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تأثير لهب النار على خواص الخرسانة ذاتيه الرص خفيفة الوزن المسلحة بالألياف والمحتوية على انواع مختلفة من المضافات المعدنية

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" Impact of fire flame on the properties of self-compacting lightweight concrete reinforced with fibers and containing different types of mineral admixtures "

A Thesis
Submitted to the College of Engineering at the University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master in Engineering/Civil Engineering/ Construction Materials

By

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Ali Mohammed Abbas

2024

Certificate

I certify that the preparation of thesis entitled " **Impact of fire flame on the properties of self-compacting lightweight concrete reinforced with fibers and containing different types of mineral admixtures** ", was prepared by " **Ali Mohammed Abbas Mohammed** ", under my supervision at the Department of Civil Engineering in the University of Babylon in partial fulfillment of the requirements for the degree of Master of science in Construction Materials Engineering

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Contents

List of Figures

List of Plate

List of Tables

Abstract

Fire is one of the most severe environmental condition encountered which it caused a deterioration in the mechanical properties of concrete owing to the high temperature to understand the strength characteristics of concrete structures exposed to high temperatures is important. In order to predict how these structures will perform after exposure to this condition. This study endeavors to interrogate the fire resistance properties of self-compacting lightweight concrete (SCLWC) made with lightweight expanded clay aggregate (LECA) with density 700kg/m^3 as coarse aggregate reinforced with Steel Fibers (S) and Polypropylene Fibers (PPF) with different type of mineral admixtures.

SCLWC mixes were divided into four groups according to the type and amount of fibers and the type of mineral admixtures which is replaced (10%) by mass of cement, without, silica fume, fly ash and metakaoline respectively. Each group contains w/c 0.36 and each group contains five mixes. First mix was without fibers, second and third mixes were reinforced with steel fibers with percentages of (0.25% and 0.5%) by volume respectively. Fourth and fifth mixes were reinforced with hybrid fibers (steel + polypropylene) with percentages of (0.25% +0.15%) and (0.5%S+0.15 %) by volume of concrete.

Fresh and mechanical tests were conducted for the self-compacting lightweight concrete included (slump flow, T500 mm, L - box, V- funnel, fresh density, compressive strength, splitting tensile strength, flexural strength, weight loss, oven dry density and Ultrasonic pulse velocity).The concrete specimens, cured for 28 days, were subjected to fire flame temperatures of 300°C, 450°C, and 600°C, for 1 hour in line with ISO-834 practical curve .

The results of this study showed that the V-funnel flow time and T500mm values increased with replacement of mineral admixtures, also they increased by raising the quantity of fibers, but decrease slump and L-box compared to the

control mixture .The results showed that the fresh density of SCLWC was varied from 1849- 1922 kg/m3 which reduced with replacement of mineral admixtures, while it was somewhat higher as the microsteel fiber content enhanced.

The main finding of this study is that at 600 °C the addition of 0.5% steel fibers cannot effectively prevent spalling at 1-hour fire exposure, and only enhances the residual (compressive , splitting tensile and flexural) strengths and ultrasonic pulse velocity better than the case of adding hybrid (S+PPF). While the use of hybrid fibers is the best for producing a self-compact lightweight concrete with more resistance to spalling. The small amount of PPF melts at a temperature (160-165) °C which creates sufficient channels to release the internal vapor pressure from the SCLWC samples structure. Also at 600 °C, mixes containing 10% metakaolin (MK) gave more residual compressive strength than the (SCLWC, 10silica fume and 10fly ash mixes) by about (3%, 10% and 0.3%) (4.6%, 10.4%, 0.5%) at 28 and 56 day respectively. Also for both the flexural, splitting tensile and ultrasonic pulse velocity there was an increase residual strength with10% metakaolin at,28 and 56 days.

الخلاصة

يعد الحريق من أشد الظروف البيئية التي يمكن مواجهتها والتي تسبب تدهورًا في الخواص الميكانيكية للخرسانة بسبب ارتفاع درجات الحرارة حيث من المهم فهم خصائص قوة الهياكل الخرسانية المعرضة لدرجات حرارة عالية. من أجل التنبؤ بكيفية أداء هذه الهياكل بعد التعرض لهذه الحالة. تسعى هذه الدراسة إلى التحقق من خصائص مقاومة الحريق للخرسانة خفيفة الوزن ذاتية الرص (SCLWC) المصنوعة من ركام الطين الممتد خفيف الوزن (LECA) بكثافة 700 كغم/م^3 كركام خشن مقوى بألياف الصلب (S) وألياف البولي بروبيلين (PPF) مع أنواع مختلفة من المضافات المعدنية.

تم تقسيم خلطات SCLWC إلى أربع مجموعات حسب نوع وكمية الألياف ونوع المضافات المعدنية والتي تم استبدال (10%) من المضافات بكتلة الأسمنت، بدون اضافة, 10%دخان السيليكا, 10%الرماد المتطاير و10%الميتاكاولين على التوالي. تحتوي كل مجموعة على 0.36w/c وتحتوي كل مجموعة على خمس خلطات. الخلطة الأولى كانت خالية من الألياف، الخلطة الثانية والثالثة تم تدعيمها بالألياف الفولاذية بنسب (0.25%، 0.5%) من حيث الحجم على التوالي. تم تقوية الخلطتين الرابعة والخامسة بالألياف الهجينة (فولاذ + البولي بروبلين) بنسب (0.25% +0.15%) و (0.5%%S+0.15) من حجم الخرسانة.

تم إجراء اختبارات حديثة وميكانيكية للخرسانة خفيفة الوزن ذاتية الدمك والتي شملت (slump flow، T500 ملم،L -box، V -funnel، الكثافة الطازجة، مقاومة الانشطار، مقاومة الانشطار، مقاومة الانثناء، فقدان الوزن، الكثافة الجافة وسرعة الموجات فوق الصوتية). تم تعريض عينات الخرسانة، التي تمت معالجتها لمدة 28 يومًا، لدرجات حرارة لهب النار تبلغ 300 درجة مئوية، و450 درجة مئوية، و600 درجة مئوية، لمدة ساعة واحدة بما يتماشى مع المنحنى العملي ISO-834.

أظهرت نتائج هذه الدراسة أن قيم V-funnel و T500mm زادت مع استبدال الخلطات المعدنية، كما أنها زادت بزيادة كمية الألياف، ولكن انخفضت slump وL -box مقارنة بالخلطة المرجعية. تراوحت الكثافة الطازجة لـ SCLWC من 1849 إلى 1922 كجم/م^3 والتي انخفضت مع استبدال المضافات المعدنية، في حين كانت أعلى إلى حد ما مع تعزيز محتوى الألياف الدقيقة.

