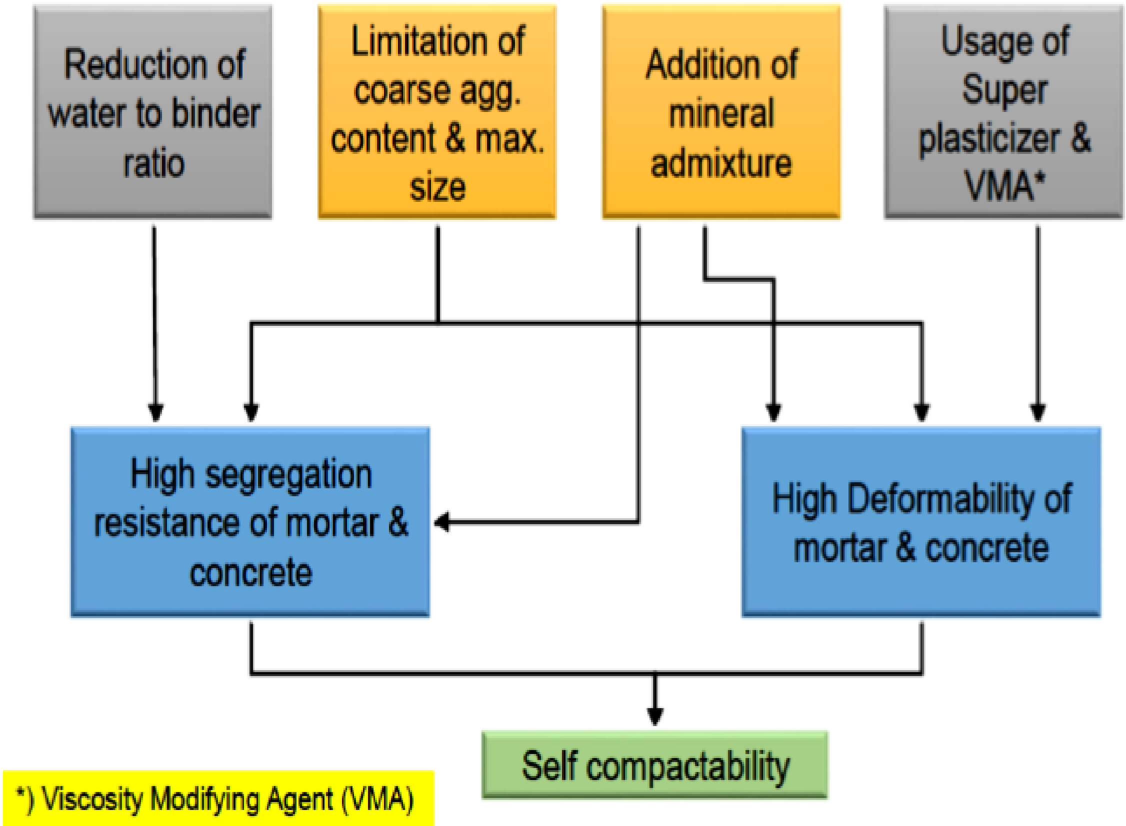

Fig. (2.1) Mechanism to attain self-compact capabilities (Al-Neshawy, F., and Sistonen, E., 2015).

2.5 Hardened Characteristics of Self-Compacting Concrete

2.5.1 Strength

SCC with a comparable water-to-cement ratio frequently has a slightly higher compressive strength than vibrated concrete because of the absence of vibration and better interactions between the aggregate and cement paste **(EFNARC, 2005).**

Furthermore, SCC has often a lesser water to powder ratio than vibrated concrete, which means a better compressive strength is anticipated. SCC shows almost no bleeding, as opposed to vibrated concrete. Actually, bleeding is the release of water to the surface, which may stay above the aggregates and create a weak and porous interfacial transition zone (ITZ), which is really the region of the cement paste surrounding the aggregate particles that is already disrupted by the presence of the aggregate, **(Newman and Choo, 2003)**.

SCC exhibites greater compressive strength than ordinary concrete with 15percent for cube specimens and 5percent for cylinder specimens at the same water content and w/c ratio, **(Bradu et al. ,2016)**.

2.6 Light Weight Concrete(LWC)

Since it solves the issues of weight and durability in structures, lightweight concrete is crucial in the structural construction sector. There are a wide range of qualities of lightweight aggregate for building, as well as how the substance affects durability. The compressive strength, water absorption, and workability of concrete with lightweight aggregate are its most important properties. LWAC, or lightweight concrete with aggregate, is used to make structures that are as light as possible. The benefits of LWAC as a construction material were first recognized during the Roman era **(Zulkarnain and Ramli , 2008)**.

Various types of materials would be used to produce a variety of lightweight concrete types. Low heat conductivity and low density are LWC's main advantages. Advantages include a reduction in dead load, faster construction rates, and lower shipping and processing costs. It is lighter than typical concrete with a dry density ranging from 300 to 1840 kg/m^3. The usage of lightweight concrete is initially introduced by the ancient Greeks in the second century B.C., but it has since become widely used in other countries like the United States and the United Kingdom etc., **(Chandra, and Berntsson ., 2002)**.

2.6.1 Types of Lightweight Concrete

According to how it is produced, LWC can be divided into the following categories, **(Neville and Brooks, 2010)**:

a) utilizing lightweight aggregate with a low specific gravity (less than 2.6) as opposed to conventional aggregate. Lightweight, aggregate concrete is the name given to this type of concrete.

b) creating cellular, aerated, or foamed concrete by creating bubble voids inside the concrete mass.

c) By removing the finer aggregates from the mixture, it is common practice to use the coarse aggregate with standard weight. No-fines concrete is the name given to this kind.

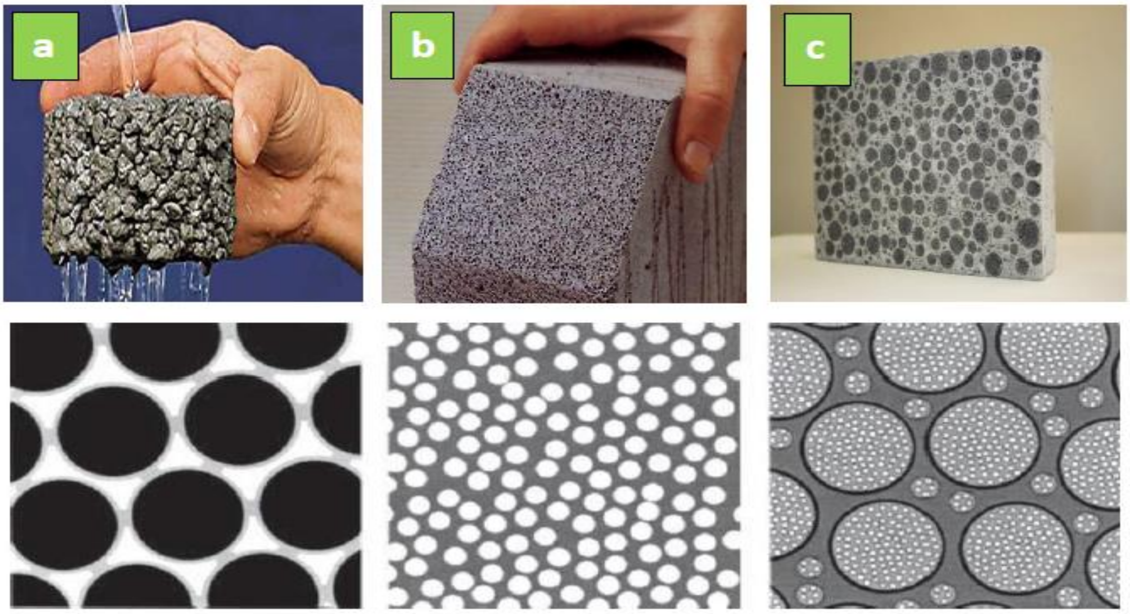

Fig. (2.2) Some kinds of lightweight concrete, (a) No fines concrete, (b) Aerated concrete and (c) Light-weight aggregate concrete (Slaby et al. , 2008).

2.6.2 Advantages of light weight concrete

Lightweight aggregate's first and most significant advantage is that it is perfect for earthquake design as it reduces the dead load of a concrete building. Additionally, because to its outstanding performance during natural disasters like earthquakes, which is made possible by its small weight.

In comparison to ordinary concrete, the air voids offer a number of advantages, such as improved heat and sound insulation, a higher strength-to-weight ratio, a higher tensile strain capacity, and a lesser coefficient of thermal expansion **(Rishab Meena et al 2020)**.

2.7 Lightweight Aggregate Concrete

Compared to concrete constructed using normal-weight aggregate, it has much reduced density and thermal conductivity (NWA), also known as NWAC , LWAC has recently gained popularity as a building material. A significant component of the load carried by structural members in established infrastructure is dead load, that comprises a substantial quantity in the form of the structural members' own mass. Therefore, reducing the self-weight of structural members is crucial for designing members with smaller cross sections that have decreased self-weight, which translates into an affordable design. LWAC is the preferred substance as a result when structural concrete component' dead loads need to be reduced and their thermal insulation capabilities must be enhanced,**(Zhou & Brooks, 2019)**.

LWAC is not frequently utilized as structural concrete because of its strength restrictions. Yet, The effectiveness of LWAC was demonstrated whenever Light Weight Aggregate is employed as a partial substitution for NWA in concrete mixtures., (**Wang, Fang., 2017b Rumsys et al., 2018; Wang ; Yoon & Kim, 2019)**.In other words, it is still difficult to overcome LWAC's weaker strength than NWAC for structural applications. **(Ahmad et al., 2019; Alqahtani & Zafar, 2020).**

Despite the fact that artificial light weight aggregate made from industrial waste has recently become more popular since it conforms with the production of sustainable concrete, natural light weight aggregate has long been the primary material used to create light weight aggregate concrete **(Wang et al., 2018; Zhou & Brooks, 2019) .**These aggregates were used to make lightweight concrete when the aggregate weight was substantially lower than 1120 kg/m^3. a cubic meter of lightweight concrete could be more expensive to produce than a cubic meter of conventional concrete, LWAC can lower the cost of the entire building by lowering foundation and dead weight costs, **Mehta and Monteiro (2006).**

Structure-specific lightweight aggregate concrete and partially-consolidated lightweight aggregate concrete can be classified as lightweight aggregate concrete based on their intended uses. Generally, prefabricated concrete blocks or panels, as well as in-situ walls and roofing, were cast using the partially compacted lightweight aggregate concrete. This type of concrete needs to be sufficiently low density and have low drying shrinkage in order to provide the best heating insulation. **(Samidi 1997)**.

Concrete made from lightweight aggregates that is structurally sound and has an air-dry unit weight between 1120 and 1920 kg/m3 and a 28-day compressive resistance greater than (17 MPa) is known as lightweight aggregate concrete (LWC) **(ACI.213R-03, 2009).**

Lightweight aggregates can be gathered from a variety of substances, including natural ones such slate, diatomite, clay, volcanic cinders, pumice, and clay, as well as non-natural ones that are byproducts of other processes, like shale, sintered fly ash, clay, and iron blast furnace slag. (**ACI 213R-87)** . Figure 2-3 demonstrates the lightweight aggregate sorts **Shetty (2006).**

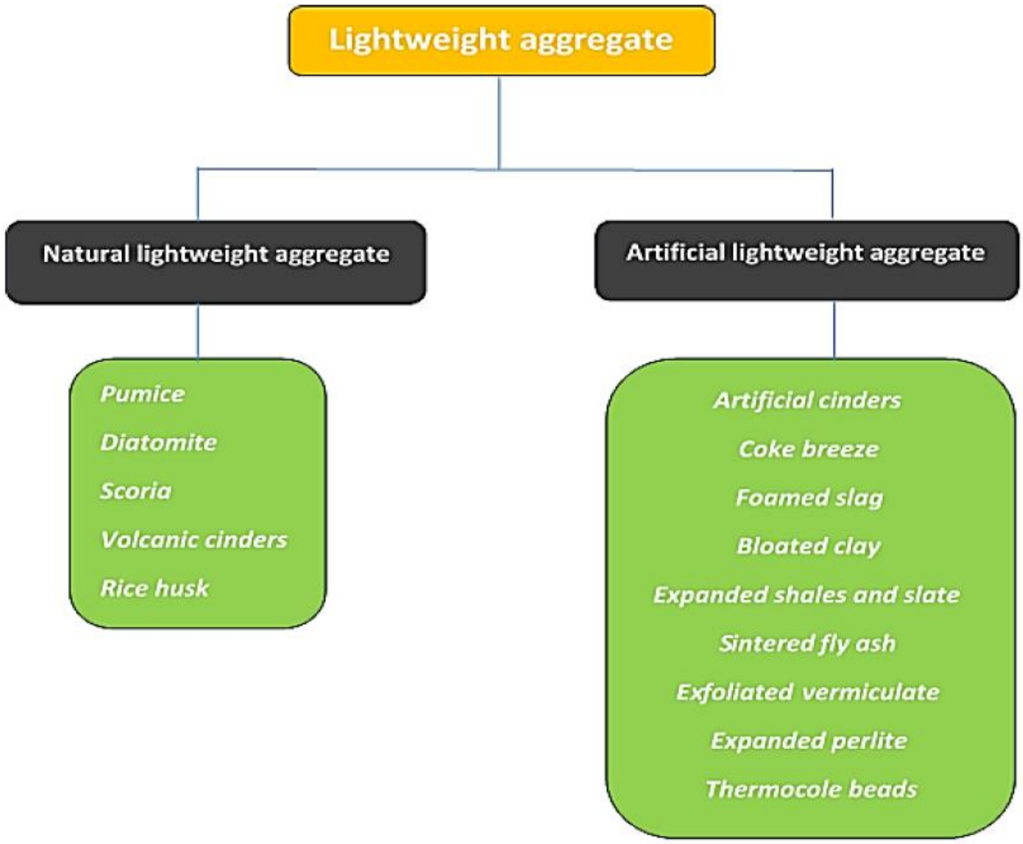

Fig. (2.3) Natural and non-natural lightweight aggregate*(Shetty 2006).*

According to **ACI 213R-87**, lightweight aggregate concrete can be divided into three categories depending on its air dry unit weight: low-density concrete (300- 800 Kg /m^3), moderate strength concrete, and structural concrete. There seem to be three approved specifications for producing concrete, masonry units, and insulating concrete utilizing lightweight aggregates, which are specifications of **ASTM C 332, ASTM C331 and ASTM C330**.

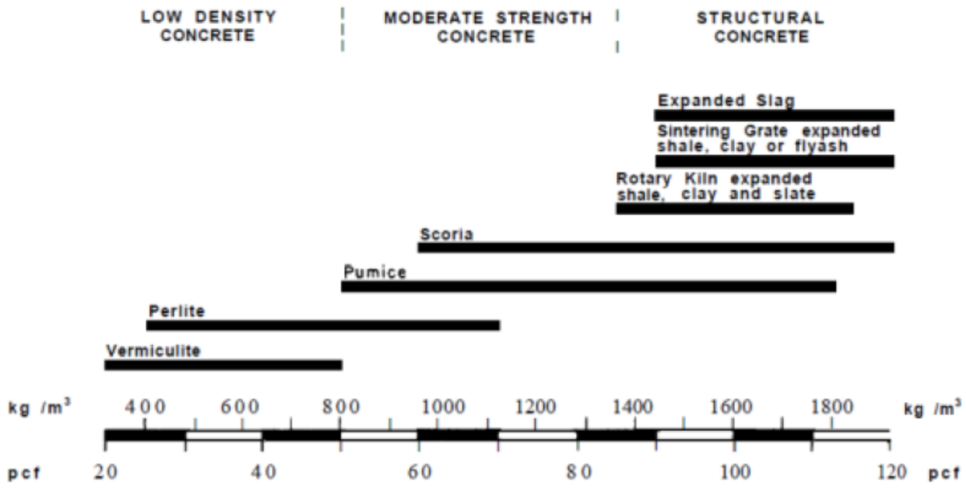

Fig. (2.4) Spectrum of lightweight aggregates (ACI 213R-87).

2.7.1 Hardened Properties of Lightweight Aggregate Concrete

2.7.1.1 Compressive strength

When compared to the design characteristics of cast-in-place, prefabricated, or pre-stressed concrete, compressive strength rates often required by the construction industry can be inexpensively attained using lightweight concrete., (**Shideler, 1957; Hanson, 1964; Holm, 1980**.) The density of LWC is mostly determined by the cement content, and this determines the material's compressive strength. In a manner similar to how regular concrete strengthens with age, the compressive strength increases. Common design strengths of LWC at age 28 days range from 21 to 35 MPa. The particle size and composition of LWC have a significant impact on its density and compressive strength, **(Sajedi & Shafigh, 2012)**.

Lightweight expanded clay aggregate (LECA) can replace regular aggregate and achieve compressive strengths up to 29 and 25 MPa at 20 and 40 percent, correspondingly, and further enhance can be achieved at a longer curing period ,60 days or more , **(Prakash & Krishnamoorthi, 2017)**.

2.7.1.2 Tensile Strength:

About 75–100percent more splitting tensile strength than standard weight concrete of the same strength can be found in LWC. The tensile strength is often increased by substituting regular weight fine aggregate for light weight fine aggregate, **(ACI-213R-03, 2003).**

The fracture path usually moves through LWA particles instead of around particles as in the case of natural aggregate (see Fig. 2.5). **Prakash and Krishnamoorthi., (2017)** Showed that the tensile strength of LWC with expanded clay decreases as the percentage of LECA replacement increases.

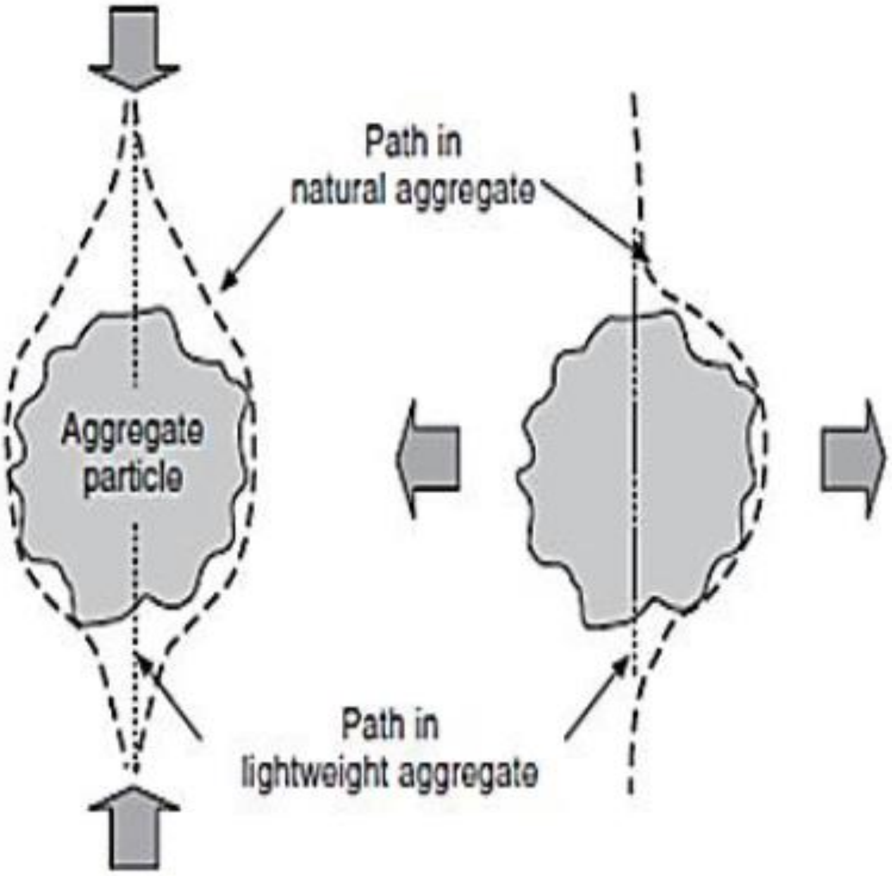

Fig. (2.5) Lightweight and normal weight aggregate fracture paths, (Elsabe, K., 2016).