تتمثل النتيجة الرئيسية لهذه الدراسة في أنه عند درجة حرارة 600 درجة مئوية ، فإن إضافة 0.5٪ من الألياف الفولاذية لا يمكن أن تمنع بشكل فعال التشظي عند التعرض للحريق لمدة ساعة واحدة ، وتعزز فقط نقاط القوة المتبقية (الانضغاط, الشد والانثناء) و سرعة الموجات فوق الصوتية أفضل من حالة إضافة الالياف الهجينة (S + PPF). في حين أن استخدام الألياف الهجينة هو الأفضل لإنتاج خرسانة خفيفة الوزن مدمجة ذاتيًا بمقاومة أكبر للتشظي. عند 600 درجة مئوية أيضاً، أعطت الخلطات التي تحتوي على 10% ميتاكاولين (MK) مقاومة انضغاط متبقية أكثر من (SCLWC، 10% دخان السليكا و10% رماد متطاير) بحوالي (3%، 10%، 0.3%) (4.6%، 10.4%، 0.5%) عند 28 و56 يومًا على التوالي. أيضًا بالنسبة لكل من الانشطار والانثناء وسرعة الموجات فوق الصوتية، كانت هناك زيادة في القوة المتبقية مع 10% ميتاكاولين عند 28 و56 يومًا.

ABBREVIATIONS

Abbreviations	Descriptions
C–S–H	calcium silicate hydrate
FA	fly ash
ISO	International Standard organization
LECA	lightweight Expanded clay aggregate
LWC	light weight concrete
MK	Metakaolin
NWAC	Normal Weight Aggregate Concrete
PP	Polypropylene
SF	silica fume
SCLWC	Self-compacting light weight concrete
SCC	self-compacting concrete
S	steel fiber
SP	Superplasticizer
U.P.V	Ultrasonic pulse velocity

CHAPTER ONE

INTRODUCTION

1.1 General

Self-compacting light weight concrete (SCLWC), which combines the advantages of two special concrete, namely self-compacting concrete (SCC) and light weight concrete (LWC), has recently attracted the attention of many researchers. SCC is a workable cement-based material that stays stable because of its own weight and can be spread into place without needing to be compacted **(Hossain, K.M.A. 2015).** On the other hand, LWC is vibrated concrete that is lighter than traditional concrete and has a variety of applications.

The structural LWC is described by **(ACI.213R-03, 2009)** as a concrete with an equilibrium density between 1120 kg/m^3 and 1840 kg/m^3 and a compressive strength of at least 17 MPa. LWC can be made in a variety of methods, like using light weight aggregate, omitting fine aggregate from the concrete mix, and creating big voids within the concrete. Indeed, there is growing interest in using light weight aggregate in SCC. Pumice, scoria and diatomite are example of naturally occurring light weight aggregate. Rotary kiln expanded clay, shale and slate are examples of artificial light weight aggregate **(Neville, 2005).**

The new generation of concrete ,SCLWC , is anticipated to have low density , high insulation capacity , good durability including high resistance to fire and chemical attack ,as well as self –compatibility ,which intern decreases construction time and noise caused by the vibration that comes with using ordinary concrete . These characteristics are due to previously mentioned features of SCC and LWC **(Papanicolaou and Kaffetzakis, 2011; Güneyisi, et al., 2012).**Additionally, since the construction field is currently having trouble finding qualified workers , the self-compatibility of SCLWC can be a remedy for such deficiencies by reducing the labors during constructions **(Ting et al. , 2019).**

1.2 Application of Self-Compacting Lightweight Concrete

Self-compacting concrete be applicable in the sector of precast concrete units and renewal of ancient structures where further weight would not be preferable. The thermo-isolating SCLWC was successfully used in buildings and housing as shown in Figure (1-1), **(Ghafoori, 2010)**.

Figure (1-1): Some applications of SCLWC a) Precast panel, b) lightweight Block, c) lightweight girder for bridge, and d) lightweight floor system, (Ghafoori, 2010).

1.3 Standard Fire Curve (ISO 834–1. (1999))

Standard, heating conditions, test steps, and criteria for the measurement of the fire endurance of building construction elements in different categories are specified by International Standard ISO 834. This testing technique allows the fire resistance of construction elements (walls, columns, beams, floors, and roofs) to be determined based on the time length for which the test samples satisfy the specified criteria. The ISO 834 standard indicates that the rise in furnace temperature of the test sample is subject to the equation shown below:

$$\mathbf{T = 345 * \log_{10}(8*t + 1) + T_0} \qquad (1\text{-}1)$$

Where:

t = time, in (minutes),

T = temperature of furnace at time (t), in (°C)

T_o = initial furnace temperature, in (°C).

Values obtained from the above relationship are presented in Table (1-1). The curve representing this relationship between the time and temperature which is called the standard time-temperature curve is presented in Figure (1-2).

Table 1-1: Time-temperature data for the ISO 834 standard fire curve **(ISO 834–1. (1999))**

Time (t) (min.)	**Temp. (T) (°C)**	**Time (t) (min.)**	**Temp. (T) (°C)**	**Time (t) (min.)**	**Temp. (T) (°C)**
5	**576**	**45**	**902**	**85**	**997**
10	**678**	**50**	**918**	**90**	**1006**
15	**739**	**55**	**932**	**95**	**1014**
20	**781**	**60**	**945**	**100**	**1022**
25	**815**	**65**	**957**	**105**	**1029**
30	**842**	**70**	**968**	**110**	**1036**
35	**865**	**75**	**978**	**115**	**1043**
40	**884**	**80**	**988**	**120**	**1049**