2.8 Light weight self-compacting concrete

Numerous efforts have been made in recent decades to create new, high-performance materials with the advantages and traits of self-compacting concrete and light weight concrete. This is due to the development of concrete technology. It has been developed a novel type of concrete called lightweight self-compacting concrete, that combines the qualities of both light weight concrete and self-compact concrete. By substituting LWA with NWA in SCC, LWSCC is created. ACI **213** , states that the density of structural LWC must lie among 1120 and 1920 kg/m3. Aggregates normally account for around 60% of the volume of self compact concrete and constitute the majority of the concrete's weight **(Topçu et al., 2010)**. As a result, concrete's density and thermal conductivity can be decreased because LWA's porous structure. The utilization of LWSCC provides a variety of benefits, including reduced self-weight, a faster constructing period, lesser construction cost, the removal of machine vibrating noises, and enhanced heat and sound insulation because of the cavities in light wight aggregate **(Grabois et al. ,2016)**. Given that the existing construction industry is struggling to find competent people and to hire the next generation of trained workers, light weight self compacting concrete, that is less labor-intensive, could be a timely fix for these problems. **(Kim 2010)**. Additionally, LWSCC, that is excellent in producing precast components, can be utilized to improve automation or even mechanization of operations in the construction sector. The construction processes are now simpler because to the on-site assembly of precast building component modules **(Ting et al., 2019).**

Significant research on the characteristics of LWSCC, both while it is fresh and after it has hardened, has been done in the last ten years **(Lotfy et al., 2015)**. They tested light weight self-compact concrete with several kinds of expanded light weight aggregate, like furnace slag, expanded clay, and expanded shale.

According to the researchers' findings, among the three aggregates, light weight self-compact concrete with expanded shale as the light weight aggregate had the best workability in terms of filling ability, passing ability, and segregation resistance, **(Lotfy et al; 2015, Floyd et al.,2015)**. They explained that this was because the fine portion of expanded shale aggregates has been finer than the other two light weight concrete, that results in increased packing density and decreased gap among aggregate particle.

(Hossain et al.,2015) showed a sequence of experimental studies to examine the factors that influence the viability of LWSCC. They looked examined how LWSCC's workability was impacted by the water to binder ratio (w/b), the amount of superplasticizer, and the overall binder content. Aggregates in LWSCC were made of expanded shale. According to their study findings, w/b ratio and superplasticizer dose increase, in addition to the combination of these two variables, considerably improve the filling and passing abilities of LWSCC, such that slump flow raises, v-funnel flow duration decreases, and L-box ratio improved . Yet, there is a limit to how much the LWSCC's filling capacity can be improved with a fixed amount of superplasticizer and binder. In order to maintain the same filling ability, there was a higher necessity for superplasticizer due to the increase in binder content. Contrarily, it was discovered that increasing the binder concentration improved segregation resistance since it increased the packing density of the LWSCC combination.They concurred with the research findings of **(Sonebi et al., 2007)** that water and superplasticizer dosage have a significant impact on the fresh properties of self-compact concrete. When affected by water and superplasticizer dosage, light weight self-compact concrete behaves similarly to the typical SCC. In general, the water to binder ratio, superplasticizer dosage, and overall binder content have a significant impact on the performance of light weight self-compact concrete workability with respect to filling ability, passing ability, and segregation resistance.

2.8.1 Problems in lightweight self-compacting concrete.

When creating the mix design for the LWSCC, there are several common problems. LWA has poor workability and a relatively low compressive strength when compared to gravels since it is a porous substance with an uneven shape. As a result, to attain acceptable workability and specified compressive strength for LWSCC , a substantial volume of cement paste is needed. LWA has such a porous structure and a high water absorption capacity, thus leading to absorb water during batching and have poor workability as a result. The volume of water needed for batching is difficult to estimate due to LWA's high water absorption rate. A common solution to this issue is to permit light weight aggregate to attain saturated surface dry (SSD) state before mixing. **(Domaga 2015).**

Attention should be taken though, as various sorts of light weight aggregate absorb water at varying rates. A lot of water may make bleeding and segregation more likely **(Juradin et al., 2012)**. Furthermore, lightweight aggregates frequently possess densities that are lesser than those of the mortar matrix and natural aggregates in concrete **(Topçu et al. 2010)**. Since LWA and regular weight sand have different densities, this can change the LWSCC mixture's initial characteristics. The endurance and structural performance of concrete in its hardened stage can be significantly impacted by the poor self-compaction and segregation of aggregates that result **(Kwasny et al., 2012).** As a result, the use of light weight aggregate in self compact concrete is still regarded as a recent development in concrete technology, calling for more investigation and analysis. Furthermore, there is currently no code of behavior or set of rules for developing Lightweight self compact concrete mix designs.

2.8.2 Application of lightweight self-compacting concrete

Since 1992, Japan has used LWSCC as an alternative material for structural building, including the construction of cable-stayed bridges **(Ohno ,1993)**.

Additionally ,**(Shi ,2005)** applied a thin precast C-shaped wall using LWSCC. Dymond **(Dymond ,2007)** had created and built a 20-meter-long pre-stressed beam utilizing light weight self compact concrete.

The structural elements of the stadium walkway were built utilizing light weight self-compact concrete While **(Lahkega and Stenah, 2011)** investigated the feasibility of applying LWSCC in full scale wall. The structural elements of the stadium walkway were built using light weight self-compact concrete, according to **(Ting, 2019)**. The application of light weight self-compact concrete in the construction and research fields has recently gained popularity.

2-8-3 Concrete with Lightweight Expanded Clay Aggregate(LECA)

The widely used lightweight expanded clay aggregate is an artificial lightweight aggregate that is typically used in the manufacturing of lightweight concrete (LECA).

In addition to the generic name "LECA," this substance also goes by several other patented names depending on the nation where it is produced, including "Kermazite," "Aglite," and "Liapor."

The size, density, and compressive strength of the created aggregates differ; smaller aggregates having higher densities and compressive strengths, and vice versa. Sizes for LECA products typically range from 0 to 4 mm, 4 to 8 mm, 8 to 12 mm, and 12 to 20 mm. In addition to possessing a natural pH value of close to 7, excellent acoustic resistance, superior thermal insulation, and not being biodegradable, flammable, or affected by water, LECA is recognized to be effective in a variety of industries, including building, water treatment, and agriculture. **(Rashad,2018; Othman,2020)**

Due to its unique qualities, LECA may be employed in various structural and geotechnical applications. Employing LECA, an effective lightweight concrete building was created. Additionally, LECA was used in a variety of civil engineering disciplines as subbase for buildings and agriculture, as well as for drainage and lightweight fill in railway, road, and other traffic zone embankments. Due to its characteristics, LECA might replace natural aggregates in a number of civil engineering projects..

Bogas et al., 2012 observed that LECA (maximum size 12.5 mm) was used in self compact concrete mixes to provide appropriate segregation resistance.

It is well recognized that the kind of LWA and mixture composition affect how easily a combination performs. As shown by numerous examinations, the previous investigation in this chapter projected that the insertion of LECA in the mixture rather than normal weight aggregate boosted workability (78.3 percent). Despite the fact that LECA has a higher water absorption than standard weight aggregates, that affects workability negatively, LECA has rounded surfaces, that enhance workability. As a result, a mixture containing LECA often has more workability than one having normal weight one. The effect of LECA on segregation is currently not well understood and requires further research, however the study that may be cited indicates that LECA inclusion could prevent segregation. It is important to highlight that the larger density variation between the LECA and the surrounding matrix should be considered in the mix design.

Bogas and Gomes, 2013 Compositions of produced, lightweight concrete from Lica with a maximum size of 12.5 mm. The total porosity of the LECA is 60 percent. There were several w/b ratios of 0.3, 0.35, 0.4, and 0.45 .With the addition of LECA, the findings showed a raise in workability, with an average slump increase of 27.55 percent.

Bogas and Nogueira 2014 discovered that adding LECA (size 4–12 mm) as coarse aggregate increased the workability of concrete mixtures. When compared to standard weight combinations, LECA mixtures had an average slump of 174.4 mm as opposed to 166.5 mm.

Shebannavar et al. 2015 created more workable concrete mixtures by substituting LECA with normal weight coarse aggregate (size 4.75– 20 mm).

Alaa Rashad 2018 used LECA made from an unique plastic clay. At 1100–1300 C, the clay was dried, heated, and burned in rotating kilns. Owing to the circular movement of the kiln, LECA is a porous ceramic product with a homogeneous pore structure and almost potato-shaped or round shape. The LECA's lightweight, thermal, and acoustic isolation characteristics are due to the large number of tiny, air-filled cavities that make up the material. The primary conclusions of that study are that adding LECA to the matrix improved its workability, reduced its density, mechanical strength, resistance to freeze/thaw, water absorption, and resistance to chloride penetration, yet improved its thermal insulation and fire resistance.

Nepomuceno et al., 2018 observed that SCCs containing LECA as coarse aggregate had compressive strengths ranging from 35 to 57 MPa when the w/c ratios were between 0.61 and 0.29, respectively, while SCCs containing normal weight coarse aggregate had compressive strengths ranging from 53 to 87 MPa, respectively.

2-9 Rubber

The exponential rise in population and transportation growth is driving up tire manufacture for automobiles. Tires that are no longer useful produce a significant amount of rubber waste. Useless waste tires from various types of cars are multipling quickly and are in fact becoming one of the most significant environmental and sustainable problems of our time. Up to a billion worn tires are dumped annually, and by 2030, that number is expected to rise to approximately 1.2 billion, **(Rahman et al. 2012)** Furthermore because of the excessive amount of discarded tires, landfill are overflowing with scrap tires, increasing the risk of fire hazards and exposing more people to potential environmental problems like mosquitoes, rats, mice, and other insects **(Emiro˘ glu, M. et al. 2012)**. Since old tires were broken into small pieces and utilized as aggregates instead of burning them, this solution is both financially and environmentally feasible because it eliminates the need for expensive natural aggregates **(Thomas and Gupta, 2015)**.

Each year, simply in Europe, over 8.3 million tons of used tires were wasted **(Liu et al 2016)** Some of which were undoubtedly dumped illegally, endangering both human health and the beauty of the environment. Each year, 289 million used tires are disposed of in the United States **(Miller, 2017)**. In Australia, this number is near 51 million **(Aslani et al.,2018)**.

Rubber tire production each year can be roughly estimated in the billions. One billion tires a year are thought to reach the end of their useful lives. A sizable portion of this number is solely dumped untreated in landfills. Land is used up significantly when tires are disposed of in landfills. There is an urgent need to properly and environmentally dispose of used tires .As was already indicated, one of these solutions to this problem and to enhance some undesirable concrete qualities is to use recycled tire rubber in place of aggregate in concrete **(Raffoul et al. ,2018)**

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Wang et al.,2020 used the modified asphalt with crumb rubber while also looking into how much energy, CO2, and money may be saved. It is technically and financially viable to create asphalt paving for roads from scraped rubber tires. According to the ASTM most latest study, 225 million tires were produced in overall in 2017. 1 million tires were utilized to produce ground rubber, accounting for 25percent of the total tires produced. Nevertheless, just 12percent of the ground rubber was utilized in the asphalt business up until now, which is a modest amount of scraped rubber tires (Hemida and Abdelrahman, 2020).

Eltayeb et al., 2020 found that rubberized asphalt pavements have been shown to perform significantly better than traditional asphalt roadways. After End of Life Tires (ELT) were recycled, numerous paths to reuse were developed, especially for use in civil engineering applications. For example, scrap tire rubber can be used to mixtures to replace some of the natural fine and course particles in concrete.

2.9.1 Waste Tire Rubber Classification

According to their size, the classification of waste tire rubber is as follows:

1. Chipped rubber (shredded): Because of their huge size, chipped rubber (shredded) is commonly used to substitute coarse aggregate or gravels. This sort of rubber requires two phases of shredding and cutting: the first reduces the size of rubber particles until they achieve a particular dimension of 430- 300 mm length and 230-150 mm breadth. The second stage creates a rubber cube with dimensions of 150-100 mm on each side. Chips particles with diameters of 5 to 76 mm are created if the cutting process is sustained.

2. Crumb rubber: Which is used to replace fine aggregate. This type

is manufactured in factories using special mills that convert chip rubber particles into smaller particles ranging in diameter from 4.75 to 0.425 mm.

3. Ground rubber The finest sort of rubber utilized in cement replacement is ground rubber. To convert crumb rubber to ground rubber with a size range of 0.475 mm to 0.075 mm, complex micro-milling techniques are required.

For the construction sector, mechanical and chemical techniques were devised to acquire the ideal rubber particle size **(Medina et al., 2017)**. Waste tires were grounded into crumbs utilizing two distinct processes: mechanical grinding at room temp and cryogenic grinding at a temp under the glass transition temp **(Medina et al., 2016)**. The most widely utilized size range for CR particles somewhere between two and four mm, that may be produced by a variety of grinding processes **(Fraile-Garcia et al., 2018)**. Currently, modern technology enables waste tire rubber particles to be ground to a particle size range of "100-150 m "**(Dobrota˘ et al.,2018)**. Waste tire CR particles were sieved, separated, and utilized in mortar and concrete to substitute fine aggregates or coarse aggregates **(Mishra et al .,2015); (Elchalakani et al., 2015);(Meddah et al.,2017); (Pham et al .,2018))** . When tire granules are pulverized and sieved into powder or ash, they can occasionally substitute cement in some applications **(Fernández-Ruiz et al .,2018)**.

The application of waste tyre rubber in Self Compacting Concrete was investigated by **Bignozzi and Sandrolini (2006)**. Self Compacting Rubberized Concrete, according to the authors, exhibits diverse and cutting-edge mechanical behavior and qualities that are desirable for the creation of noise-reducing pavements.

Petersson et al., 2009 claimed that one of the most exciting rubberization techniques for concrete in terms of waste material recycling is the application of ground-up used tires. Tire waste surrounds the waste materials significantly because of their short lifespan and the fact that there is a great demand for them. They have more flexibility and stiffness characteristics than rubber. Furthermore, due to their anti-caustic properties, anti-rot features, and ability to withstand various weather conditions, they may be employed in practically any atmospheric scenarios. Over the past 20 years, numerous studies have been undertaken to determine how the size and quantity of different rubber types and rubber scraps impact the durability, use, and aesthetic qualities of rubberized concretes.

2.9.1.1 Effect of Waste Rubber on hardened properties of concrete and durability.

Elena and Maria, 2011 conducted a study to obtain rubberized concrete when rubber scraps are added to a pit of fine or coarse aggregate. The result of this mechanism is that the concrete is elevated with high strength, low unit weight, strong resistance, and better ductility or deformability.

Dass et al., 2013, studied the effects of adding rubber particles as aggregate on the compressive, flexural, and tensile strength of concrete. The results of the research's tests indicate that employing recycled tires in concrete mixtures at specific percentages is very likely. Examples of recycled crumb rubber concrete were made by substituting fine aggregates (0, 5 percent, 10percent, 15 percent, and 20 percent) in some concrete mixes with recycled crumb rubber waste. Subsequently, the material's flexural strength, split tensile strength, compressive strength, and stress-strain behavior were examined. The findings indicated that all strength categories in the crumb rubber combination decreased, whereas slump values increased as the amount of crumb rubber climbed from 0 percent to 20 percent. Additionally, research shown that the concrete's split tensile strength and compressive strength both decreased by around 37percent and 30 percent, respectively, when 20percent of the sand was substituted with rubber.

Noor, 2014 looked at the durability and physical performance of rubberized concrete. This research main objective was to develop rubberized concrete with structural strength that would be attained with a straightforward mix design.

Nurazuwa Noor, 2014 found that one of the solutions suggested was the use of scrap tire rubber as a partial or complete replacement for fine aggregate. It was thought that incorporating rubber fibers into concrete would strengthen its resistance to acid rain, lower heat transmission, and minimize noise. Additionally, adding the cubes of recycled tire rubber to concrete makes it more elastic, durable, and resilient. Additionally, rubberized concrete, which incorporates used tire rubber as an element, can increase the flexibility and toughness of concrete structures in difficult settings.

Obinna Onuaguluchi *et al.* (2014) found that crumb rubber increased the porosity of concrete.

Matthew *et al*. (2014) rubber in concrete can rise water absorption coefficient and water penetration depth.

In a different investigation, ground rubber and crumb rubber, two distinct kinds of rubber particle samples, have been used. **(Khalid and Hameed, 2015)** . For both coarse and fine aggregates, the percentages of rubber replacement were 5 percent, 10 percent, 15 percent, 20 percent, 25 percent, 30 percent, 35 percent, and 40 percent. Just five minutes could be spent on the mixing. The experimental text claims that adding rubber to concrete lessened the slump, with zero slump occurring at a 40percent replacement rate. In comparison to conventional concrete, the combinations had a poor compressive quality. The best option for producing lightweight concrete without sacrificing compressive strength or slump was found to be substituting 5 percent–10 percent of the concrete with rubber.

Gupta et al., 2015 noted that when rubber fiber content rises, so does water permeability. The permeability of rubberized concrete may, nevertheless, be decreased by using silica fume in place of cement.

Thomas et al., 2016 additionally discovered that rubberized concrete absorbed more water than control mix concrete.

For the purpose of refining constitutive models**, Strukar et al., (2018)** reported an experimental study on the stress-strain behavior of rubberized concrete. By conducting uniaxial compressive tests on concrete with rubber replacing 10 percent, 20 percent, 30 percent, and 40percent of the aggregate, it was possible to study and analyse the effects of rubber content on mechanical behavior. Compressive strength, elastic modulus, strains at high stress levels, and failure patterns are all examined along with the full stress-strain curve. The mechanical qualities of the substance, such as elastic modulus and compressive strength, would be diminished by the inclusion of rubber aggregate. However, the resulting stress-strain curves showed benefits, including (1) less softening stiffness in the post-peak region, (2) better ductility. The results of the tests also showed that there was an inverse relationship between the presence of rubber aggregate and compressive strength. The elastic modulus reduced with increasing rubber content, according to the stress-strain curves for rubberized concrete. The increase in strain at peak stress and ultimate strain was evidence that rubberized concrete was much more ductile than regular concrete.

(Siddika et al., 2019) reviewed the characteristics and applications of rubber from used tires in concrete. As a consequence, waste buildup increases to dangerous levels. Tire litter is one of the many modern advancements that are causing serious environmental problems because of their swift ascent and myriad variations. Therefore, it is advantageous to recycle used tire rubber into aggregates as an additional construction resource. The study also aims to provide a theoretical framework for the application of rubberized concrete (RuC) composite materials to enhance construction processes, including applications to raise the sustainable development of concrete structures in the building sector. RuC has a low mechanical strength in general, but with proper processing and the inclusion of additives, this strength can be improved. RuC has been extensively explored as a substance, although further research is needed on its structural components.

The behavior of long-lasting rubberized concrete has been experimentally explored by **(Ali and AL.-Mutairee , 2020)** . This research presented the findings of experiments performed on concrete samples made from scrap tire rubber to ascertain flexural tensile strength, compressive strength, rupture modulus, and impact resistance. For coarse and fine aggregate, waste rubber was employed in four various volume levels (5 percent, 10 percent, 15 percent, and 20 percent, respectively). The findings showed that mechanical properties like compressive, flexural, and breaking tensile strength are reduced when crumb rubber was used in place of natural fine and coarse aggregate. But, the impact resistance rises from 396 percent to 426 percent, respectively, when 20percent of the coarse and fine aggregates were swapped out for crumb rubber.

(Fawzy et al., 2020), researched the characteristics of rubberized concrete and its uses in structural engineering.

-The density of the concrete mix decreased as the amount of rubber particles in the mix rose, and this loss in density grew significantly when rubber was used. Rubberized concrete might be created in lightweight mixes due to its lower density to meet the needs of various applications.

- Comparing rubberized concrete to regular concrete mixes, the former has lower compressive strength. Unless more than 20percent of the overall aggregate material was replaced with rubber, the reduction in compressive strength may be considered acceptable.

-Enhancing the rubber percentage in rubberized concrete mixture improved abrasion resistance, water absorption, and shrinkage. It also improved sound isolation and resilience to freezing and thawing.

-It was observed that rubberized concrete has a lower modulus of elasticity than standard concrete mixtures, and that the loss in modulus of elasticity increased as the rubber percentage rose.

2.9.1.2 Effect of rubber on fresh characteristics of concretes

According to research done by other writers Cairns et al. (2004), the workability decreases as the rubber component increases, and at a rubber concentration of 50 percent, the slump value disappears. These authors used long, angular coarse rubber aggregates with a maximum diameter of 20 mm, producing concretes with an acceptable workability despite having less rubber in them.

In the study by Albano et al., 2005, fine aggregates were replaced with 5percent and 10percent of scrap rubber waste with particle sizes of 0.29 mm and 0.59 mm, which demonstrated a 88 percent reduction in concrete slump.

Skripkiunas et al .,2007, research has also shown that the volume and size of the rubber waste additive have an impact on how the slump changes. The slump was observed to diminish by (150 cm to 8.3 cm) when rubber wastes additive is added up to 10percent of the total aggregate content. When 20percent rubber waste is added as an additive, the slump value drops to (4.75 - 1.0) cm, or 30 percent of the total aggregate amount, correspondingly. When the same number of rubber wastes with a 2/3 particle size were employed, the slump decreased to (1.5 - 0 cm), and the workability of the mixture was eliminated.

According to Zheng et al., 2008, the mixture prepared with finely ground rubber is easier to work with than the mixture made with coarse tire chips**.**

Ayman et al., 2010 noticed a 10 percent replacement of rubber did not impact workability; nevertheless, a replacement of more than 10percent resulted in a considerable drop in workability.

According to Youssf et al., 2014, a suitable amount of super plasticizer (1–3percent by weight of cement) can be employed to regulate the workability of rubberized concrete. In contrast to ordinary concrete, rubberized concrete that contains both rubber powder and crumb rubber exhibits high workability when a suitable amount of additive is utilized, according to **Elchalakani (2015)**, when employed to replace up to 50 percent of the total aggregate, rubber particles have adequate workability, but their strength is proportionately lower.

Trilok et al.,2015 demonstrated that including rubber fibers had little to no impact on how workable concrete was.

Pelisser et al., 2011 explained that when silica fume is added to rubberized concrete, only a 9 percent reduction had been seen, despite the density of the rubberized concrete being 13 percent lower than that of conventional concrete increased concrete structure densification.

Parheco-Torgal et al., 2012 investigated a study on crumb rubber replacing all of the mineral aggregate in rubberized concrete and tire chips replacing coarse aggregate in part. It was noted that replacing fine aggregate with another material lowered the density of the concrete by 34%, whilst replacing coarse aggregate produced a 45 percent reduction. A total density reduction of 33 percent was produced by the combination.

Gesog Lu *et al.*, 2014 The lowest density of 1900 kg/m3 and the highest density of 2240 kg/m3 made, and it was discovered that the rubberized concrete had a higher density the finer the rubber particles were. The density of the concrete was increased without changing the permeability coefficient "K," as the fine rubber filled in the minuscule voids between the concrete particles.

Nadal Gisbert *et al*.,2014 outlined how well the density of the concrete decrease as the amount of rubber rises because of the voids around the rubber.

Gesog Lu *et al*., 2014 found that adding rubber to concrete produces lighter-weight concrete. The densities of the rubberized concrete were (2 - 11) percent lighter than the specimens of control concrete.

Kardos *et al*., 2015 found that adding crumb rubber to the concrete caused the air content to increase.

2.10 Maximum rubber aggregate size and replacement level

More than crumb rubber, chips have a negative impact on strength. Additionally, chips increase the SCRC's propensity for isolation. The granular particles are more expensive than the others, while the chipped particles are more affordable **(Herna´ndez et al., 2002)**.

Nevertheless, **(Hernandez et al., 2002)** substituted up to 25percent volumetric replacement of a coarse aggregate with "4 -10 mm" chipped rubber and a "4 -10 mm" natural aggregate, but with a reduction in compressive strength of 33percent and 75percent compared to 10percent and 25 percent, respectively.

Ganjian et al., 2009 conducted two sets of tests using 5 percent, 7.5 percent, and 10percent of scraped rubber tires by weight; in the first set, they replaced natural aggregates with the powder from the scraped rubber tires, and in the second set, they replaced cement with the powder from the scraped rubber tires.

Najim and Hall, 2010 Many studies have documented the usage of crumb rubber aggregate in the manufacturing of SCRC as a fractional substitute for sand rather than coarse aggregate. In contrast to powder or chips, the size of the rubber particles and the size of the sand particles have been very similar.

Although a recent research **(Najim and Hall, 2010)** found that 180 kg/m3 of 314 mm crumb rubber had been the highest amount necessary to meet both fresh and hardened-state requirements, the full replacement of rubber aggregate in SCRC hasn't yet been established.

Dong et al.,2013 examined the tensile and compressive strengths of concrete mixtures made with coated and uncoated rubber as aggregates. They found that utilizing coated rubber raised the strengths of the concrete mixtures by 10 percent to 20 percent in comparison to the uncoated rubber concrete mixtures. In their analyses of rubber-modified concrete, **Dong et al. (2013) and Huang et al. (2013)** discovered that coated rubber concrete exhibits greater compressive and tensile strength than uncoated rubber concrete.

Thomas et al., 2015a used compression experiments on concrete where crumb rubber was used in place of the natural fine particles to show a progressive decline in compressive strength. They conducted experimental tests on both sets, comprising compressive, tensile, and flexural tests. For all sets of studies, they found that a 5 percent replacement did not significantly alter the concrete qualities, while greater replacement percentages resulted in more noticeable alterations. Scraped rubber was used as a partial replacement for fine natural aggregates by **Thomas et al. (2016)**. They found that when the replacement was less than 25%, the strength of concrete under compression loading was good; but, when the replacement was greater than 25 percent, the compression strength dramatically decreased.

Noaman et al., 2017 used crumb rubber as an aggregate in place of sand to examine the fracture strength of plain and steel reinforced concrete. They conducted various experimental tests, including splitting tensile, compression, and three-point bending tests to determine the critical strain energy release rate, using 5 percent, 10 percent, 15 percent, 20 percent, and 25percent crumb rubber by sand volume.

mechanical characteristics, elastic-plastic fracture toughness, and fracture energy. They saw a noticeable improvement in the standard concrete's fracture strength.

2.10.1 Applications and Advantages of Rubberized Concrete

It has been shown that rubberized concrete is more affordable and more temperatures, pressure, and controlling resistant than regular concrete. Research has shown that RCC (rubber crumbs concrete) samples, as opposed to regular concrete mixes, get the capacity to stay structurally intact after a calamity (did not break). For a building with high resistant properties, this behavior could be preferred. Concrete samples accumulated with dense rubber showed a higher effect resistance than unrubberized concrete, in particular **(Bignozzi and Sandrolini, 2006)**.

Topcu (1995) has investigated the mechanical and physical characteristics of rubberized concretes with a 20MPa initial compressive strength. 15 percent, 30 percent, and 45percent of the overall volume of aggregates have been made up of rubber, which was then used create the rubberized concrete. According to the results of this investigation, rubberized concrete's compressive strength has generally decreased.

Fattuhi and Clark (1996) have suggested that the following uses for rubberized concrete may be possible: 1)- Where vibration dampening is required, such as in railway stations and machine foundation pads. 2)- In pile heads, paving slabs, and trench and pipe beds. 3)- Where the requirement for impact or blast protection is present, such as in railway buffers, barriers, and bunkers.

Bignozzi and Sandrolini, 2006 investigated that when rubberized concrete is compared to conventional concrete, it is shown to be less expensive and more temperature, pressure, and control resistant. Studies have shown that RCC (rubber crumbs concrete) samples have always had the ability to remain structurally intact after a disaster, as opposed to ordinary concrete mixes (did not break). This behavior might be preferred for a structure with strong resistance qualities. In particular, it was noticeable in concrete samples piled with dense rubber. Rubberized concrete had a higher effect resistance.

The unique properties of rubberized concrete have also led to the discovery of new and cutting-edge applications, such as its use in sound barriers as a sound absorber, in the construction of highways as a shock absorber, and inside structures as an earthquake shock-wave absorber.Waste tire rubberized concrete is being used in non-load bearing building walls, precast sidewalk panels, and precast roof for green buildings **(Kamil et al., 2005)**.

Al Bakri et al., 2007 investigated the concrete strength with rubber waste collecting.The intention was to deliver lightweight concrete by substituting a small amount of aggregate with tire rubber. The main goal of the test was to determine how the waste rubber aggregate contributed to the overall improvement of the lightweight concrete. **Khorrami et al., 2010** investigated the results of two clusters of crumb rubber and two different treatments; the rubber particles were afterwards added to a concrete mixture after being exposed to CCl_4 for 10 minutes (carbon tetrachloride).

2.11 The Summery of Literature Review

- Due to its unique qualities, LECA may be employed in various structural and geotechnical applications. Employing LECA, an effective lightweight concrete building was created. Additionally, LECA was used in a variety of civil engineering disciplines as subbase for buildings and agriculture, as well as for drainage and lightweight fill in railway, road, and other traffic zone embankments.
- The excessive amount of discarded tires, landfill are overflowing with scrap tires, increasing the risk of fire hazards and exposing more people to potential environmental problems like mosquitoes, rats, mice, and other insects.
- Waste rubber is the least expensive aggregate for concrete when compared to sand and other natural materials. Even so, the amount of tire rubber needs to be monitored carefully because too much of it could weaken the concrete.
- The LWSCC decreases workability as rubber content and rubber size rise (both flowability and passing ability).
- In furthermore, regardless of the size and type of the crumb rubber, raising the rubber content led to a systematic decrease in the L-box height ratio.
- an increment in rubber particle replacement of sand whilst maintaining a constant water content causes a reduction in the segregation ratio.
- The compressive strength of SCC was consistently reduced when utilizing several forms of rubber aggregate as a partial replacement for natural aggregate, irrespective of rubber replacement level, or substituted type of aggregate. In every case, a decrease in compressive strength has been noted, and the decrease in

compressive strength seems to be more pronounced with higher levels of rubber substitute**.**

- The tensile strength decrease by less than 11percent for each type of 5 wt.% rubber. But even so, the 15 % replacement of CR resulted in a 39 percent reduction in strength**.**
- The 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.
- According to the literature review, we find that there is a very little researches dealing with rubberized lightweight self-compact concrete in hardened, fresh and durability behavior**.**

3.1 Introduction

The information for the experimentation program is presented in this chapter. Additionally, it explains the testing method used to accomplish the goals outlined in the first chapter, and the details of the items used, the ratio of the combination, the preparation and curing of the specimens, and the research plan.

The goal of this experimental study is to determine the effects of adding waste tire (rubber) on particular fresh and hardened features of light weight self-compacting concrete, which also comprises one type of cement, namely regular (ordinary) Portland cement, and expanded clay aggregate (LECA).

The tests were conducted to demonstrate the behavioral changes that took place in the fresh, hardened and durability states. During the fresh state for LWSCC, the slump flow, T500, L-box, V-funnel, flow time and fresh density were carried out.

The hardened tests including the compressive strength, splitting tensile strength, static elasticity modulus. And finally the durability tests including the water absorption, and the sorptivity. All these tests at the age of 28 days were assessed for the three different sized of crumb rubbers (No. 18, No. 5, and mixed crumb rubber) after the concrete has been cured. Six prepeared crumb rubber contents of 0 percent , 5 percent , 10 percent, 15 percent, 20 percent, and 25 percent were viewed as experimental work so 18 distinct light weight, self-compacting rubberized concrete mixtures were available.

Table (3.1): The details of the experimental work.

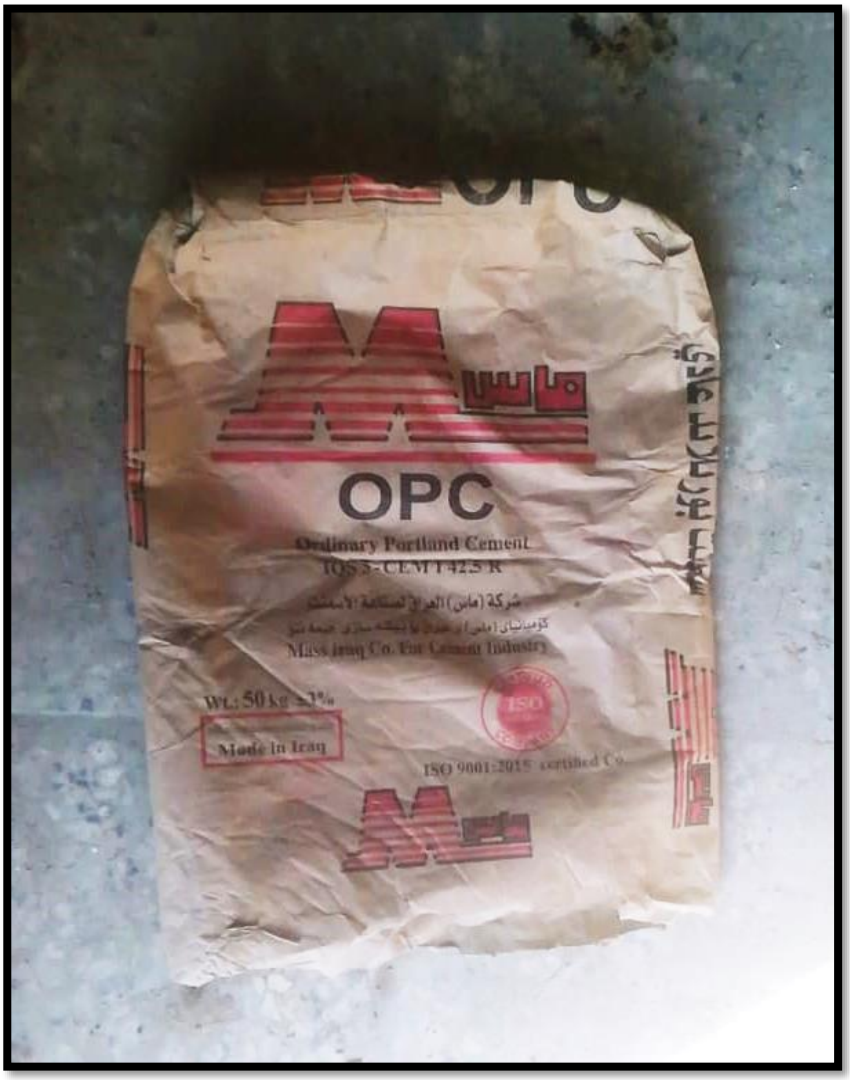
Mix code	Fresh tests	Hardened tests	Durability Tests
Control	a- Slump flow diameter. b- T50 slump flow and V-funnel flow times. c- L-box height ratio. d- Segregation Resistance of SCC Mixes. e- Unit weight.	a- Compressive Strength . b- Splitting Tensile Strength. c- Modulus of Elasticity .	a-Water Absorption. b-Sorpitivity .
FCR5			
FCR10			
FCR15			
FCR20			
FCR25			
CCR5			
CCR10			
CCR15			
CCR20			
CCR25			
MCR5			
MCR10			
MCR15			
MCR20			
MCR25			

3.2 Properties of Construction Materials

Knowing the properties and features of the constituent materials is crucial because concrete is a composite substance made up of many different components, like gravel (that was substituted with Lica in this research), sand, water, cement, and admixtures. Strict guidelines were created for material selection, component proportioning, and ingredient management in order to ensure proper manufacturing of concrete. The origins of the substances, chemical make-up, and physical characteristics of the materials employed are discussed in detail under this experimental investigation, as shown in the following subsections. These materials' primary characteristics are as follows:

3.2.1 Portland Cement

All types of concrete samples utilized in this experiment were cast using ordinary Portland cement (type 1 Al -Mass). Table (3.2) lists the physical and chemical qualities. According to Iraqi specifications, the qualities of regular Portland cement were examined. The University of Babylon's Construction Material and Environmental Laboratories tested the cement's chemical and mechanical characteristics.



Plate(3.1): The type of cement that used in thus work.

Table (3.2): Chemical and physical properties of cement

Chemical Test Results			
Oxide		Test	Limits of IQS No.5:2019
Lime	Cao%	61.52	……………………
Silica	Sio%	21.67	……………………
Alumina	Al_2O_3%	5.33	……………………
Iron oxide	Fe_2O_3%	3.31	…………………..
Magnesia	MgO%	2.97	≤ 5%
Sulfate	SO_3(%)	2.51	2.5% ≤ if C3A < 3.5%
Free Lime(%)	FreeCaO	0.84	"2.8% ≤ if C3A >
Loss of Ignition.(%)	L.O.I	3.14	≤ (4.00%)
Insoluble residue.(%)	I.R	0.91	≤ (1.50%)
Lime Saturation Factor	L.S.F	0.86	
	Main Compounds		
C_3S%	38.08		……………………
C_2S%	33.43		……………………
C_3A%	8.55		……………………
C_4AF%	10.06		……………………

Physical Test Results

Oxide		Test Results	Limits of IQS No,5:2019
Initial setting time(hour:time)		02:23	>00:45(hour:min.)
Final setting time(hour:time)		03:25	≤10:00(hour:min.)
Fineness(blain) in m^2/kg		326	>250 m^2/kg
Compressive strength(MPa)	2 day	18.4	>=10.00 Mpa
	28 day	43.75	>=42.5 Mpa

3.2.2 Fine Aggregate (Sand).

For the concrete mixtures in this experiment, natural sand has been employed. The fine aggregate in concrete has a nominal maximum size of

4.75 mm, rounded particle shape, smooth texture, and fineness modulus of (3.03). The fine aggregate grading is displayed in Table (3-2), and it complies with the Iraqi specification [5]. Table (3-3) lists the fine aggregate's physical and chemical properties. The University of Babylon's civil engineering department's construction material and environmental laboratories have conducted tests on fine aggregate.

Table (3.3): Sieve analysis of sand.

Sieve size(mm)	Passing%	
	Sand	*Limit of IQS No. 45/1984 for Grade No. (2)*
10	100	100
4.75	100	90-100
2.36	94.85	75-100
1.18	86.6	55-90
0.6	58.44	35-59
0.3	29.75	8-30
0.15	7.22	0-10

Table (3.4): Physical and chemical properties of fine aggregate.

Property	Test Results	IQS No.45 / 1984 for grade No.(2)
Specific gravity	2.65	----------
Fineness modulus	2.23	----------

<u>3.2.3 Lightweight Coarse Aggregate.</u>

The light weight expanded clay aggregate (LECA), which was imported from Iran, was employed in regular sizes ranging from 0.475 cm to 1 cm. Porous ceramic materials with uniformly tiny, closed-cell pores and finely sintered, robust external surfaces define this category of lightweight aggregate. LECA is manufactured from clay mineral raw materials that are heated to between 1100 and 1200 °C in rotary kilns, causing the particles to swell and greatly increase in volume. While Tables

(3.6) ,(3.7) details its chemical and physical properties, Table (3.5) lists the specifications for **ASTM C330 (2017)** for gradation of lightweight aggregate as well as the test results of LECA employed here.

In order to prevent LECA from absorbing water during mixing due to its high water absorption capacity, as shown in Plate (3-2a), LECA was submerged in water for at least 48 hours. The LECA was dispersed in the laboratory air until the surface dried, as shown in Plate (3-2b), such that the aggregate had the saturated and surface dry state (SSD), as recommended by ACI211.2-98.

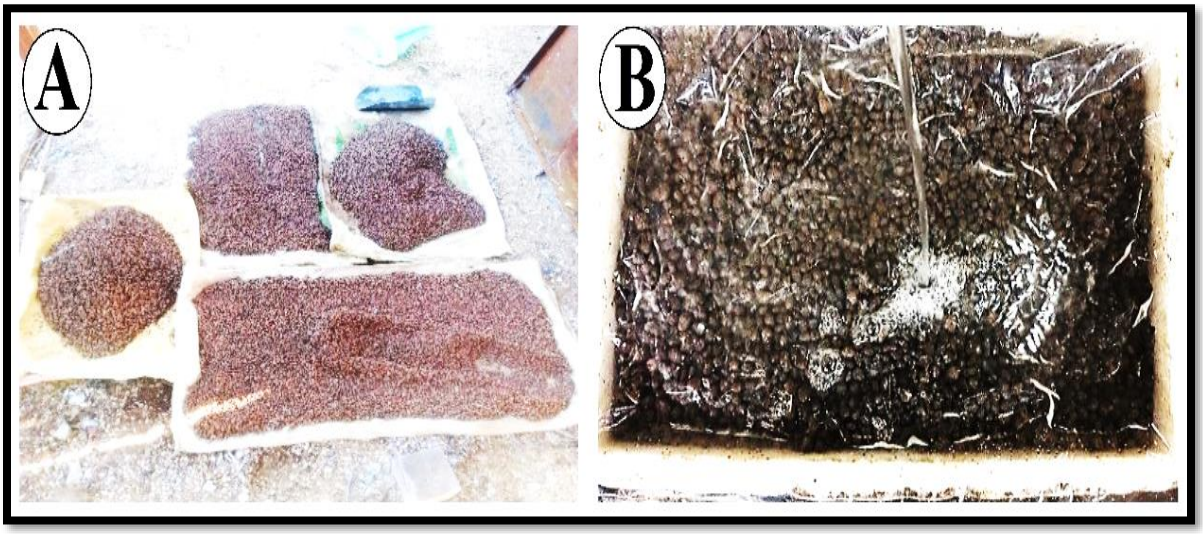


Plate (3.2): (a) LECA was soaked in water , (b) LECA was drained in the laboratory air.