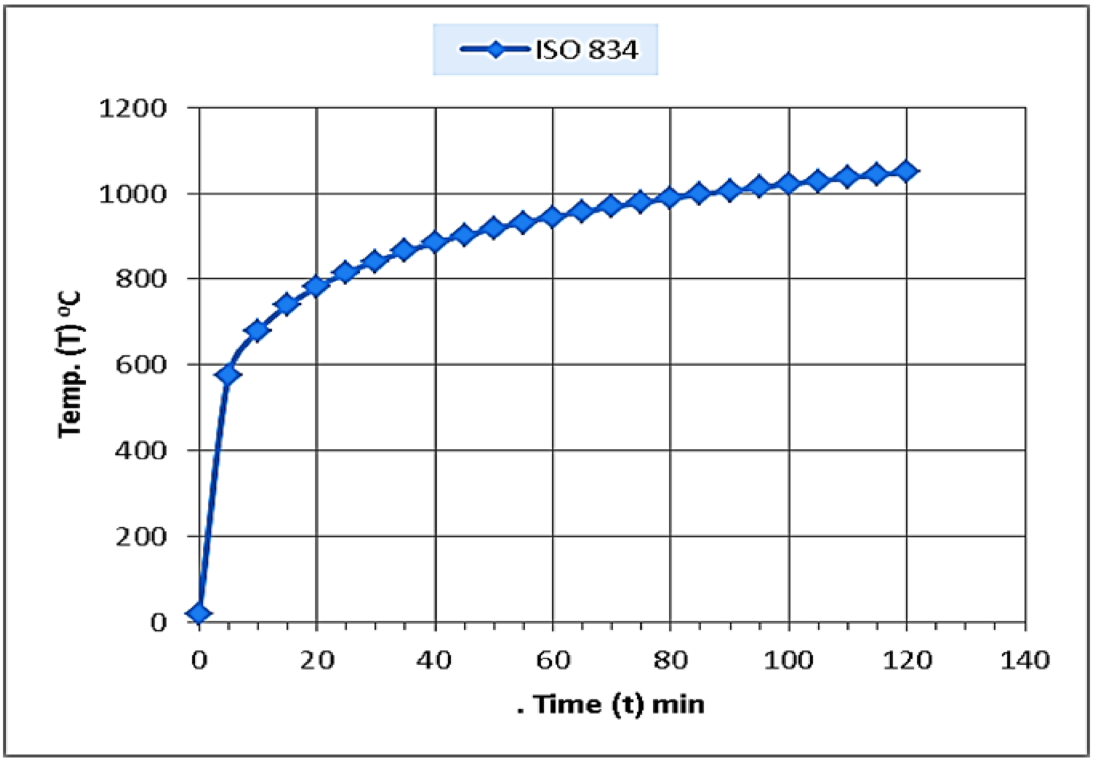

Figure (1-2): Standard Fire Curve for the ISO 834.

The specimen's fire resistance represents the time (in minutes) of heating until failure occurs, and is defined by one of the following specifications:

• **Load-bearing capacity:** failure occurs when the test sample collapses in such a manner that it no longer performs the load-bearing function which it was intended.

• **Insulation**: the failure happens in construction elements that separate two building parts (e.g., floors and walls) in three cases one, the temperature on the unexposed face rises by more than (140°C) over the initial temperature. Two, the maximum temperature rises more than the initial value by over 180°C at any point on the unexposed surface. Three, the unexposed surface temperature exceeds 220°C.

• **Integrity:** construction elements like floors and walls collapse occurs when the element shows holes, cracks, or other openings that hot gasses or flames may pass. This can be tested by using standard cotton pads or observation. The element loses its integrity if cotton pads with 100 mm2 in area of 20 mm thickness are ignited when held at a distance up to 30 mm from any opening on the unexposed side. Similarly, the element loses its integrity when sustained flaming of at least 10-sec duration appears on the unexposed side.

1.4 Problem Statement

The advantages of concrete in a fire are two- fold. It is: incombustible (e.g. when compared with wood); and a good insulating material possessing a low thermal diffusivity (e.g. when compared with steel). However, there are two problems of concrete in fire. These are: deterioration in mechanical properties as temperature rises, caused by physicochemical changes in the material during heating and; explosive spalling, which results in loss of material, reduction in section size and exposure of the reinforcing steel to excessive temperatures. Consequently, both the separating/insulating and load-bearing functions of the concrete member could be compromised.

Structural LWC generally exhibits greater fire resistance than normal weight concrete when exposed to fire conditions. This superior performance is due to combination of lower thermal conductivity (leading to lower temperature rises on exposed surface) and lower coefficient of thermal expansion (leading to lower forces developed under restraint). Some LWC may not exhibit the same level of performance as normal weight concrete under severe fire conditions. In these concretes, spalling under fire conditions is one the major concerns.

In recent time, the inclusion of polypropylene fiber had been reported to be a feasible method to prevent spalling of concrete subjected to elevated temperature. Additional problems arise due to the fact that by adding polypropylene fibers, the residual properties of heated concrete may be adversely affected. The current study reveals on the attempt to achieve the maximum amount of improvement possible through the employment of fiber (steel fiber) and hybrid fibers (steel +polypropylene inside the SCLWC mixes.

1.5 Research Significance

With the growing utilization of SCLWC in structural contexts and its associated advantages, a thorough comprehension of the core response of SCLWC under elevated temperatures becomes crucial. This understanding is vital for ensuring the safety of structural fire design when employing fiber-reinforced SCLWC. In most papers the effect of high temperature on concrete has been studied by subjecting concrete to elevated temperature in furnace without a fire flame. Since this cannot simulate the real situation, the present study applies a direct fire flame at temperature levels 300,450 and 600°C for 1 hour on SCLWC reinforced with fibers

1.6 Objective of the Research

It was found that the literature lacks investigating on the impact of fire flame on the behavior of self-compacting lightweight concrete reinforced with single and hybrid fibers which need a considerable attention to find the extent of damage that may occur in these important compassions. The main aims of this study can be divided into the following categories:

1- To evaluate the fresh properties of SCLWC mixtures. As fresh state tests, the slump flow (mm) and T500mm (s), V-funnel time, L-box, and segregation resistance are performed.

2-Determining the impact of steel fibers at two percentages (0.25 , 0.5) and hybrid fibers (steel+ polypropylene) at two percentage (0.25+0.15) (0.5+0.15) on the properties of SCLWC before and after being subjected to fire flame.

3-studying the impact of mineral admixtures including (silica fume, fly ash and metakaolin) with replacement from cement weight with a ratio (10%) by weight of cement on the properties of SCLWC before and after being subjected to fire flame .

4- Evaluating the impacts of fire flame exposure on the properties and spalling potential of SCLWC

1.7 Layout of Thesis

- **Chapter One (Introduction)**

This chapter offers background about the subject of this research. it also presents the goal and objectives of this research study.

- **Chapter Two (Literature Review)**

This chapter investigates the findings of previous scientific research into the properties of SLWC and as well as the performance of structural parts after burning.

- **Chapter Three (Experimental Program)**

In this chapter, the materials and the methods adopted in this research are presented and discussed. This includes mixes proportions, casting methods, testing setup, and the instrumentation used to develop and test SCLWC .