Table (3.5): Grading of LECA coarse aggregate

Sieve size (mm)	**Cumulative Passing %**	**Limits of ASTM C330 Max.size**
12.5	100	100
10	97	80-100
8	80	-
6	46	-
4.75	7	5-40

2.36	2	0-20
1.18	0	0-10

Table (3.6): Physical and chemical properties of LECA

Chemical Properties	
Chemical Composition	**Percentage by Weight%**
CaO	3.78
SiO_2	61.58
Al_2O_3	16.99
Fe_2O_3	7.62
MgO	2.56
SO_3	0.19
TiO_2	0.80
MnO_2	O.10
Na_2o	1.03
K_2 o	2.34
Loss on Ignition (L.O.I.)	0.2

*Chemical tests were conducted by manufacturer.

Table (3.7) Physical Properties of LECA

Properties	Test results
Specific Gravity (SSD)	1.2
Absorption %	12
Bulk density Kg/m^3	705

3.2.4 Waste Tires Rubber

Crumb rubber grade from 0.15mm to 4.75mm was used in place of fine aggregate made from used tire rubber from General Company for Rubber Industries and Tires/Al-Najf with varied sizes of (0.15-0.18)mm, (1.8-2.36)mm, and (2.36-4.75)mm. Three various sized crumb rubbers (No. 18, No. 5, and mixed crumb rubber) and six designated crumb rubber contents of 5 percent, 10 percent, 15 percent, 20 percent, and 25 percent have been regarded as experimental Fig. (3-1) shows the different size of rubbers. The chemical composition and physical characteristic are illustrated in Table (3.8). Physical and chemical analysis were conducted at "General Company for Rubber Industries and Tires/Al- Najf".

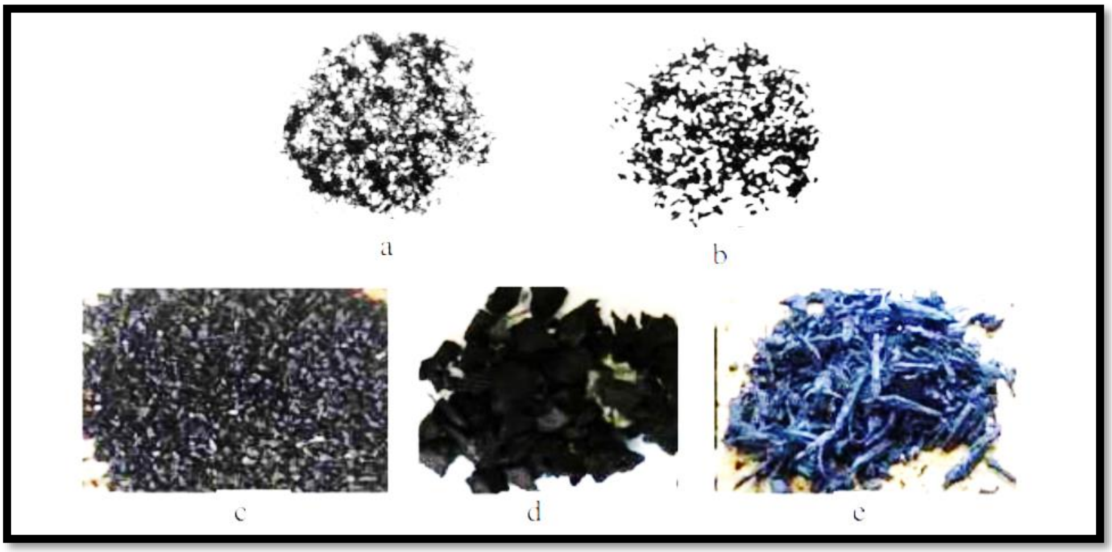


Fig. (3.1): Available waste tire rubber in Iraq: a-Ground crumb rubber (0.15-.18) mm; b-Crumb rubber (1-2.36) mm; c-Crumb rubber (2.36- 4.75) mm; d-Chip rubber (4.75-10) mm; e-Rubber fibers.

Table (3.8): Waste tires rubber chemical and physical characteristic.

Chemical composition		Physical properties	
Major rubber components	Results	Properties	Results
Acetone extract	10	Fines modulus	2.25
Rubber hydrocarbon	25	Specific gravity	1.78
Carbon black content	30	Water absorption	2%
Natural rubber content	31		
Ash content	4		

The grading of crumb rubber is shown in Tables (3-9). After eliminating all rubber fibers, sieve examination of the rubber particles was undertaken to guarantee that the same gradation of fine aggregates is used within the limitations of IQS. Sieve analysis was conducted in the Civil Engineering laboratory at University of Babylon.

Table (3.9): Grading of the crumb rubber and fine aggregate used for rubberized concrete.

Sieve size (mm)	Passing Percentage of crumb rubber	Passing Percentage of fine aggregate%	Limits of (IQS.No.45/1984)(zone 2)	
			Min.Limit	*Max.Limit*
10	100	100	100	100
4.75	94	100	90	100
2.36	82	94.85	75	100
1.18	66	86.6	55	90
0.6	52	57.9	35	59
0.3	20	28.15	8	30
0.15	5	7.22	0	10

3.2.5 Water

Washing rubber and coarse aggregate (lica), casting, and curing concrete samples were all undertaken with tap water.

3.2.6 Limestone Powder (LSP)

Limestone powder known locally as "Al-Gubra" was brought from local market and used as filler in LWSCC. Indeed, this product is cheap and widely available in Iraq in contrast with fly ash, which is not available in Iraq. A fine powder of limestone utilized in this research was grinded by blowing method so that the particle size was smaller than 0.0125 cm as recommended by EFNARC (2005). LSP can:

Improve cohesion and fluidity, prevent moderate heat generation, and increase resistance to segregation.

The limestone's chemical composition is listed in Table (3.10).

Table (3.10): Chemical analysis of the limestone powder

Oxide	Content (%)
CaO	56.10
Fe_2O_3	0.12
Al_2O_3	0.72
SiO_2	1.38
MgO	0.13
SO_3	0.21
L.O.I	40.56

3.2.7 Super-Plasticizer

Superplasticizer used in the experiments was **SikaViscocrete-5930L** which is an aqueous solution of modified polycarboxylic polymers with long chains, free of chlorides and compatible with **ASTM C494 (2017**). This type of chemical admixture is specifically designed to enable the water content of concrete to operate more efficiently by significantly improving cement dispersion. In beginning of the mixing process, the polymer chains increase the negative charge on the surface of the cement particle and the dispersion of cement occurs by electrostatic repulsion. Table (3-11) demonstrates the technical explanation of (**Sika Viscocrete-5930L**).

Table (3.11): Technical description of (SikaViscocrete-5930L).

Chemical Basis	Aqueous solution of modified polycarboxylate
Color	Turbid liquid
Specific Gravity	1.05 ± 0.02
Air Entrainment	Typically less than 2% additional air is entrained above control mix at regular dosages.
Chloride Content	None
Toxicity	Not classified as hazardous material.
Storage	Stored at temperatures between 5 °C and 35 °C.
Fire	Nonflammable

*According Manufacturer

3.3 Mix Proportion

After many trial mixes, the reference mix contained the following ingredients per cubic meter: 440 kg cement, 820 kg sand, 370 kg LECA, 110 kg limestone powder, and 180 kg water. The crumb rubber mixes had the same mix ratios except for sand content which was partially substituted by rubber by volume depending on the specific gravity of the materials.

3.3.1 Design of self-compacting Lightweight concrete mixture

As was previously mentioned, the mass of lightweight concrete (LWC) is often a determining factor. Lightweight structural concrete (LWC) is defined in (ACI 213R-03) as concrete that has a hardened density of less than 2000 kg/m3 and a compressive strength at 28 days that is greater than 17 MPa, as opposed to regular concrete, which has a density that is between 2200 and 2600 kg/m3. This work's LWC combinations used cement, natural sand, and LECA as a coarse lightweight aggregate, and chemical admixture. The creation of concrete mixtures that met the demands for density and compressive strength was guided by ACI Committee 211.2-98. Figure (3-3) displays the proportion of LWC mix materials as a percentage by volume, while Table (3-10) gives the ratio of the mixture, compressive strength, fresh density, and slump.

Because there is currently no established procedure for producing such a novel type of concrete, the trial mixing approach is the most effective for choosing proportions for LWSCC. It is crucial to utilize a low water to binder ratio and a high binder content to achieve the desired compressive strength, air dry density of less than 2000 kg/m^3, and appropriate fresh characteristics, according to **EFNARC (2005)**.

Different blending ratios were found using a variety of mixing ratios that were taken into consideration from earlier investigations.

Utilization of powder concrete improves homogeneity, which is crucial for this type of concrete. The high Portland cement amount, is used to achieve increased strength. The use of a minor water/powder ratio of 0.3-0.38 is another crucial component. Different amounts of chemical additives are used to make fresh concrete more workable at such a low water-to-cement ratio. In fact, a substantial amount of limestone powder (LSP) is used as the filler to increase density .These shortcomings have been used to create LWSCC mixtures that will be used in this study in order to attain the hard and fresh properties based on **EFNARC (2005).**

As seen in Table (3.12), six LWSCC trial mixes were made. According to the above requirements, one of them, mix No. 6 was adopted in the experiments. Figure (3-2) shows the proportion of ingredients of LWSCC mix as a percentage by volume.

Table (3.12): Details of LWSCC trial mixes (kg/m3).

Trial Mix No.	1	2	3	4	5	6 Selected
Cement Kg/m^3	495	478	456	425	402	440
Sand Kg/m^3	795	795	795	795	795	820
LECA Kg/m^3	360	360	360	360	360	370
LSP Kg/m^3	105	122	144	175	198	110
Water Kg/m^3	180	180	180	180	180	180
SP by wt. of cm (%)	1.5	1.5	2	2	1.25	1.35
W/p Ratio	0.3	0.3	0.3	0.3	0.3	0.34
W/c Ratio	0.36	0.37	0.39	0.42	0.44	0.43
Slump mm	655	647	721	600	610	695
T500 sec	4.6	5.5	4	6.2	3.0	4.3
L. Box	0.82	0.95	0.78	1.3	0.81	0.86

V-Funnel ,sec	20	20.9	17.3	24	22.6	17.4
Fresh Density kg/m^3	1953	1948	1951	1941	1945	1930
28-day Compressive Strength MPa	31.7	33.2	35.3	36.1	34.4	33.5

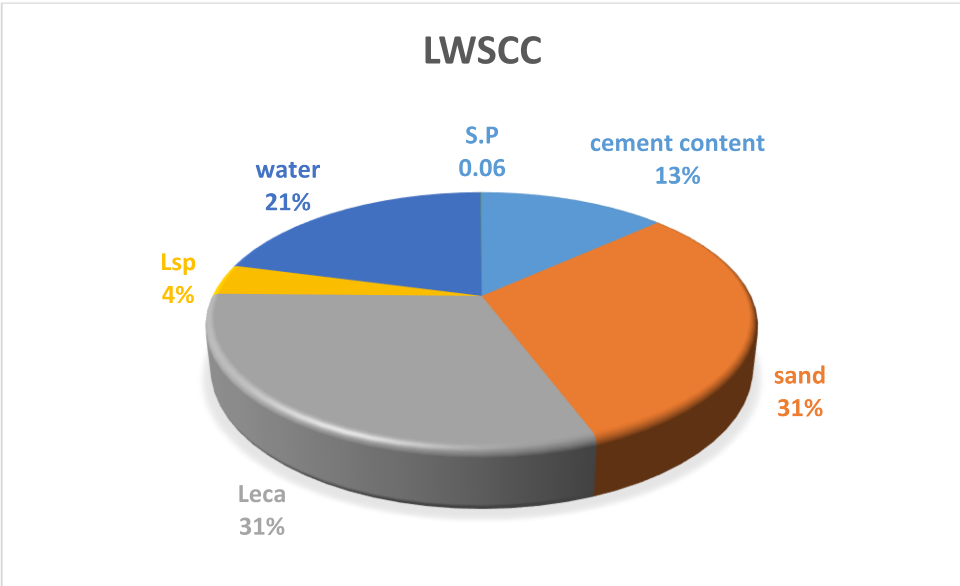


Fig. (3.2): Materials proportion used in LWSCC mixture (% by volume)

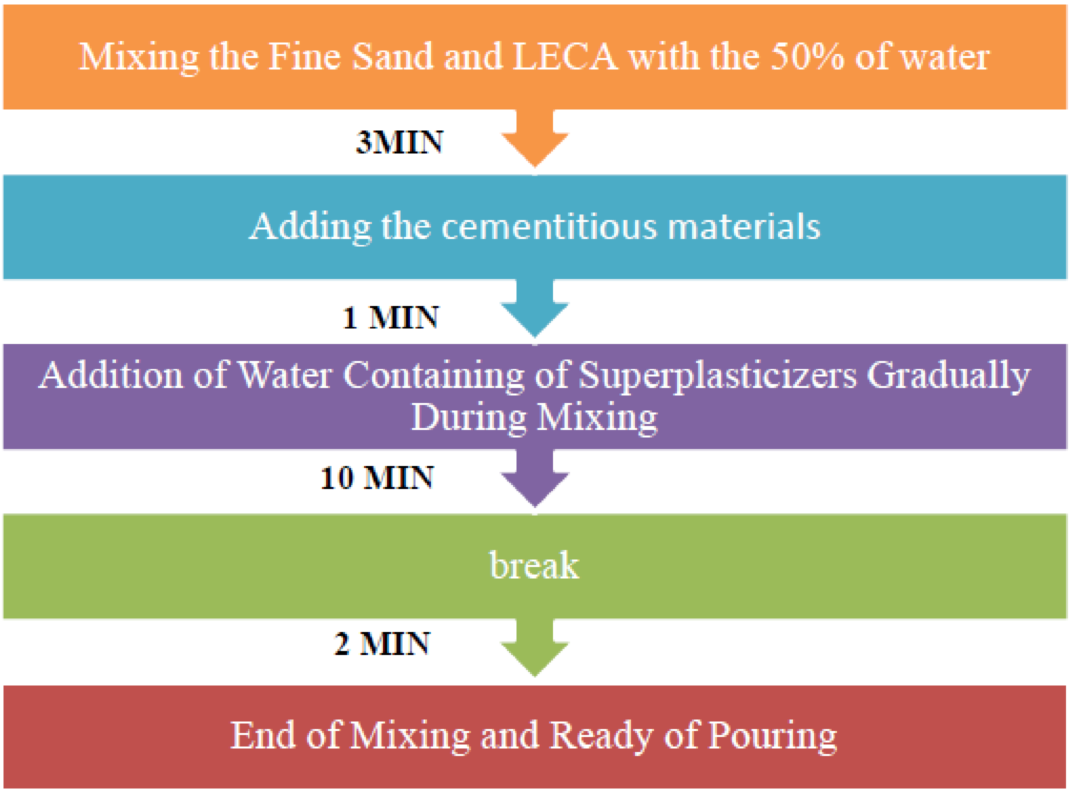
3.4 Concrete Mixing, Placing and Curing Procedures

Fresh mixtures collapse due to LECA's high water absorption rate. As a result, LECA was submerged in water for 48 hours to achieve the saturated surface dry (SSD) condition shown in Plate (3.2). The lightweight aggregates were then spread out and allowed to dry until all free water from the tops of the particles was gone.

A homogenous mixture was obtained after blending the aggregate combinations thoroughly. After being weighed, all the ingredients were backed into the plastic container for the pre-mixing process. To achieve the required homogeneity and workability of the concrete mixture, the mixing process is crucial. As shown in Plate (3-3), the mixing was done in a pan-type laboratory mixing machine with a 0.09 m^3 capacity. Before commencing to combine, the mixing device should be kept clean, moist, and free of water.

Plate (3.3): Mixer used in this study

To combine LWSCC with LWC, this mixer was employed. According to Lotfy, 2012, LWSCC and LWC were combined with certain modifications. Because lightweight aggregates can absorb a lot of water, they were pre-soaked for at least 48 hours before being drained of any remaining water and having their mass determined (Plate 3-2). After three minutes of blending the LECA and sand with half of the mixing water, the cement and limestone powder were added to the mixer and combined for an additional 60 seconds. After another 10 minutes of mixing, the remaining water and SP were added to the mixture. Before pouring the new mixes, a two-minute break was taken. The whole mixing process lasts about 16 minutes. Figure (3-3) displays the series of mixing . Beyond mixing, the LWC mix underwent a flow test, whereas the LWSCC undertook slump flow, V-funnel, L-box, segregation testing.



Total mixing16 MIN

Fig. (3.3): mixing time process.

After thorough washing, oil is applied to the internal surfaces of models of cylinders and cubes to avoid adhesion when the concrete hardens. After the concrete had been well mixed in the mixer, the LWSCC mixtures—which did not require compaction—were poured into the solid steel molds and filled to the brim without being compacted. The fine texture of the upper concrete surface is due to the hand trowel leveling technique. The samples were held in the molds for one day before being put in the water tank to begin the curing process, which lasted until the samples were 28 days old. The casting and curing of the specimen are depicted in Plates 3–4.

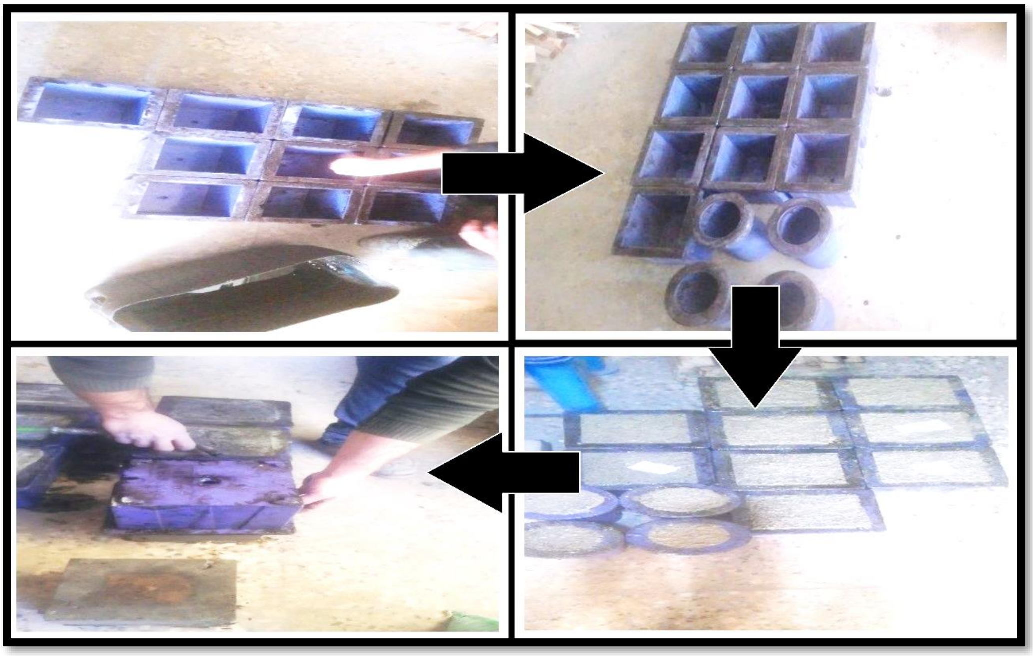


Plate (3.4): casting process of the specimens.

3.5 Fresh Concrete Tests

3.5.1 Test Methods for Fresh LWSCC

The testing of concrete in its new circumstance is one of the study's goals. Stability, mobility, and fill capacity are three of self-compacting concrete's (SCC) essential performance traits. These could be established by combining tests that assess the value of the LWSCC. Different approaches were developed throughout the LWSCC characteristic classification attempts. In this investigation, four tests—fresh density, V-funnel, L-box, and slump flow tests—were applied.

All tests were carried out at the building materials laboratories at the Engineering College, Civil Department, University of Babylon.

3.5.1.1: Tests of Slump Flow and T500

A skilled user could be able to see how self-compacting concrete is resistant to segregation through the Slump Flow test, which is employed to assess filling capacity. This is a combination of flow diameter and slump. The flowability and flow rate of the SCC are determined using the measurements of T_{50cm} and slump flow in the absence of interference. According to the European Self-Compacting Concrete Guidelines, the device used and the testing procedure (EFNAR C 2005). A slump flow is shown by plate (3-5). The cone was first dampened before being placed on the wooden foundation. Then, without compacting, fresh mixture was added to it (Plate). In order to enable the concrete to start flowing and form a circle, the cone was then lifted.

The maximum diameter of a circle as well as the perpendicular diameter on it were measured. The slump flow value was calculated from Eq. (3.1).

Slump Flow = (D max. + D perp.) / 2 ---------------------------- (3-1)

Where :

D max. = Largest diameter of the flow spread (mm).

D perp. = diameter of the flow spread at right angle to D max. (mm) .

The slump flow time T_{50cm} was the interval from when the cone left the base to when the concrete made its initial contact with the circle with a diameter of 50 cm.

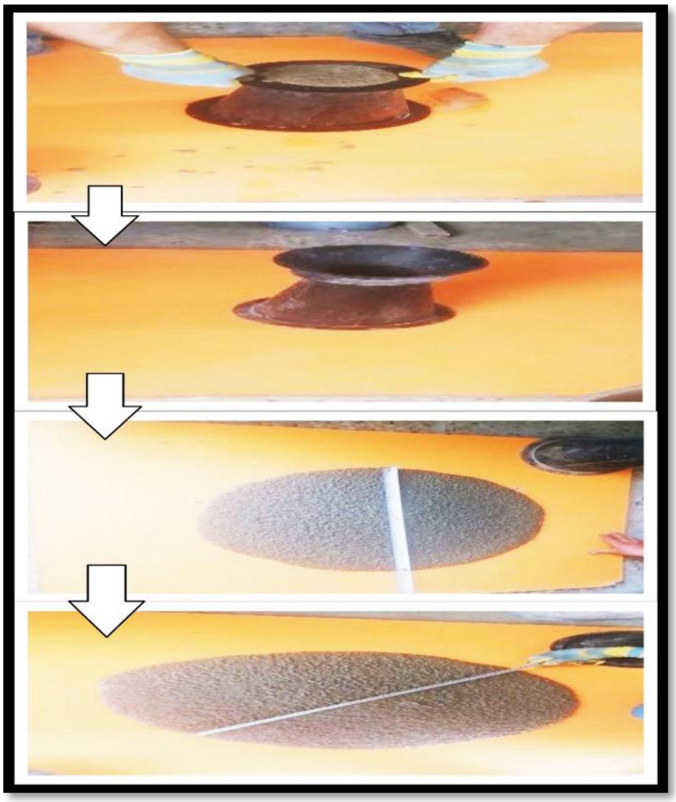


Plate (3.5): The Slump Flow Test Procedure.

3.5.1.2 L-Box Test

The test is intended to assess SCC's ability to flow unhindered through small openings, such as those between structural reinforcement and other obstructions. This was carried out using the procedure described at **EFNARC (2005)**, using L-shaped box with a gate at the vertical part and 2 ϕ12 smooth bars as shown in Fig. (3-4).

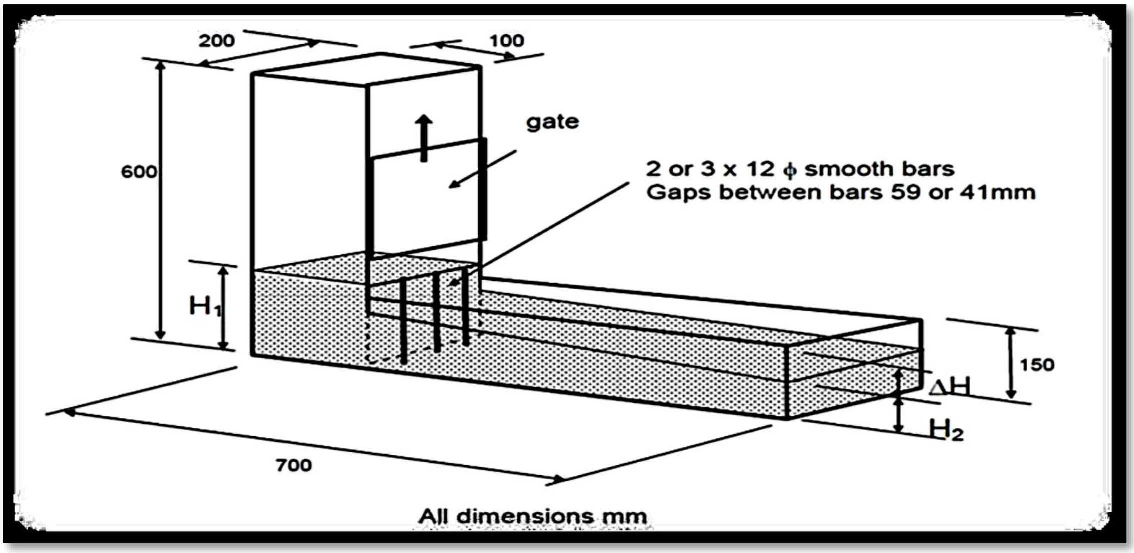


Fig. (3.4) L-Box apparatus

After dampening the box, fresh concrete was poured into the vertical portion of the L-box and allowed to stand for a minute. After that, the sliding gate was raised, allowing concrete to pour out through the L-horizontal box's portion. The height of the concrete was then gauged twice. The first one appeared at the start of horizontal section (H1), while the second appeared at the conclusion of that same section (H2).

the blocking ratio (BR) was calculated by using Equation (3-2) expressed in dimensions to the nearest (0.01).

$$BR = \frac{H2}{H1} \qquad \text{------------------------------- (3-2)}$$

Where:

H_2=vertical distance, at the end of the horizontal section of the L-box to concrete surface (mm).

H_1 = vertical distance, at the beginning of the horizontal section of the L-box to concrete surface after bares (mm).as see in plate (3-10).

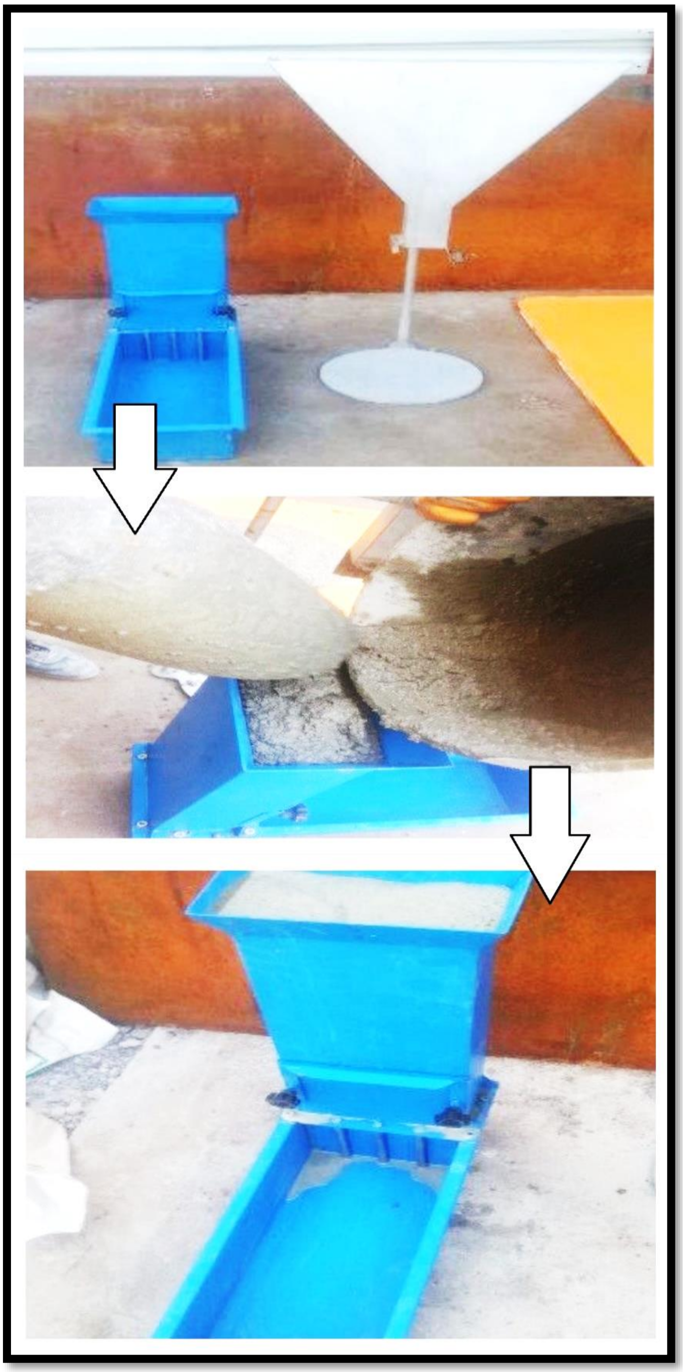


Plate (3.6): The L-Box Test Procedure

3.5.1.3: Tests of V-Funnel and V-Funnel at T5 Minutes

The V-funnel test is used to gauge material resistance to segregation as well as filling capacity and mix viscosity. The equipment utilized and testing methods detailed in the (EFNER 2005). Plate (3-7) shows the V-funnel that is being used.

The interior surfaces of the funnel are completely filled with concrete after being moistened. The trap door at the bottom of the funnel was freed after a (10± 2) second delay in filling the funnel, allowing the self-compact concrete to transfer by gravity and allowing the time to be measured to the nearest 0.1 second. A stopwatch was used to record the V-funnel flow time. The time was calculated from opening the gate until it was possible to look vertically through the funnel into the jar below. After settling for five minutes, the concrete in the funnel needs to be replenished. The flow time dramatically increases when segregation in the concrete is present. The flow time was once more measured to determine how long it would take to discharge concrete.

Plate (3.7): The V-Funnel Test Procedure

3.5.1.4 Fresh Density Test

The mass of all the fresh ingredients of concrete, multiplied by the bulk size the concrete occupies, results in fresh density, also known as unit mass or unit weight in air. After pouring, fresh unit weight was immediately measured.

3.5.1.5 Sieve Segregation Resistance Test

The ability of a fresh mix to preserve its original, suitably uniform distribution of constituent substances is known as segregation resistance. This test is used to assess the resistance of SCC to segregation. The test equipment and protocol as defined in **(EFNARC, 2005)**. The test is shown in Figure 3.12Approximately (10± 0.5) liters of concrete have been added to a container, and it was left to stand level and undisturbed for (15± 0.5) minutes. The sieve receiver was set on the scale, and its weight (Wp g) was measured. A sample of (4.8 ±0.2) kg of concrete was poured into a 5 mm sieve with a diameter of (500 ±50) mm from a height of (500± 50) mm, and the actual mass of concrete (WC g) was recorded on the sieve. The concrete was placed in the sieve for (120±5) seconds to allow any laitance or mortar to pass through it while standing on the sieve receiver. Concrete that would have entered the receiver was measured along with its mass (Wps g). The following Equation (3-3) was used to compute the segregated share (SR) to the nearest 1 percent.

$$SR(\%) = \left(\frac{Wps - Wp}{Wc}\right) \times 100 \qquad (3\text{-}3)$$

Where:

SR: Segregation resistance.

Wps: mass of the pan and concrete, g.

Wp: Mass of the pan, g.

Wc: actual mass of concrete, g.

plate (3.8): Sieve Segregation Resistance Test

3.6 Testing Hardened of Self-Compacting Lightweight Concrete

3.6.1 Compressive Strength Test of Self compavting light weight concrete.

Self Compacting Concrete and light weight Self Compacting Concrete compressive strengths were calculated using (BS. 1881: Part 116:1989). (150 by 150 by 150) mm cubes. A mechanical compression instrument with a 2000 kN force was used to assess them. The accepted outcome for each blend was determined by taking the average of three cubes. The age 28 days was the starting point for the test. Plate (3–9) indicates whether the experiment test was successful.

Plate (3.9) Compression strength testing machine with a specimen.

3.6.2 Splitting Tensile Strength Test

This property was measured under the requirement of **ASTM C 496/C 496M – 2004**. diameter of cylinder is 100 mm and 200 mm for height. thinning wood strips has been positioned between the sample and the higher and lesser bearing base plate of testing machine which display at Fig. (3.5). splitting tension was measured by the Eq. (3-4). Each splitting tensile strength value reported in this study was determined by averaging the results of three cylinders at the age of 28 days.

-

$$ft = \frac{2p}{\pi d l} \qquad \text{----- (3-5)}$$

Where:

f_t = Splitting tensile strength (MPa).

P = Maximum applied load indicated by tensile machine (N) .

d = Diameter of cylinder (mm).

l = Length of cylinder (mm).

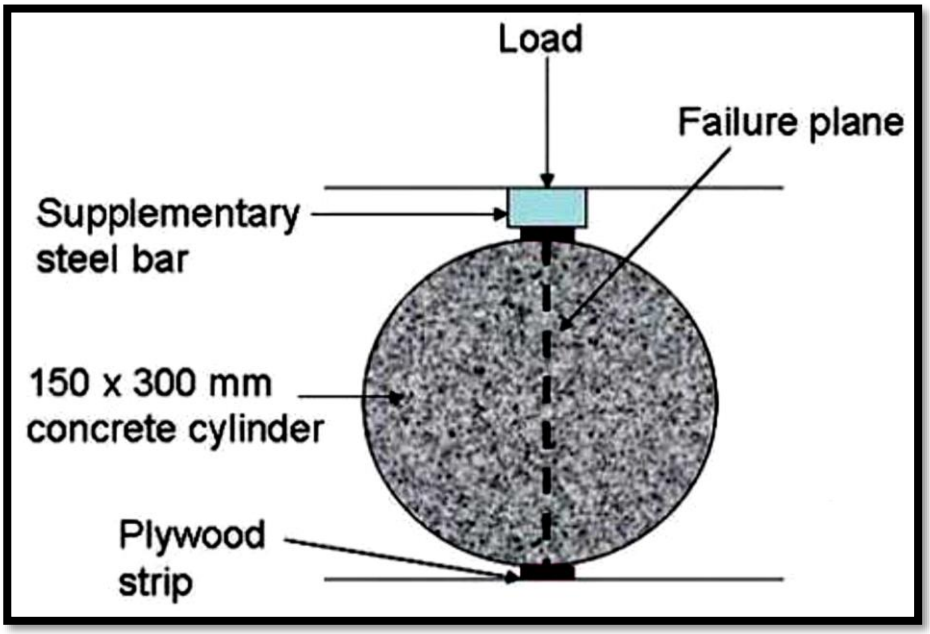


Fig. (3.5) splitting tensile strength test set up.

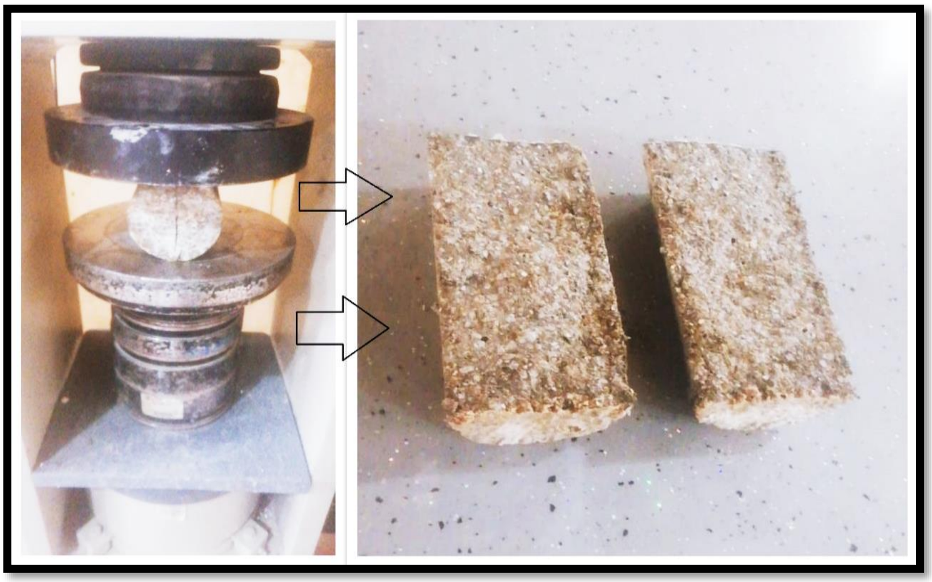


Plate (3.10): Splitting tensile strength test.

3.6.3 Static Modulus of Elasticity

According to ASTM C469, 2014, as illustrated in Plate, the static concrete elasticity module was performed on cylindrical samples measuring 150 x 300 mm (3.11). The top cylinder's surface was ground using a machine with electric grinding, as described in Chapter Three. To prevent any strength losses, the experimental program was well-finished and streamlined. They put the samples through testing using a hydraulic machine with a 1900 KN capability. The samples were averaged over two samples, and their ages (28 days) were recorded. The following formula was used to calculate the static elasticity modulus:

Es= $(S2-S1) \,/\, (e_2 - 0.00005)$ **-- (3-5)**

Es: Static elasticity modulus, (GPa).

S2: Stress equivalent to forty percent of the ultimate load, (MPa).

S1: Longitudinal strain-related stress (5 x 10-5), (MPa).

e2: Longitudinal strain resulting from S2 stress.

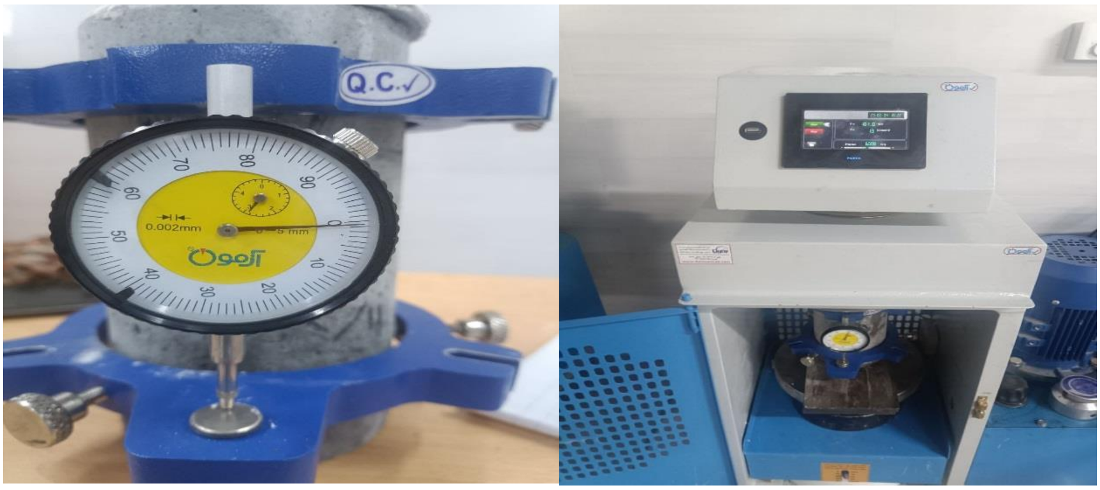


Plate (3.11): Modulus of elasticity test.