Chapter Four (Results and Discussion)

Presentation and discussion of experimental test results, the properties of SCLWAC with and without fibers prior to exposure to fire flame are described, and the effect of exposure to fire flame is discussed. The hardened properties and spalling potential of SCLWC are discussed. This chapter also includes the effectiveness of polypropylene and steel fibers as a means of resisting SCLWC spallation hazards during heating. The effect of mineral admixture on SCLWC properties before and after exposure to fire flame is discussed

- **Chapter Five (Conclusions and Recommendations)**

It included a summary of the research outcomes as well as recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The fire may occur at any time inside the building and this poses a danger to safety. Also, high temperatures caused by flame considerably affect the quality and deformation features of different structural members; this chapter discusses the literature relating to this study. The background and definition of self-compacting concrete (SCC), light weight concrete (LWC) and self-compacting light weight concrete (SCLWC), mechanical properties of these types of concrete, the influence of mineral admixture and fibers on SCLWC before and after fire flame exposure

2.2 **Self -Compacting Concrete**

Self-compacting concrete (SCC) is one of the innovative concrete that is progressively used for experimental jobs and actual projects. It spreads through the congested reinforcement, reaches every corner of the formwork, and is consolidated under its own weight. While, providing these characteristics, SCC keeps its stability without segregation or bleeding **(Libre et al., 2012).**

The utilization of this method offers several benefits, such as reducing concrete construction time through improved productivity levels, constructing heavily reinforced sections, enhancing the quality of in situ concrete, minimizing noise and injuries associated with vibration and casting activities, leading to improved working conditions, as well as achieving excellent concrete surface quality **(Safiuddin et al., 2010).** Figure (2-1) depicts SCC at situ.

Figure (2-1) Depicts the SCC at Situ [EFNARC 2005]

SCC advantages are: (1) the considerable reduction in the required workers number and the mechanical vibration noise, (2) the improved smooth surface finish comparing to the traditional concrete, (3) decreased formwork damage due to mechanical vibration (4) increment of the forms life, (5) keeping bar configurations reinforcement from damage, and (6) strong bond between concrete and pre-stressed strands **(Hwang and Hung., 2005)**.

The disadvantages of SCC may include

(1)Increased costs of materials, such as cementations materials and admixtures (2) Higher formwork pressures, increased formwork costs (3) Required higher quality control(4) Increased variability in workability (5)High paste volumes or low coarse aggregate contents reduced hardened properties such as modulus of elasticity and dimensional stability (6) In some cases the use of admixtures delayed setting time.

2.2.1 Fresh Properties of Self-Compacting Concrete

Three important workability characteristics must be available in any SCC, namely filling ability, passing ability, and segregation resistance.

2.2.1.1 Filling ability (excellent deformability): SCC is able to flow and fill the formwork under its own weight **(EFNARC, 2005)**.

2.2.1.2 Passing ability: SCC is able to pass through congested regions like heavy reinforcement without blocking. Blocking is the non-uniform distribution of local aggregate within the matrix in the vicinity of obstacles resulting in interlocking and blocking of the flow.**(ACI237R -07, 2007)**.

2.2.1.3 Segregation Resistance: In its fresh state, the ability of concrete to maintain a homogeneous composition, as stated by **(EFNARC, 2005)**, is crucial for ensuring the quality of in-situ homogeneity in Self-Compacting Concrete (SCC). SCC is susceptible to segregation both during and after the placement, but the segregation that occurs after placement poses the most significant risk. Such post-placement segregation can result in surface defects like cracks or a weakened surface.

2.3 Light Weight Concrete (LWC)

There are different types of LWC according to the materials included in their composition. LWC is characterized by being light in weight, low in thermal conductivity, low in density, easy to transport and lay, and with higher workability. The ancient Greeks used lightweight concrete in construction for the first time in past centuries, and since then, The utilization of lightweight concrete has proliferated extensively to various countries, including the USA, UK, and France., etc., **(Chandra & Berntsson, 2002).** According to **(ACI.213R-03 2009),** structural lightweight aggregate concrete is described as concrete made from lightweight aggregates that have a compressive strength greater than 17 MPa and an air-dry density from 1120 to 1840 kg/m^3.

2.3.1 Properties of Light Weight Concrete

Lightweight concrete has an oven dry density of 300 to 2000 kg/m3, a cube compressive strength of 1 to 60 MPa, and thermal conductivities of 0.2 to 1.0 W/mK. These values are comparable to those for normal weight concrete, which range between 2100 and 2500 kg/m3, have a compressive strength of 15 to 100 MPa, and have a specific gravity of (1.6–1.9). **(Newman & Choo, 2003)**.

2.3.2 Classification of Lightweight Concrete

Light weight concrete can be classified into the following kinds based on its manufacturing method:

1. Light Weight Aggregate Concrete: It is produced of porous light weight aggregate with a specific gravity below 2.6.
2. Cellular, Aerated, Gas or Foamed concrete: This kind of concrete is created by adding larger spaces into the mortar or concrete. Fine voids created by air entrainment must be segregated from these gaps.
3. Concrete of No fines: This concrete type is made by removing the fine aggregate in the mix, resulting in a significant number of interstitial spaces. Coarse aggregate of normal weight is utilized in this concrete. In essence, the existence of voids in the mortar, aggregate, or the interstices between coarse aggregate particles causes the density of the concrete to drop in each process. When compared to standard weight concrete, the existence of voids diminishes the strength of light weight concrete. Figure (2-2) depicts a schematic of the main procedures used to produce lightweight concrete.