3.6.4 Water Absorption Test

According to ASTM C 642, 1997, the water absorption of SCLWC was measured. Plate shows the process for evaluating the water absorption (3. 14 a, b, c and d) The samples were first removed from the water tank and dried at 100 to 110 °C to a constant mass plate for 24 hours (3.14 a). We measured the mass of each dried sample (A). The samples then spent 24 hours submerged in water. (plate 3.14 b) and the mass of the saturated surface dry samples was measured, (B).(plate 3.14 c and d) The water absorption was calculated from Equation (3.6).

$$\text{Absorption after immersion, } \% = [(B - A)/A] \times 100 \quad \text{--------(3.6)}$$

Plate (3.12): Water absorption test

3.6.5 Sorptivity

The sorptivity test was performed to measure the resistance to capillary suction-driven water movement through concrete. The resistance of concrete to absorbing water increases with a lower sorptivity value. The capillary water absorption measures of sorptivity were assessed using (ASTM C1585, 2004). Three (100×100×100 mm) cubes were chosen for testing for each mixture and age to assess sorptivity coefficients at ages 28 days (after initial curing for 28 days). The samples were taken out of the water and baked at 50°C for three days to reach constant weight. They were then allowed to cool to room temperature in a sealed container before beginning the absorption method. Only one surface of the concrete specimen was permitted to come into contact with water, and the water level had to be between 1 and 3 millimeters above the specimen's base. In order to guarantee the unidirectional passage of water through the concrete specimen, the opposite surface was exposed to air, while the other four surfaces were sealed with epoxy resin. The specimens' initial weights were calculated to the closest 0.01g before they were found in the water. The samples were then covered with a plastic sheet and kept in the conditioning room to prevent moisture loss while resting on a specific tray designed for this test to permit unrestricted passage of water to the surface.as seen in Figure 3.19. At intervals of 1, 5, 10, 30, 60, 120, 180, 240, 300, and 360 minutes after the cube surface was submerged in water, the water absorption was measured (specimens were taken from the tray and the weights were recorded). After that, measurements are made once daily for up to three days, then three times, each at least 24 hours apart, from days 4 to 7, before the final measurements, which are made to determine the secondary absorption qualities, are made at least 24 hours after the measurement on day 7. Due to capillary action, the specimen can absorb water over a longer period of time. Water was continually added to the tray throughout the test to maintain a 3 mm water depth. Plotted against the square root of time is the estimated absorption value at each instant. The slope of the best fit line to these information has been used to calculate the sorptivity. Utilizing Equation 3-8, the sorptivity was calculated, and the findings of three specimens were averaged.

$$S = \frac{I}{\sqrt{t}}$$

S = Sorptivity in ($mm/min^{0.5}$), I=m_t /ad .

"I= absorption(mm)"

"m_t = the change in specimen mass in grams, at the time t" .

"a= the exposed area of the specimen, in mm^2".

"d= density of water (used 0.001 g/mm^3)"

t = time elapsed in (min)

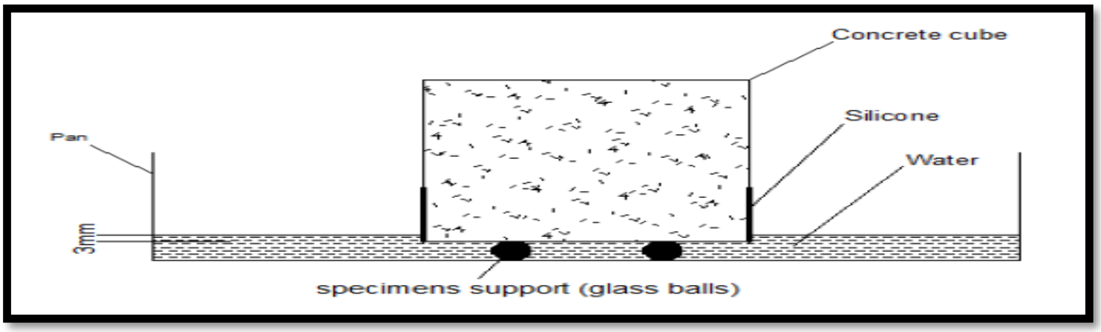


Fig (3.6): Sorptivity test.

Plate (3.13): Sorptivity test

4.1 Fresh properties

The four essential characteristics of self-compacting concrete that can be used to specify its filling ability and stability in its fresh state are passing ability, viscosity, flowability, and segregation resistance. Each of these characteristics may be examined using one or more testing techniques EFNARC (2005). For example, the T50 slump flow time and V-funnel flow time tests can be used to estimate viscosity, whereas the slump flow test may be employed to evaluate flowability. The criteria of concrete in the fresh form that seem to be suitable for a particular application must be fulfilled by all four of the aforementioned important features, and the self-compacting concrete should then define the class or goal value stated in Table4.1. Slump flow diameter, T50 slump flow time, V-funnel flow time, L-box height ratio, and L-box were evaluated and graphically represented in Figure 4.1 to characterize the flowability, viscosity, and passing ability of the made SCRCs.

Table 4.1 EFNARC-recommended classes for passing ability, viscosity, and slump flow (2005).

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

Table 4.2 Slump flow, V-funnel and L-box properties of LWSCRCs.

Mix code	T50 S	Slump flow diameter (mm)	TVs	H1/H2	SR%
Control	1.56	760	6.79	0.940	14.4
FCR5	2.29	752	9.48	0.939	12.4
FCR10	2.39	741	10.49	0.925	11.9
FCR15	2.40	722	11.41	0.911	11.1
FCR20	2.43	712	13.51	0.902	10.6
FCR25	2.94	695	14.22	0.881	10.0
CCR5	2.40	740	10.94	0.920	9.8
CCR10	2.80	732	13.46	0.896	8.1
CCR15	3.08	720	15.11	0.892	7.4
CCR20	3.30	705	16.18	0.885	7.0
CCR25	3.40	675	17.42	0.890	6.1
MCR5	2.30	742	11.31	0.930	11.7
MCR10	2.48	737	11.98	0.924	10.1
MCR15	2.56	730	13.1	0.910	9.6
MCR20	2.61	715	14.85	0.894	9.0
MCR25	3.01	682	15.79	0.865	8.7

4.1.1 Slump flow diameter

The slump flow diameter of the reference light weight self-compacting concrete mix was 760 mm, but the rubberized self-compacting concretes in the research had slump flow diameter values between 675 and 750 mm, that have been calculated by averaging two measured diameters of flowed concrete as shown in Figure 4.2. In Figure 4.3, the slump flow diameter values for the crumb rubber's size and composition were shown. As a consequence, thus according Table 4.1's findings, self-compacting concrete made using crumb rubber could be classified as SF2 in accordance with EFNARC (2005) and is acceptable for many common applications, including walls and columns. The superplasticizer content has been raised for each replacement level of rubber to produce SCRC that might be categorized as SF2, but in order to evaluate the effect of rubber size, it was kept fixed for the crumb rubber size at the identical replacement rate. According to the findings, the diameter of the slump flow reduced as the rubber content rose. The slump flow diameter value of 760 mm for the reference mixture reduced to 695, 675, and 682 mm for the mixtures made with No. 18, No. 5, and Mixed crumb rubber, correspondingly, at the maximum replacement level of 25 percent. The concrete made with No. 5 crumb rubber had the lowest slump flow diameter values. The size of the crumb rubber may provide an explanation. Tiny particles made up the No. 18 crumb rubber, whereas longitudinal particles made up the No. 5 CR. As a result, the longitudinal particles prevented other combination materials from rolling freely, which has a negative impact on the self-compatibility of concrete. Never the, such values of slump flow are appropriate to achieve adequate self-compability.

Fig 4.1 Measurement of slump flow diameter for LWSCCs.

Mohammadi et al. (2015) state that self-compacted concrete derived from LECA demonstrates an acceptable slump flow values due to uniform mixture which encourage the particles packing and reducing the free moisture.

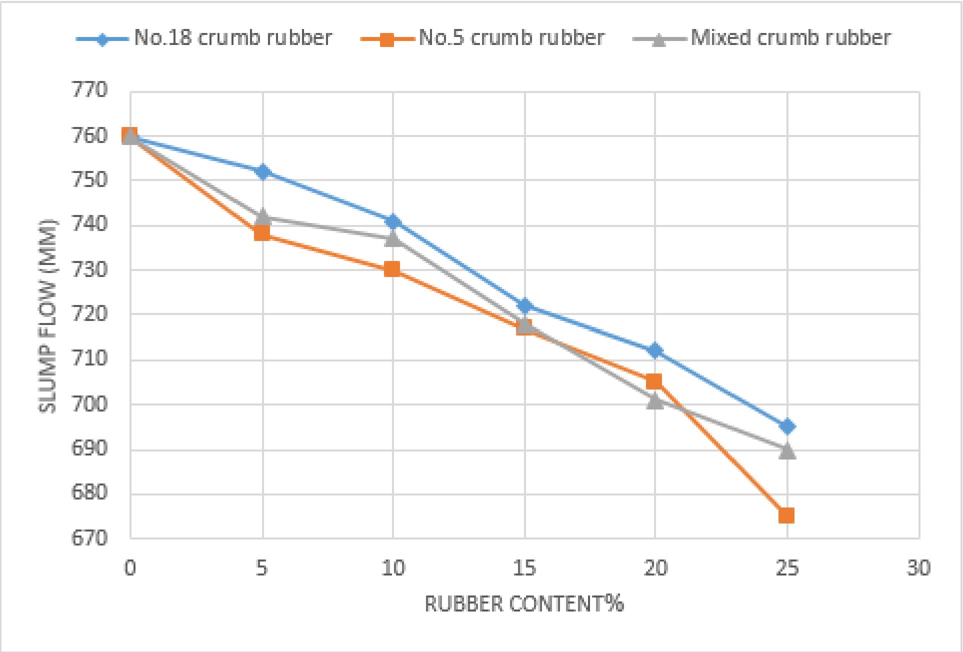


Fig 4.2 Variation of slump flow diameter and slump classes of LWSCRCs.

4.1.2 T50 slump flow and V-funnel flow times.

Figures (4.3. & 4.4) provide the T50cm slump flow and V-funnel flow times for self-compacting rubberized concretes". Rubber content had an impact on slump flow time as well, with a rise in rubber content causing a longer slump flow time.

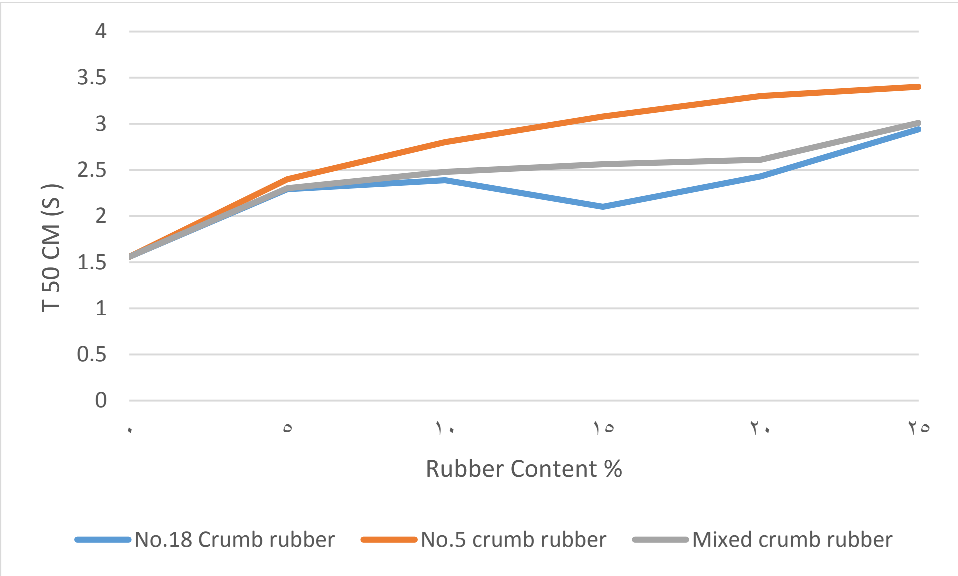


Fig 4.3 Variation of T50 slump flow time of SCC with respect to crumb rubber content.

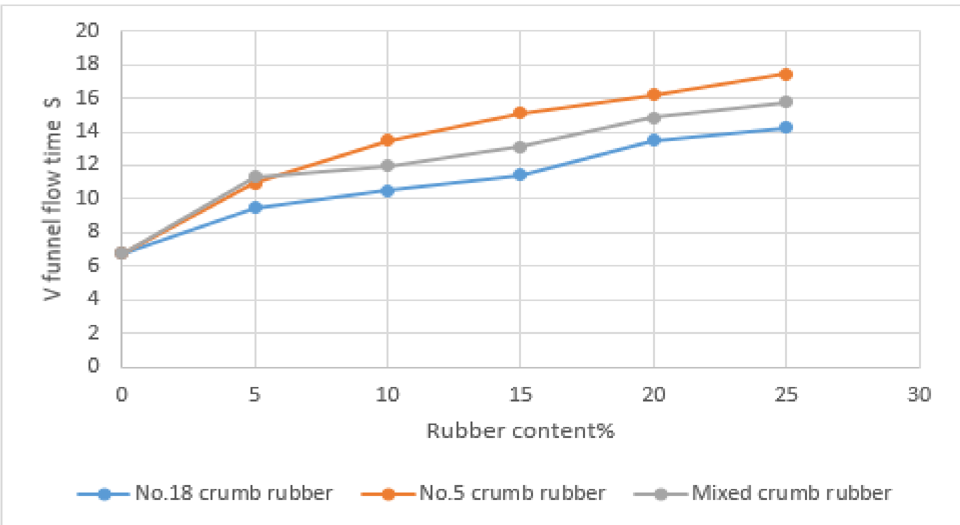


Fig 4.4 Variation of V- funnel flow time of SCC with respect to crumb rubber content.

Additionally, No. 5 crumb rubber had the longest slump flow time, as is evident from Figure 4.3. The mixtures with No. 18, No. 5, and mixed crumb rubber at 25 percent replacement level exhibited slump flow times of 2.94, 3.40, and 3.01 s, correspondingly, while the reference mixture would have a slump flow time of 1.56 s. Similar to slump flow diameter, At every replacement rate, the mixtures prepared with No. 18 crumb rubber displayed the shortest slump flow times.

The mixtures' V-funnel flow time values nearly followed the same pattern as the T500cm slump flow time. The-funnel flow time was also gradually increased as the crumb rubber concentration. Mixtures flowed through the V-funnel between 6.79 and 17.42 seconds. T50cmV-funnel flow time for the reference mixture was 6.79 s, while that for the mixtures FCR25, CCR25, and MCR 25 was 6.84 s, with the corresponding values for the V-funnel flow times being 14.22, 17.42, and 15.79 s. Additionally, the reference concrete falls into the VF1 class category, but when the rubber was replaced with fine aggregate, the viscosity class was modified to VF2. However, according to the findings of the T50cm slump flow and V- funnel flow durations, the produced concrete meets the requirements for self-compacting concrete according to **EFNARC (2005)**.

Since the reference mixture was in the VS1/VF1 range, all light weight self-compacting rubberized mixtures remained within the bounds of the VS2/VF2 viscosity stipulated by EFNARC (2005).

The results above show that LWSCC decreases workability as rubber content and rubber size rise (both flowability and passing ability). This might be as a result of the low density and high surface abrasion of rubber, which increase inter-particle friction and decrease the specific gravity of the combination. Consequently, this result is congruent with **(Batayneh et al., 2008; Guo et al., 2017; Taha et al., 2008)**.

In furthermore, the smaller rubber particles get a greater specific surface area, that raises interparticle friction and hinders the rubber's ability to flow well and fit through narrow openings **(Youssf, et al., 2014; AbdelAleem et al., 2018).**

4.1.3 L-box height ratio

The passage ability of the created rubberized self-compact concrete mixtures had also been assessed using the L-box height ratio via the H2/H1 ratio. As according EFNARC (2005), the three bar L-box test findings that replicate more crowded reinforcement are depicted in Figure 4.5. To verify that the self-compacting concrete has the required passing ability, the L-box height ratio should be equal to or greater than 0.8. A perfectly fluid behavior of the concretes is observed when the L-box height ratio is 1.0. (EFNARC,2005). All mixes satisfy the EFNARC restriction for the specified L-box height ratio, as shown in Figure 4.6. The L-box height ratio value for the reference mixture was 0.940 while it was varied between 0.881, 0.890, to 0.865 for light weight concretes with different types with percentages of crumbed rubbers. For example , at 25% replacement level , the L-box height ratio was 0.881 , 0.890 and 0.865 for mixes FCR 25 , CCR25 , MCR25.

The L-box height ratio was lowest in mixes made with No. 5 crumb rubber, though, and there wasn't much of a distinction among concrete made with No. 18 and mixed crumb rubber either. In furthermore, regardless of the size and type of the crumb rubber, raising the rubber content led to a systematic decrease in the L-box height ratio.

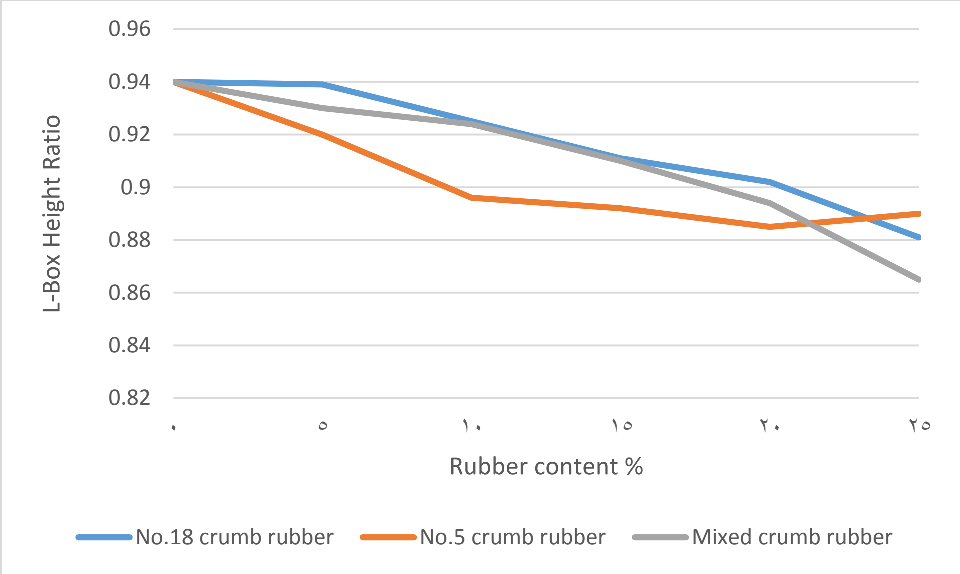


Fig 4.5 Variation of L-box height ratio and passing ability classes of SCC with crumb rubber.

4.1.4 Segregation Resistance of SCC Mixes

The ability of SCC to remain homogeneous during transportation and placement is called segregation resistance of can be evaluated by the Sieve segregation resistance test. It can also be visually checked during the slump flow test. The results of the values of the sieve segregation resistance test of 18 different light weight self-compacting rubberized concrete mixtures are illustrated in Table 4.2. Through the results obtained and shown in Figure 4.6, it was found that the segregation rate were good for all mixtures, as they varied between (6.1–14.4%), which were considered determinants of **(EFNARC, 2005)**, which determined the segregation rate $\leq$ 15% (SR2 class).

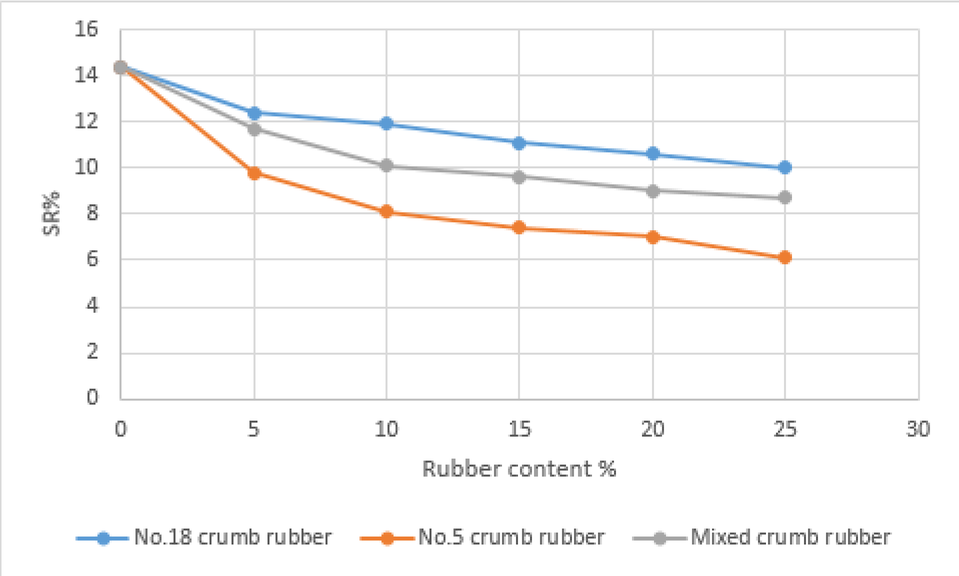


Fig 4.6 Variation of Segregation resistance of LWSCC with crumb rubber.

Given that the SR ratio fell as the rubber content increased, which in turn resulted in superior segregation resistance performance, it is evident that the inclusion of rubber aggregate enhanced the segregation resistance of SCC (see Figure 4.6). According to the T500 and V-funnel time data, this behavior can be caused by the high viscosity of the rubber mixtures (see Figures 4b and 5). In other ways, the higher the viscosity and segregation resistance, the higher the T50cm and V-funnel time **(Younis, K. H., Naji, H. S., & Najim, K. B. (2017).**

According to **EFNARC(5)**, all mixtures—with or without rubber—may be regarded as suitable because they all fall into the SR2 (SR ≤ 15%) category of sieve segregation resistance. Thus, the findings corroborated those of **Khaleel H. Younis1, (2019)**, who discovered that an increment in rubber particle replacement of sand whilst maintaining a constant water content causes a reduction in the segregation ratio. The thickening impact of rubber particles could be primarily blamed for the phenomena of the decrease in the segregation ratio. The better outcomes were seen for light weight self compacting concretes integrated with coarse crump rubber at which SR ranged from 6.1 to 9.8 percent. Or else, all mixtures with the rubber particles percentage replacement ranging from 0 to 25percent could indeed conform up to the standard of segregation (segregation ratio ≤15 percent).

4.1.5 Unit weight

The self-weight of any structure is completely dependent on the unit weight of the ingredient materials. Thus, it is a considerable parameter for mortar or concrete. Therefore, the bulk density of concrete was determined as the weight per unit volume of concrete.

Since rubber is lighter than sand, using it reduces the unit weight of concrete by a small amount.

The density values of light weight self-compacting concrete containing crumb rubber were 1511 – 1873.1 kg/m^3 as illustrated in Table 4-3 and figure (4.7).

When more of the fine aggregate was replaced with crumb rubber, the density of LWC dropped. This is as a result of crumb rubber's specific gravity, which was 1.78, being lower than that of fine aggregate (2.65).The use of crumb rubber to reduce the density of light weight self-compacting concrete from (2.34 to 21.22)% when compared to the unites with , crumb rubber depending on its content and size **(Tanapan Kantasiri et .al 2017)**.

Other scientists have previously shown that the specimens' weight loss rose as the amount of crumb rubber rose **(Sanghar Bhutto, Tanapan Kantasiri et .al 2017, et.al 2020)**.

Assessing that information presented in Figure (4.8) revealed that for No. 18 CR, the percentage of decrease ranged from (4.28 to 21.22percent) since the unit weight values for finer sizes of crumb rubber were lower than those for coarser sizes.

Also the reduction in unit weight for (Mixed crumb rubber) ranged from 2.34% to 18.12%.

Table 4.3 Unit weight test results of SCRC.

Mix code	**Unit weight(kg/m3)**
Control	1918
FCR5	1835.9
FCR10	1790.6
FCR15	1688.1
FCR20	1593.3
FCR25	1511.0
CCR5	1870.8
CCR10	1799.4
CCR15	1701.2
CCR20	1604.4
CCR25	1533.5
MCR5	1873.1
MCR10	1802.7
MCR15	1730.6
MCR20	1635.8
MCR25	1570.4

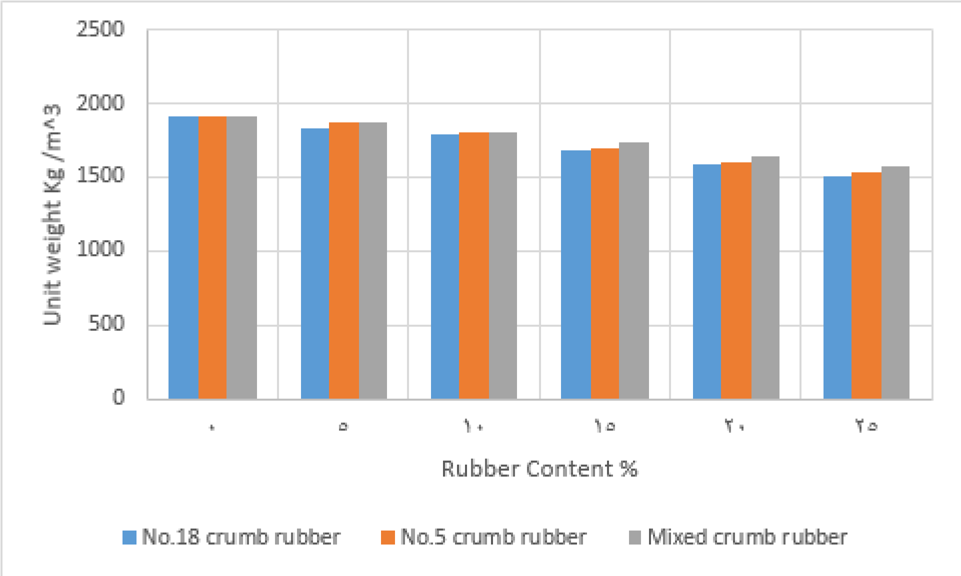


Fig 4.7 Variation of Unit weight of LWSCC with crumb rubber.

4.2 Mechanical Properties

The compressive strength, splitting tensile strength, and the modulus of elasticity of several rubberized low weight self-compacting concrete specimens were examined.

4.2.1 Compressive Strength

The most crucial design factor for any kind of concrete construction is compression strength. This important factor directs the design process and can affect a project's and a building's costs. At the age of 28 days, the strength development of LWSCCs was examined in this regard.

Concrete is well renowned for being strong in compression and weak in tension. Because of this, the compressive strength of concrete is sometimes regarded as its most significant characteristic and is the most widely used indicator of how well-hardened concrete performs.

The compressive strength values of 28-day ranging from 21.7 MPa to 42.4 MPa were recorded as seen in Table (4.4) and Figure (4.8) . This confirms that all light weight self-compact concrete satisfies the requirements of structural light weight concrete based on (ACI 213R) which points out that the compressive strength of light weight concrete should be less than 17 Mpa. The maximum compressive strength was achieved with the control mixture, and as the rubber concentration increased, compressive strength steadily declined.

The compressive strength of SCC was consistently reduced when utilizing several forms of rubber aggregate as a partial replacement for natural aggregate, irrespective of rubber replacement level, or substituted type of aggregate. In every case, a decrease in compressive strength has been noted, and the decrease in compressive strength seems to be more pronounced with higher levels of rubber substitute, as shown in Table (4-4) and Figure (4-7).

Table (4.4) Compressive strength test results of LWSCC.

Mix code	**28-day compressive strength (MPa)**
Control	42.4
FCR5	40.8
FCR10	36.7
FCR15	34.2
FCR20	29.1
FCR25	23.7
CCR5	33.5
CCR10	28.9

CCR15	26.7
CCR20	23.2
CCR25	21.7
MCR5	35.3
MCR10	32.7
MCR15	29.8
MCR20	27.2
MCR25	22.4

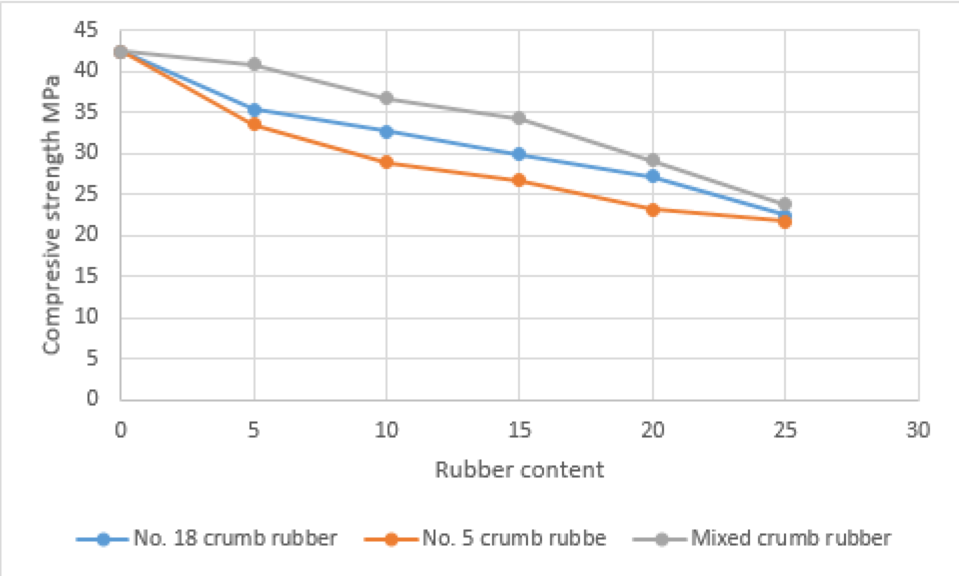


Fig (4.8) Variation of 28-day compressive strength with respect to crumb rubber size and content.

The lower rubber modulus of elasticity in comparison to natural aggregates, the increasing quantity of air trapped among rubber particles and cement paste, and the poor adhesive and bond strength among rubber particles and cement are the main causes of this lowering influence **[AbdelAleem, B. H (2018)]. According to [*Hama, S. M.*, et.al (2017)]**, The hardened concrete specimens' compressive strength is decreased by rubber particles, which act as cavities in the material. The compressive strength of self-compacting concretes formed using No. 5 crumb rubber was the lowest, whilst still No. 18 crumb rubber was the strongest. It has been demonstrated that when compared to fine particles, coarse rubber particles have a more detrimental impact on the characteristics **(*Dong, Q* et.al 2013) .**

As the additive level was raised, the compressive strength decreased. This finding demonstrated that the compressive strength decreased as the amount of rubber added rose, as stated by **(*Hsiung C* .et.al 2004).**

4.2.2 Splitting Tensile Strength

The general degree of compressive strength of concrete or mortar determines the ratio of tensile to compressive strength. Concrete's compressive strength and splitting tensile strength (STS) are directly inversely correlated. But, the proportion between the two strengths relies on the concrete's overall level of strength **(Neville, 2011).**

In other terms, the STS likewise rises with increasing compressive strength, however at a declining rate. Because cracks spread quickly under tensile pressures, concrete's tensile strength is often lesser than its compressive strength. But given that cracking in concrete typically results from tensile strains that happen beneath load or from climate conditions, it is a crucial feature. Microcracking, namely at the interfacial region between the aggregate particles and the cement paste, known as the interfacial transition zone, controls the failure of concrete under tension (ITZ).Values for splitting tensile strength derived from cylindrical specimens are shown in Table (4-5) .Fig (4.9) shows the variation in splitting tensile strength observed over the course of 28 days for all rubberized light weight self-compact concrete related to the quantity and size of crumb rubber. The splitting tensile strength values in this study were measured and ranged from 2.62 MPa to 4.10 MPa. The highest splitting tensile strength was produced by the control mixture, and as the rubber content was increased, the splitting tensile strength gradually decreased.

As with the compressive strength, the highest splitting tensile strengths were recorded for light weight self-compacting concrete produced with fine crumb rubber followed by those made with mixed crumb rubber and finally coarse crumb rubber such as the reduction in this property was between 9.75 to 24.14 %, 13.65 to 31.22 and 15.85 to 36.09% respectively depending on the amount of crumb rubber. The better performance when fine crumb rubber was used may be due to the increased packing density of the mixture resulted from better gradation of particles.

Table 4.5 Splitting tensile strength test results of LWSCC.

Mix Code	**28-day splitting tensile strength**
Control	4.10
FCR5	3.7
FCR10	3.59
FCR15	3.44
FCR20	3.29
FCR25	3.11
CCR5	3.45
CCR10	3.31
CCR15	3.03
CCR20	2.81
CCR25	2.62

MCR5	3.54
MCR10	3.41
MCR15	3.30
MCR20	3.0
MCR25	2.82

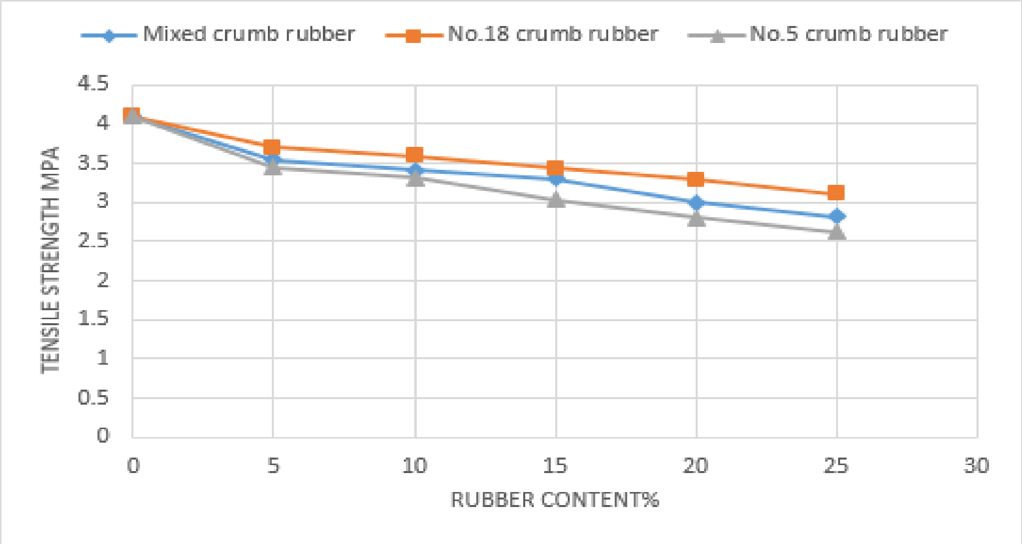


Fig (4.9) Variation of 28-day splitting tensile strength with respect to crumb rubber size and content.

In a Previous studies **K. B. Najim et .al (2012)** Fine aggregate (FA), coarse aggregate (CA), and combined fine and coarse aggregate (FCA), were partially replaced by 5, 10, and 15 weight percent's of crumb rubber from scrap tires. Their findings showed that the tensile strength decreas by less than 11percent for each type of 5 wt.% rubber. But even so, the 15 % replacement of CR resulted in a 39 percent reduction in strength.

All concrete, typically, has a limited strain capacity and tensile strength (10percent of compressive strength) **(Neville, 1995)** Tensile strength is crucial in the design of airport slabs, highways, and other structures where shear strength and crack resistance have been crucial. When crumb rubber is added to SCC, these flaws are made worse because there is a general tendency for tensile strength to decline for similar causes as compressive strength. Multiple factors, such as aggregate type, particle size distribution, and curing age, affect the connection among compressive and splitting tensile strength **(Mehta and Monteiro, 2006)**.

Plate (4.1): Mode of failure under splitting tension test.

4.2.3 Modulus of Elasticity

One of the most important characteristics of solids is their stiffness, which is characterized by the statical elastic modulus (Ec). This characteristic is significantly affected by the constituents of concrete and their amount. Besides that, it is generally accepted that there is still a direct relationship between the concrete strength under compression and the elasticity-modulus because the compression force increases the slope of the upward part of the stress-strain diagram **(Ramezanianpour ,2009)**.

The calculated findings for the elastic modulus at 28 days for all LWSCRC combinations are presented in Table 4.6. Figure (4.10) depicts the findings of a test to determine "the static modulus of elasticity" as a function of rubber size and content.

In this investigation, elasticity moduli" with values between 12.0 GPa and 24.2 GPa have been attained. The control mixture yielded the higher modulus of elasticity finding, and when the rubber content rose, a systematic reduce in modulus of elasticity was seen.

Because of the problem with the lightweight aggregate's porous nature, putting LECA to concrete resulted in a decrease in the elasticity modulus's value. Indeed, lightweight concrete seems to have an elastic modulus that is between 15.0 to 20.3 GPa, which is substantially lesser than the modulus of natural weight concrete. **(Lo et al. ,2003)**.

Graphs in Figure (4.10) showed that the static elastic modulus decreased with increasing rubber size and content.

Table 4.6 Modulus of elasticity test results of LWSCRC

Mix code	28-day modulus of elasticity (GPa)
Control	24.2
FCR5	21.8
FCR10	20.1
FCR15	19.4
FCR20	17.6
FCR25	15.1
CCR5	22.1
CCR10	21.3
CCR15	18.5
CCR20	16.2
CCR25	12.6
MCR5	20.9
MCR10	19.3
MCR15	18.1
MCR20	16.3

MCR25	12.0

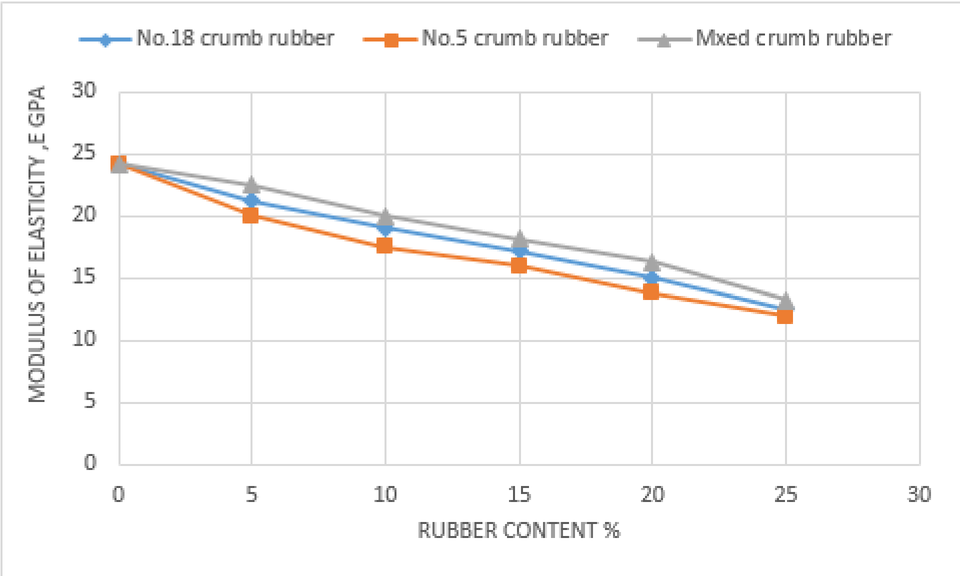


Fig 4.10 Variation of 28-day modulus of elasticity with respect to crumb rubber size and content.

The static elastic module suffered as a result of the use of CR particles in place of fine natural aggregates (sand). Because of the air entrainment caused by CR particles and the rubber aggregate's comparatively low elastic modulus in comparison to sand, the static elastic module decreased as the rubber substitution level increased (**Najim, K.B. et al . 2012**) . Additionally, it was stated that the decrease was due to the rubber particles' lesser rigidity compared to the natural aggregates. In other terms, the type of aggregate used has a significant influence on the elastic modulus of rubberized light self-compacting concrete **(Hesami, S et al 2016 : , AbdelAleem et al 2018: , Duarte, A.P.C. et al 2015 ;, Rahmani, E et al 2013).** For example, when the crumb rubber addition rose from 0percent to 15 percent, the modulus of elasticity decreased from 44 GPa to 36 GPa, respectively (**Hesami, S.et al .2016)**. As the amount of water/powder dropped, the elastic modulus rose; however, as the CR rose, it fell. When

20percent CR aggregate was added to the reference mix, the elastic modulus of self compact concrete dropped from 33 GPa to 22 GPa (**Raj et al .2011).**

(Tian et al. 2020) found that when the crumb rubber percentage increased from 0 to 30 percent, the elastic module value decreased from 34 GPa to 23 GPa.

4.3 Durability Properties of light weight Self-Compacting Concretes.

The durability of mortar and concrete is one of the important properties. Durability is largely dependent on transport properties, which are highly influenced by the pore system. The water absorption, porosity, and sorptivity tests for samples were carried out at 28 days to assess the durability of the concrete mixes. The results have been noted and discussed for each test below**.**

4.3.1 Water Absorption

Water absorption properties of concrete could significantly affect its durability traits. The durability characteristics of concrete may be severely harmed by water infiltration by hazardous ions. In general, LWAC has a larger water absorption capacity than traditional concrete because it has more pores than typical natural aggregates, that could result in higher water absorption characteristics.