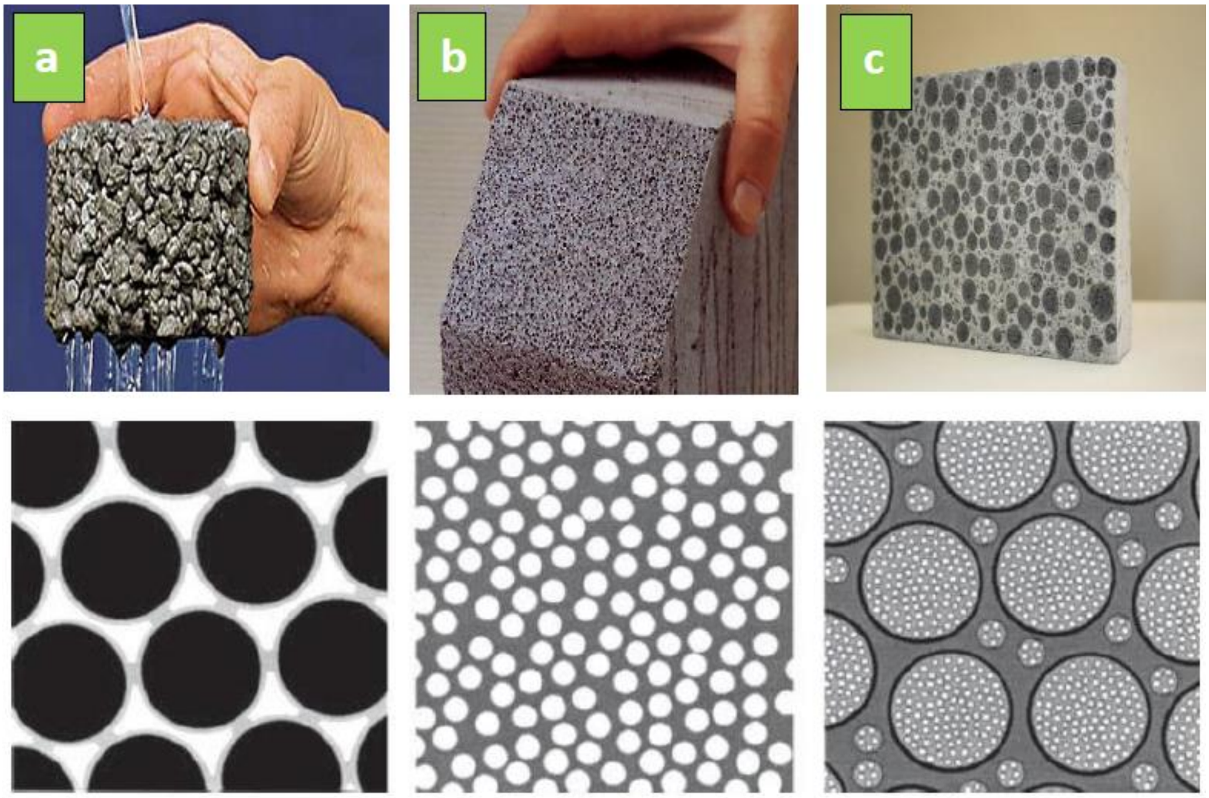

Figure. (2-2) Some kinds of lightweight concrete, (a) No fines concrete, (b) Aerated concrete and (c) Light-weight aggregate concrete (Slaby et al. , 2008).

There is another classification of lightweight concrete, which is according to the utilization purpose as:

i) Structural lightweight concrete has (17) MPa or more cylinder compressive strength after 28 curing days and the approximate range of density is around 1400-1800 kg/m^3.

ii) Masonry concrete (structural / insulating lightweight concrete) with a range of compressive strength (7 – 14) MPa and domain of density between (500- 800) kg/m3.

iii) Insulating concrete: with a compressive strength range from (0.7-7) MPa and value of density is less than 800 kg/m^3. and the thermal-coefficient should be lower than 0.3 J/m^2 sec °C/m **(Neville and Brooks, 2010).**

2.3.3 Lightweight Aggregate Concrete (LWAC)

When the aggregate density is lower than 1120 kg/m^3, so it is considered lightweight aggregates and it is utilized to make lightweight concrete **(Mehta and Monteiro, 2006).**

Multiple origins contribute to lightweight aggregates, encompassing natural elements like pumice, diatomite, clays, volcanic cinders, shale, and slates, alongside artificial resources (secondary products) like sintered fly ash, shale, clay, and iron blast furnace slag (**ACI 213R-87**). Figure 2-3 depicts the lightweight aggregate sorts **(Shetty 2006).**

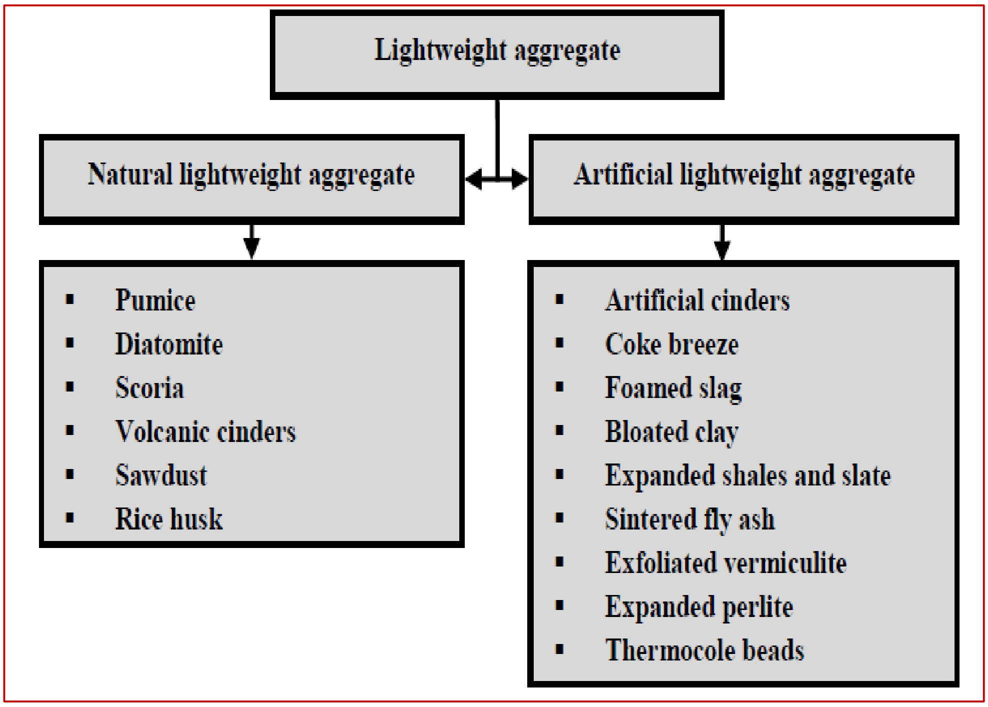

Figure. (2-3) Natural and non-Natural lightweight Aggregate **(Shetty 2006).**

The properties of lightweight aggregate used in concrete conforms the features of LWAC **(ACI 213R-87)**, LWAC may be created with compressive strength up to 35 MPa. There are a several LWA values that might be used to create a concrete with cylinder strengths ranging from 48 to 69 MPa **(Walraven, 2002)**. Figure (2-4) depicts the range of lightweight aggregates. Derived from the air-dried density of the lightweight aggregate concrete it may be divided into three categories **(ACI 213R-87):** low-density concrete, moderate strength concrete, and structural concrete. Three criteria endorsed by the International Building Code must be met when utilizing lightweight aggregates to produce concrete, masonry units, and insulating concrete (**ASTM C 332, ASTM C331 and ASTM C330)**.

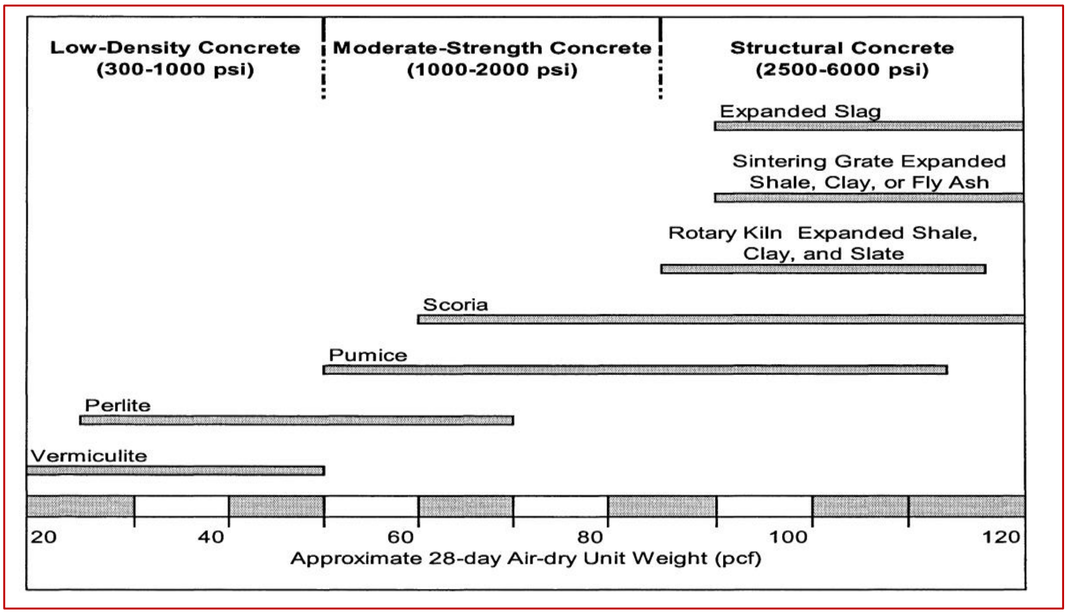

Figure. (2-4) Spectrum of Lightweight Aggregates (ACI 213R-87).

The primary purpose of generating lightweight aggregate is to reduce the overall cost of the project. To begin with, the production cost of a cubic meter of lightweight concrete (LWC) might exceed that of standard concrete. Nevertheless, due to the reduction in dead weight and foundation expenses brought about by structurally competent lightweight concrete, the overall construction outlay is diminished. **(Mehta and Monteiro, 2006).**

2.3.4 Lightweight Expanded Clay Aggregate (LECA)

Light weight expanded clay aggregate is a special type of aggregate which is formed by heating clay with no or very little content of lime. The clay is dried, heated and burned in rotary kiln at a temperature of 1100 °C – 1300°C since it is exposed to high temperature as a result, during the cooling process, gas is generated within the pellets and becomes trapped inside them. Meanwhile, the burning off of organic compounds causes the pellets to expand, resulting in the formation of ceramic pellets with a porous structure and formed a honeycombed structure .Outer surface of each granule is sintered. Pore structure gives light weight and high crushing resistance, thermal as well as sound insulation to the material. It has a circular or a potato shape formed due to circular movements in the kiln **(sravan et al., 2020)**

LECA typically displays a vesicular texture and can appear as dark brown, reddish, or grey. These color variations are likely linked to the diverse chemical compositions of LECA. Available in a range of sizes from 0.1 mm to 25 mm, LECA proves suitable for both fine and coarse aggregate applications. Its bulk density spans from 250 to 750 Kg/m^3. The utilization of LECA has led to the successful construction of lightweight concrete structures. Furthermore, LECA finds application across various civil engineering contexts, initially crafting one cubic meter of LWC could prove more costly compared to standard concrete. However, the overall construction expenditure is lowered as structurally capable lightweight concrete reduces both the load and foundation costs. It also serves as a lightweight retaining wall backfill and as a foundation for agricultural and building projects. Given its attributes, LECA has the potential to substitute natural aggregates in diverse civil engineering endeavors **(Sravan et al., 2020).** Due to its small specific weight, low conduction coefficient, and relatively good chemical stability, LECA has become a popular option for fabricating LWC in many regions of the world **(Koksal et al., 2012).**

Alaa M. Rashad., (2018) studied the use of lightweight clay aggregates as building materials. An overview of LECA as a building material is given. According to the conclusions of the study, LECA has a positive effect on workability, and reduces specific tensile creep and improves sound insulation.

Arioz et al., (2008) carried out the first experiment to examine the characteristics of LECA. Two types of LECA were utilized, each made from different clay with a different chemical makeup. One kind was derived from the pottery business, and the other from leftover brick powder. Temperatures ranging from 900 to 1250°C were also tested. The aggregates' microstructural and physical properties were investigated the influence of several elements such as clay type, firing temperature. It was determined that the clay type, as well as the amount and type of pore formation, had a substantial impact on the LECA characteristics.

Khafaji and Al-Majed., (2016) implemented the first experiment to investigate the characteristics of LECA. Two kinds of LECA were utilized, each made from different clay with a different chemical makeup. One kind was derived from the pottery business, and the other from leftover brick powder. Temperatures ranging from 900 to 1250°C were also tested. The aggregates' microstructural and physical properties were examined. An investigation was conducted to assess how various factors, including the type of clay, firing temperature, quantity and type of pore-generating agent, influence the surface texture, arrangement of pores, specific gravity, and water absorption characteristics of the expanded granules. It was determined that the clay type, as well as the amount and kind of pore formation, had a substantial impact on the LECA characteristics.

2.4 Self-Compacting Lightweight Concrete (SCLWC)

Self-compacting lightweight aggregate concrete (SCLWC) is an innovative construction material that merges. SCLWC possesses the ability to flow into position, fill formwork, and surround reinforcement without the need for external vibration, all while avoiding issues like bleeding or segregation. Owing to its lightweight nature and self-flowing characteristics, SCLWC has found significant application in reinforced structural elements and earthquake-resistant components.

Hossain., (2015) described SCLWC as an emerging advancement in the realm of high-performance concrete, combining the finest attributes of lightweight and self-compacting concrete. This hybrid material proves especially valuable in construction projects where extremely high concrete compressive strengths are unnecessary, but the emphasis lies on achieving low weight for the structures. For example, certain prefabricated pieces need transportation and buildings, while others necessitate the visibility of the concrete surface. It is especially suitable for the repair of ancient structures (for example, replacing wooden flooring) when extra loads are not possible. **(Choi et al., 2006;Topçu and Uygunoğlu, 2010).**

Over the past few decades, SCLWC has found widespread application in constructing various structures, such as pre-stressed beams with spans of up to 2000 cm **(Dymond., 2007),** as well as precast stadium benches **(Hubertova and Hela, 2007).**

The incorporation of coarse lightweight and fine stone particles in the concrete mix can be a crucial factor in enhancing the strength of lightweight concrete mixtures that incorporate expanded clay, slag, or natural crushed stone aggregates which showcase the most elevated levels of strength. The enhanced compressive strength and rheological characteristics are likely a result of the granular structure of the expanded clay aggregates **(Maghsoudi et al., 2011).**Constructions built using SCLWC are less expensive to build because there is a decrease in the overall dead load of structural elements, and steel constructions demand lower maintenance compared to similar structures. As a result, large-scale buildings might realize huge cost reductions that would not be possible with traditional self-consolidating concrete (SCC). The key advantages of SCLWC are its increased durability and flexibility (**Hwang and Hung ,2005).**

2.4.1 Material Used to Produce SCLWC

1-Cementious materials

SCLWC has been produced by using all kinds of Portland cement such as ordinary Portland cement, type I and sulfate resisting cement type V (ASTM C150) and non-Portland cement, such as blast furnace slag cement, conforming to ASTM C150, C595, C989, or C1157. Cement from one source may provide an excellent SCC while changing to another source provides dramatically different results **(TB-1502, 2005)**.