Two factors may be employed to express the water absorption (WA) of concrete: sorptivity, that is the rate of water uptake by capillary suction and can be employed as a measure of moisture transport into unsaturated concrete, and bulk absorption, that is the total amount of water absorbed into an unsaturated specimen. The concrete's pore size distribution and capillary pore interconnectivity have an impact on both water absorption and sorptivity **(Razaket al., 2004)**.

Table 4. 7 and **Figure 4.11** illustrate the total water absorption percentage for light weight self-compacted concrete with different percentage of rubber.

Tabel 4.7 water absorption test results of LWSCRC.

Mix code	Water absorption %
Control	3.05
FCR5	2.92
FCR10	2.81
FCR15	2.73
FCR20	1.85
FCR25	1.64
CCR5	2.95
CCR10	2.83
CCR15	2.76
CCR20	1.81
CCR25	1.67
MCR5	2.98
MCR10	2.84
MCR15	2.72
MCR20	1.80
MCR25	1.44

The water absorption test evaluates the absorption value and the voids present in the hardened concrete when it is subjected to aggressive environments. The ability of the concrete to withstand water penetration (WA) is crucial in various deteriorating methods that contain several damaging substances from the surrounding.

The water absorption of the SCLWC mixes is substantially higher than that of traditional self compact concrete, reaching up to 3.05 whereas it did not surpass 1.4percent for the latter. However, these values fell far short of the 10percent threshold that was established for satisfactory concrete **(Neville, A., 1982)**.

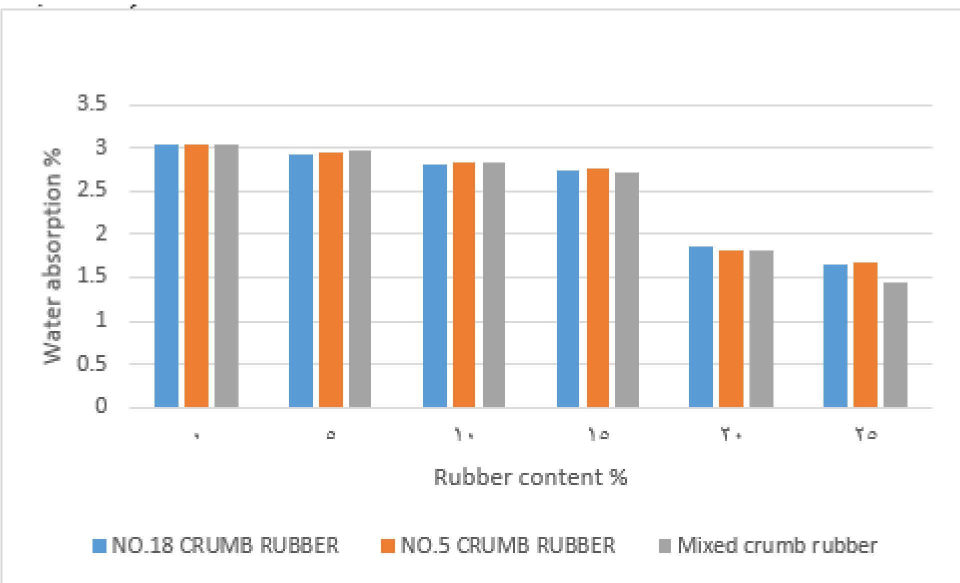


Fig 4.11 Water absorption percentage for LWSCC mixtures.

The cement hydration products (C-S-H and $Ca(OH)_2$) led to fill the voids in addition to the particles of lime stone powder which lead to precipitate of C-S-H , thus the cement hydration increased. As a result, the interfacial transition zones improved thus leading to reduce the percent of porosity and water absorption **(Chen and Kwan, 2012) (Li and Kwan, 2015)**.

Utilizing rubber as fine aggregate in LWSCC led to reduce the water absorption as shown in **Table 4-7** and **Figure 4.11** irrespective of its size and content. The reduction as compared to control mixture refer to the less affinity of water to rubber than to sand **(Marques et al., 2008)**. By increasing the rubber content in mixture leads to a rise the content of incorporated air improving thus and lowering the values of capillary water absorption **(Pedro et al., 2013)**.

(Fadiel et al., 2014) found that 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.

Bjegovi´c et al., 2011 studied the effects of using several sizes of rubber aggregate (size 2-3.5 mm, 2-4 mm, and 0.5-2 mm), by volumes of 5 percent, 10 percent, and 15 percent, to replace some of the natural fine aggregate in ordinary concrete. They discovered that raising the rubber aggregate percentage from 5percent to 15percent resulted in a 78percent reduction in water absorption.

The control mixture produced the maximum water absorption results, and as the rubber content rose, water absorption gradually decreased.

The findings demonstrate that whereas mixed crumb rubber created light weight self compacting concretes had the maximum water absorption, those produced with No. 18 crumb rubber had the lowest.

4.3.2 Sorptivity

Sorptivity is an index of moisture transport into unsaturated specimens that can be recognized as an important index of concrete durability. In other words, sorptivity is an indicator of moisture transport into unsaturated concrete because it measures how quickly water is drawn in by capillary suction. It is an easily measurable material property that describes the tendency of a porous material to absorb and transmit water through capillary action.

As shown in Tabel (4.8) and Fig (4.12), it was discovered that the sorptivity increased steadily over time as a result of water leaking in from the bottom surface. It is obvious that the No. 5 crumb rubber-concrete mixture has a higher sorptivity than the other two sets. Additionally, because of its lower density, larger void ratio, and higher absorption of unprocessed rubber, concrete mixture with No. 5 crumb rubber was shown to absorb more water.

Tabel 4.8 Sorpitivity test results of LWSCRC.

Mix code	Water sorptivity
Control	0.00005
FCR5	0.0001
FCR10	0.00012
FCR15	0.00014
FCR20	0.00017
FCR25	0.00024
CCR5	0.0009
CCR10	0.00011
CCR15	0.00013
CCR20	0.00019
CCR25	0.00026
MCR5	0.0001
MCR10	0.0009
MCR15	0.00012
MCR20	0.00016
MCR25	0.00022

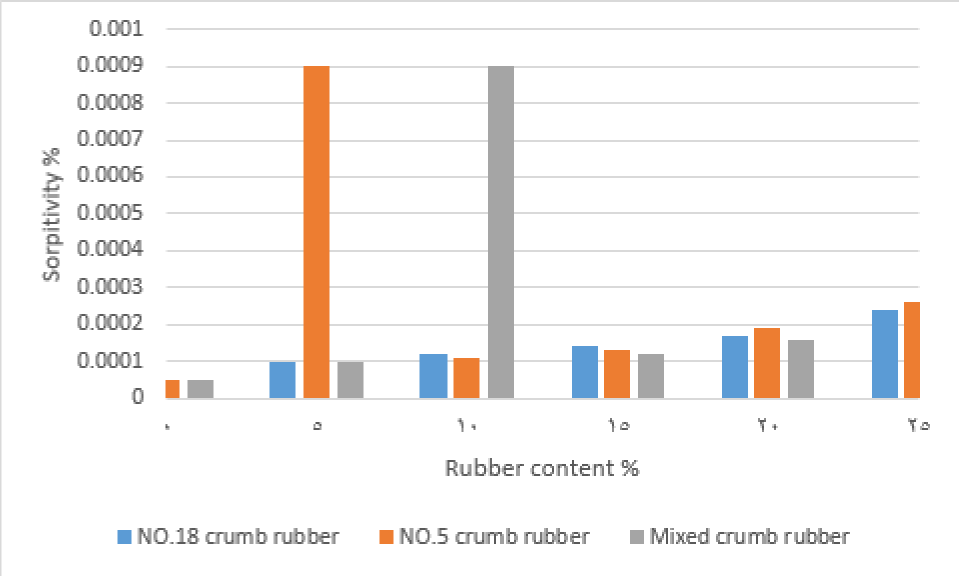


Fig 4.12 Sorpitivity values for LWSCC mixtures.

Zrar et al.(2022) claim that the introduction of CR particles progressively caused the sorptivity height to drop. The hydrophobic feature of rubber causes a contact angle greater than ninety degrees among crumb rubber particles and the cement matrix, lowering the ability of water to infiltrate samples. They determined sorptivity that decreased from 1.71 to 1.04 mm for the CR content ranging. Secondly, CR ranging from 0percent to 30 percent, correspondingly.

There are comparable tendencies, according to **Segre and Joekes**. The aforementioned could have occurred for two reasons: **Geso glu and Güneyisi (2014)** found a rise in the sorptivity of self compact concrete by partial replacement fine aggregate in self compact concrete mixtures with varied quantities of crumb rubber. First, particles capillary tubes longer and more curved, preventing water and chloride ions from entering (size 0–4 mm). With the addition of 5 percent, 15 percent, and 25percent rubber aggregate content, correspondingly, the rise in the 28-day sorptivity coefficient must have been about 5.26 percent, 25 percent, 39.47 percent, and the 90-day sorptivity coefficient was 10 percent, 29 percent, 43 percent.

5.1 Conclusions

Six different replacement levels of 0, 5, 10, 15, 20, and 25 percent of the natural aggregate with rubber have been designed and used to create a total of 16 rubberized light weight self-compact concrete mixtures which were tested for fresh and some hardened properties. The following conclusions can be drawn from the experimental program's results, which are shown above:

1- For the self-compacting rubberized concretes, slump flow diameters ranging from 560 to 750 mm were obtained. According to the EFNARC constraint, the self-compacting rubberized concretes were in the SF2 class but the reference mixture was in the SF3 class. When compared to mixtures made with No. 18 and mixed crumb rubber, the slump flow diameters of mixtures made with No. 5 crumb rubber were lesser.

2- The findings indicated that the reference combinations fall into the VS1/VF1 viscosity class, while the mixtures made using crumb rubber as a partial replacement fell into the VS2/VF2 viscosity class.

3-It was discovered that the size and content of the crumb rubber utilized had an impact on the L-box height ratio. The L-box height ratio systematically decreased as the crumb rubber concentration increased. All of the combinations, however, exhibited L-box height ratio values greater than 0.8, the bottom limit established by EFNARC. The concretes made using No. 18 crumb rubber, offered the greater L-box height ratio, and No. 5 crumb rubber usage gave the lower L-box height ratio.

4-Using rubber in SCC improve the segregation resistance (SR) since the SR ratio decreased as rubber content rose. The T500 and V-funnel time data support the possibility that this behavior is caused by the high viscosity of the rubber-mixtures. All mixes, whether they contain rubber or not, are suitable because they all fall under the sieve segregation resistance class SR2 (SR ≤ 15%) mentioned by EFNARC.

5- The density of the fresh SCC decreased by the inclusion of the rubber aggregate. With an increase in the amount of rubber, the density decreased through the lowest density (1540-1860) Kg/m^3 was recorded for fine rubber incorporating SCC followed by coarse (1565- 1892) Kg/m^3 and mixed rubber ones (1588- 1889) Kg/m^3.

6- Although the best compressive strengths were recorded for mixtures integrated with fine crumb rubber (No. 18), accompanied by mixed crumb rubber and coarse crumb rubber (No. 5), the use of crumb rubber in the manufacturing of light weight self-compacting concrete resulted in a systematic decreasing of the compressive strength

7- Successful production of LWSCRC with a compressive strength of more than 30 MPa is accomplished at low inclusion levels of up to 10percent crumb rubber regardless of its size.

8- The control combination yielded the highest splitting tensile strength result, and increasing rubber content was likewise seen to cause a systematic decrease in splitting tensile strength. The highest splitting tensile strength was demonstrated by samples made with No. 18 crumb rubber, while the lowest splitting tensile strength was demonstrated by samples made with No. 5 crumb rubber. This property diminished by up to (36.1 to9.75) % depending on CR content.

9-Similar to what was shown in compressive and splitting tensile strengths, the static elastic modulus dropped with increasing rubber size and content such that from (21.8 to 15.1) Gpa. So the findings showed that the maximum static elastic modulus was achieved by self-compacting concretes made with No. 18 crumb rubber.

10- The control mixture produced the maximum water absorption results, and as the rubber content rose, water absorption gradually decreased , mixed crumb rubber created light weight self compacting concretes had the maximum water absorption, those produced with No. 18 crumb rubber had the lowest.

11- As a partial substitute for sand, the sorptivity of SCC diminished as the CR concentration was raised. Another investigation, however, asserts the reverse.

12-Rubberized SCC may be used in a variety of structural applications. Yet, the replacement level needs to be carefully designed in order to preserve the necessary mechanical and durability features.

5.2 Recommendations

1. More research into various hardened and fresh property tests is proposed to examine LWSCRC for other applications. To increase the range of applications for LWSCRC, this could additionally incorporate dynamic and durability tests.

2- investigating how rubber's fresh and hardened characteristics are affected by treatment before it is added to LWSCC mixtures. Since the water-soaking approach for treating rubber had pretty positive results, it is important to look into other treatment options.

3In order to provide end users with a standardized method/approach for replacing rubber aggregate that may be utilized conjunction with traditional mix design procedures and provide predictions for anticipated strength reduction, the preferred extra physical properties (e.g., dynamic, thermal, etc.), unit weight (including air entrainment), and workability, further research is required. It could offer a desperately required trustworthy mechanism that would enable the confident use of reproducible mix designs. To make this happen, it is necessary to choose the optimal mixing method, the maximum/minimum rubber aggregate size that is allowed, and admixtures or rubber aggregate pre-treatment.

4- examining further durability tests for the rubberized LWSCC, like the concrete's ability to withstand chemical attack, weathering, and ecological factors.

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Appendix

Light Expanded Clay Aggregate

Leca Main Advantages

LECA aggregate advantages which make every Leca Product a unique building material.

- LIGHTNESS
- THERMAL INSULATION
- SOUND INSULATION
- FIRE RESISTANCE
- NON-DECOMPOSABILITY
- LIMITED WATER ABSORPTION

Leca Wide Applicability	Average Density* kg/m³	Leca Gradation mm
Leca Light Weight Concrete, Light Weight Block, Prefabricated Panels & Slabs. Light Filler, Leca Mortar and Water Purification System. Agriculture & Aquaculture.	510	0-4
Light Weight Concrete, Light Weight Block, Prefabricated Panels & Aquaculture, Ornamentation.	320	4-10
Light Weight Filler Concrete, Sewage System. Landscaping, Agriculture & Aquaculture, Drainage.	250	10-25
Floor & Roof Sloping, Light Weight Filler, Road Construction.	270	0-25

*Average density allowable tolerance is ±50 kg/m³

Leca 0.1-4 mm | **Leca** 4-10 mm | **Leca** 10-25 mm

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2

Appendix

Light Weight Concrete (LWC)

Structural or non-structural lightweight concrete can be defined as a concrete with closed or open structure contains whole or part ordinary aggregate and LECA aggregate.
In addition to the weight savings, lightweight concrete has substantially better fire-resistant qualities than normal weight concrete, significantly lower heat transmission, remarkable moisture resistance and more durability. It protects steel reinforcement from the corrosive action, salt water and severe environments.
For architects and engineers, Structural Light Weight Concrete (SLWC) has opened up a wide range of applications and possibility to have tall building frames, long-span roof and bridge structures and thin shell construction.

Lower weight reduces seismic forces, reinforcing and pre-stressing steel, increase live load capacity for **Bridges** and **Marine Structures**. Moreover, with Low permeability, it is highly **Durable** to freezing and thawing and chloride ions. Owing to LECA long term water absorption, LECA will act as an internal source of water for **internal curing** which will help to avoid shrinkage and improve long term strength.

Exterior of 40,000-seat Wellington Stadium NZ nearing completion,4000 precast lightweight components accommodated rapid construction

Hibernia Offshore Platform Canada

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3

Appendix

Screed, Flooring and Roofing

Designers apply lightweight concrete for floors and roofs because in order to be cost efficient and environmentally friendly. While Lightweight concrete has compressive strength same as normal weight concrete. It will reduce total dead load up to 30 percent and provides 5 times more thermal insulation.
Leca makes a smart package of lightweight elements, thinner section, better fire rate, insulating roof, improved seismic structural response, less reinforcing and lower foundation cost.

THE MAIN BENEFITS OF LECA® IN GEOTECHNICAL APPLICATIONS ARE

- Low bulk density
- High insulation capacity
- Excellent drainage properties
- Non combustible
- Resistance to heat and frost
- Low capillarity
- Easy to spread and compact
- Large load bearing capacity
- Deformation resistance
- Inert and chemically neutral
- Resistant to fungus, rot, insect and pest
- Constant and high quality of the lightweight material
- Low transportation costs

الخلاصة

الغرض الرئيسي من هذا البحث هو معرفة التأثير الناتج بالنسبة للحجم والمحتوى جراء اضافة مخلفات المطاط على خواص الخرسانة في الحالتين الطرية والمتصلبة والديمومة للخرسانة خفيفة الوزن ذاتية الرص، تم إنشاء العديد من الخلطات الخرسانية خفيفة الوزن ذاتية الرص بمحتوى مادة رابطة مقداره 520 كجم / م^3 و نسبة الماء إلى المادة الرابطة هي 0.35.

تم استبدال الركام الطبيعي حجميا بنسب مختلفة مخلفات المطاط هي 5٪، 10٪، 15٪ ، 20٪ ، 25٪ ، وتم اعتماد ثلاثة مقاسات مختلفة من المطاط (رقم 18 ، رقم 5 ، والمقاس المختلط بين المقاسين الانفين).

تم انشاء 18 خلطة خرسانية خفيفة الوزن ذاتية الرص محتوية على المطاط بنسب مختلفة، تم اجراء اختبار انسياب الهطول وزمن 500 ملم وزمن انسياب قمع V وصندوق L ومقاومة الانعزال لتحديد خصائص قابلية التشغيل للخلطات الخرسانة خفيفة الوزن ذاتية الرص.

تم اجراء فحوصات الخرسانة المتصلبة المتضمنة فحص مقاومة الانضغاط والشد الانشطاري ومعامل المرونة بالاضافة الى فحوصات الديمومة وهي فحص امتصاص الماء وفحص امتصاص الماء بالخاصية الشعرية.

كانت قيم قطر انسياب الهطول للخلطات الخرسانية التي كان مقاس المطاط فيها No. 5 أقل منها للخلطات ذات مقاس No. 18 ، وكان زمن انسياب الهطول للخلطات الخرسانية التي كان مقاس المطاط فيها No. 5 اطول في جميع نسب الاستبدال، وكانت نسبة ارتفاع L-box هي الأدنى في الخلطات المصنوعة من مخلفات المطاط المسحوق No. 5، على الرغم من عدم وجود تمييز كبير بين الخلطات الخرسانية ذات المقاس No.18 والخلطات ذات المقاس المختلط.

أظهرت النتائج أن استخدام مخلفات المطاط المسحوق في إنتاج الخرسانة ذاتية الرص أدى إلى انخفاض منهجي في مقاومة الانضغاط وقوة الشد وتم الحصول على أفضل النتائج للخلطات التي يكون مقاس المطاط فيها No.18 متبوعًا بالخلطات ذات المقاس المختلط و No .5 على التوالي.

وكذلك أظهرت النتائج ان الخلطات الخرسانية الخفيفة الوزن ذاتية الرص التي يكون مقاس المطاط فيها No.18 لها مقاومة شد اعلى من الخلطات الخرسانية التي يكون مقاس المطاط فيها No . 5، بالإضافة الى ذلك فان استخدام المطاط المكسر ذا المقاس الخشن أدى الى تقليل مقاومة الانضغاط

للخلطات الخرسانية خفيفة الوزن ذاتية الرص أكثر من الخلطات الخرسانية التي يكون فيها مقاس المطاط المستخدم ناعما.

وبالنسبة للخلطة المرجعية التي لا تحتوي على مطاط كان لها اعلى امتصاص للماء وكلما زاد محتوى المطاط قل امتصاص الماء بغض النظر عن مقاس المطاط المستخدم.

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

تأثير إضافة مخلفات الإطارات على خواص الخرسانة خفيفة الوزن ذاتية الرص في كلا الحالتين الطرية والمتصلبة

رسالة

مقدمة الى كلية الهندسة - جامعة بابل

كجزء من متطلبات نيل درجة الماجستير في الهندسة / الهندسة المدنية / مواد انشائية

من قبل

هبة محمد مهدي

اشراف

أ. م. د. علي حسون نهاب

1444هـ **2023م**