EFNARC, (2002) pointed to the C_3A content not being higher than 10% to avoid poor workability. The average cement content is 350 -450 kg/m^3. More than 500 kg/m^3 cement might be hazardous and cause shrinkage. Fewer than 350 Kg/m3 may be appropriate only with the addition of other fine filler s, such as fly ash, pozzolan, and so on. Those additions may significantly reduce the heat of hydration, shrinkage, and cost, as well as improve the long-term performance of the concrete.

2- Aggregates

When used in light weight structural concrete, normal weight aggregate should compliance with the regulation of **(ASTM C33M-18, 2018)**.

Lightweight aggregates (LWA) in structural concrete must meet the requirements of **(ASTM C330M-17a, 2017)**. LWA structures have pores that range in size from microscopic to visible to the naked eye. Water absorption and absorption rates might vary greatly. Expanded clay (LECA) and other lightweight aggregates such as expanded shale, pumice, slate, perlite, and others have been employed successfully in the production of lightweight concretes **(Lotfy, A. et al., 2016).**

3- Admixture and Fillers

In SCLWC mixes, both chemical and mineral admixtures may be employed. The ability of self-compact can be fulfilled by (a) utilizing either high range water reducer admixture (HRWRA) and with or without viscosity modifying agent (VMA) or (b) utilizing HRWRA, with high content of mineral powder. The hydration interaction is prolonged by pozzolanic materials, which also produce a good microstructure for SCLWC

4- Fibers

Without reinforcing, concrete is a fragile substance with low resistance to tension and low toughness. In order to improve the toughness, fatigue resistance , spread of the concrete cover, resistance to abrasion, and flexural strength, adding fibers with the best mechanical properties can modify the failure mechanisms of the composite **(Liao, W., et al., 2007)**.A number of consideration , including the sort of fiber , arrangement , length and amount , ratio of (w/c +p) , aggregate / binder ratio, mortar volume fraction, aggregate characteristics , and other mixture parameters affect the improvement that occurs. As is well known, adding fiber has a negative impact on the workability on concrete. The flow resistance is increased by fibers, which are needle- like particles. Additionally, it was discovered that using micro- steel fiber produced softer concrete behavior compared to using longer fibers **(Olivito, R., et al., 2012).**

Ma et al. (2013) found that increasing the volume fraction of micro steel fibers with dimension of 13 mm in length and 0.2 mm in diameter from 0 to 2%, resulted in 19 to 42 improvement in compressive strength.

According to (**Khaloo et al., 2014),** compared to longer hooked ends and other steel fibers , straight micro steel fibers had a higher negative impact on the workability of concrete because of their tiny size and lack of interlocking.

The characteristics of SCLWC strengthened by steel and polypropylene fibers (PPF) were studied by (**Liu et al., 2019).** The mechanical characteristics and microstructure of SCLWC were investigated in that research. The study's findings suggest that steel fibers' impact on self-compacting lightweight concrete's compressive strength can be disregarded, while the composite form created by combining steel fibers with PPF increased SCLWC's compressive strength through performance synergy. Compressive strength declined as PPF content increased with a fixed steel fiber content**.**

2.4.2 Fresh Properties of SCLWC

Gamal, (2007) implemented out a research to examine factors impacting SCLWC's fresh and hardened characteristics by incorporating expanded clay, he investigated the air satiability and flowability properties of SCLWC. The mix design of SCLWC was 0.3 w/c, 0.8% HRWRA (by cement weight), and various ratios of LWA/sand (2, 1.5, and 1). It was noticed that the different SCLWC parameters were enhanced by decreasing the ratio of LWA/sand; including flow ability, deformability, and self-compact ability, while decreasing the ratio of LWA/sand resulted in increasing the slump flow.

Echoing these findings, research conducted by **(Yew et al., 2020)** further elucidated the properties of fresh and hardened concrete with an increased percentage of light expanded clay aggregates replacing conventional aggregates. This work revealed a decrease in concrete density and an enhancement in workability as the replacement percentage increased, albeit at the expense of the compressive, split tensile, and flexural strength of the concrete.

Hubertova and Hela, (2007) investigated the SCLWC's development and properties made with expanded clay aggregates, and metakaolin, and silica fume. Using pre-wetted lightweight aggregates in concrete led to improve workability, compressive strengths and freeze-thaw cycles resistance in comparison to concrete mixes made with normal aggregates.

Lotfy et al., (2016) prepared SCLWC incorporating various LWA types including expanded shale, expanded clay, and furnace slag in order to study the properties of SCLWC. It was observed that the best LWA achieved the best workability of SCLWC in terms of filling ability was expanded shale in comparison to other utilized LWA. The flowability and segregation resistance were improved due to the fineness of expanded shale aggregates, as its fine portion was finer than that of furnace slag,and expanded clay, so packing density was improved and voids between the particles of aggregate were reduced. The significant improvement in workability required excess paste and it depended on the aggregate surface texture, shape, and gradation.

Mohammadi et al., (2015) conducted a study on the impact of silica fume with replacement percentages by binder (0-15)% on the SCLWC characteristics. SCLWC mixes contained expanded clay and perlite as aggregates. It was found that replacing and increasing silica fume dosage resulted in improving the SCLWC flowability and segregation resistance. Also, the workability of SCLWC incorporating expanded clay as aggregates was better than that of SCLWC containing perlite as aggregates.

Nahhab and Ketab., (2020) looked into how the maximum size of aggregate , the amount of light expanded clay aggregate (LECA) , and the volume friction of micro steel fibers affected the properties of SCLWC .They found that enlarging the maximum aggregate size led to a reduction in the fresh density of SCLWC, while a slight elevation in density was observed with a higher volume percentage of micro steel fibers .Increasing the fiber content decrease the value of fresh density .

In a study by **Pala et al., (2015),** the effects of incorporating limestone powder (LSP) and marble waste were examined in relation to the fresh and hardened characteristics of SCLWC containing cold- bonded fly ash aggregate. The inclusion of LSP necessitated an increase in the dosage of high-range water-reducing admixture (HRWRA) to achieve the desired slump flow.

2.4.3 Hardened Properties of SCLWC

An experimental investigation conducted by **(Sonia et al., 2016)** aimed at partially replacing the coarse aggregate in M25 grade concrete, with a mix design grounded in IS 10262:1982, with LECA. The creation of five distinct mixes, with replacement percentages ranging from 20% to 100%, demonstrated a linear decrease in the density and strength of the concrete as the replacement percentage escalated. The compressive strength of the concrete dipped below 25

N/mm2 when the coarse aggregate was replaced by 60%, while the concrete containing 100% LECA retained a strength surpassing 17 N/mm2, indicating its potential utility as a lightweight structural material.

Mehetr et al., (2014) studied the behavior of SCC when metkaolin (MK) and Cement Kiln Dust (CKD) were used as a mineral admixtures, By substituting cement with mineral admixtures (MK) and (CKD) at levels of 10%, 20%, and 30%, the impact of these additives on the fresh and hardened characteristics of SCC was assessed. Specifically, the investigation focused on the properties of SCC when 10% of cement was replaced with MK and CKD. a significant improvement in self- compact ability like passing ability, segregation resistance, filling ability and flowing ability of SCC was observed. The compressive strength, flexural strength and split tensile strength of SCC increased, when (MK) and (CKD) were used for 7 days to 28 days of curing, but maximum increasing happened at 10% replacement as compared to 20% and 30%.

Altalabani et al., (2020) studied the mechanical properties of SCLWC reinforced with polypropylene fibers. Compressive strength, splitting tensile strength, and flexural strength are measured at 28 days. The test results showed that the addition of fiber does not affect the compressive strength but has a slight effect on improving tensile strength. Impact resistance and bending properties showed the most significant improvement; this improvement is even more superior when macro and hybrid fibers have been added instead of single microfibers with greater improvement when higher macro fiber content is used in hybrid concrete samples.

Long, Wu Jian et al., (2013) FRSCC mechanical properties were investigated. Steel and polypropylene fiber improved the tensile strength of the concrete after 28 days, according to the test findings. After 28 days, the compressive strength of the concrete rises with the addition of steel fiber while decreasing with the addition of polypropylene fiber.

Mohamed, (2011) investigated the effect of using fly ash (FA) and silica fume (SF) with various percentages and combination of FA and SF together on SCC compressive strength. The results show that SCC with 15% of SF gives higher values of compressive strength than those with 30% of FA by about 12% for 550 kg/m3 cement content and 10% when cement content was 450 kg/. Also the results showed that the highest values of compressive strength were obtained, when SCC consisted of combination of FA and SF (10% FA and 10% SF).

The mechanical properties of fiber reinforced self compacting light weight concrete (FRSCLWC) were investigated by **(Ozel Gencel et al., 2011).** The findings from the tests demonstrated that the incorporation of polypropylene fiber led to a reduction in unit weight and an enhancement of the hardened properties of FRSCLWC. (**Hubertova and Hela, 2007)** proved that the compressive strength of SCLWC could be developed after 28 days when silica fume and metakaolin were added with a percentage of 10% from the weight of cement by 30% and 15%, respectively.

Corinaldesi and Moriconi, (2015) found that the SCLWC mixes reinforced with micro fibers showed 10% increase in compressive strength as compared to fiber-free SCLWC.

Gonen, (2015) found that the hybrid fibers (short and long micro steel fibers) performed better in terms of the compressive strength of SCLWC such that the compressive strength could be increased by up to 10% by adding long fibers, 20% by adding short fibers and 30% by adding hybrids.

Adding micro steel fiber to concrete generates a non- brittle substance (**Iqbal, Ali., et al., 2015).** In their study on SCLWC , they found that the tensile strength improved considerably by incorporating micro steel fibers though the compressive strength appeared to be decreased slightly. **(Lotfy, A., et al., 2016)** found that the best flexural strength values were recorded for a mix with coarse and fine furnace slag , while the lowest values for flexure strength were recorded for coarse and fine expanded clay.

Grabois et al., (2016), found that the tensile strength was found to be enhanced by 30 percent by adding steel fibers to the SCLWC mixes.

2.5 Structure Behavior of Concrete under Fire Exposure

Elevated temperatures are widely recognized for inflicting significant harm to the macroscopic and microscopic compositions of concrete. This leads to extensive mechanical deterioration and, in severe cases, contributes to structural issues such as concrete spalling. The chief cause of concrete degradation at high temperatures is attributed to the impairment of binders or aggregates. The influence of these factors on the mechanical characteristics of concrete under elevated temperatures has been previously studied **(Choi et al., 2017)**. According to **Kodur and Raut, (2010),** concrete exhibits the most superior fire-resistant properties among all construction materials. This exceptional fire resistance can be attributed to the chemical combination of its fundamental ingredients, cement, and aggregates, resulting in a virtually inert material Possessing low thermal conductivity, substantial heat capacity, and a gradual decline in strength when subjected to high temperatures, concrete effectively serves as a fire barrier. Its ability to impede heat transfer and mitigate strength reduction makes it capable of not only separating adjacent spaces but also safeguarding itself from the detrimental effects of fire. Exposing concrete to elevated temperatures caused by fire can result in significant structural defects. The consequences of elevated temperature exposure include a decrease in strength and the occurrence of cracking. Weakens, leading to the breakdown of the cement gel structure. As a result, the load-bearing capacity decreases, and the likelihood of drying shrinkage and structural cracking increases **(Handoo et al., 2002).** The deterioration in concrete strength due to elevated temperature exposure can be influenced by various factors such as the temperature level, rate of heating, heating duration, cooling method, applied load, type of aggregate, type of mineral admixture, and air humidity **(Bingöl et al., 2009).**

Fire causes defects in the building, subjecting concrete to elevated temperature under fire results in strength loss and cracking, it decreases the binding between cement paste and aggregate and causes the cement gel structure to break down, which reduces the load- bearing capacity and increases the likelihood of structural cracking and shrinkage (**Ibrahim, 2017).**

Concrete's exposure to elevated temperatures induces significant alterations in its physical structure and chemical composition. Dehydration occurs above 110℃, leading to the release of chemically bound water from calcium silicate hydrate, which in turn generates internal stresses due to matrix dehydration and aggregate thermal expansion. At temperatures exceeding 300℃, microcracks begin to form within the material. The crucial compound of cement paste, Ca(OH)2, dissociates at around 530℃, causing concrete shrinkage. These transformations in concrete's composition and structure can have significant implications for its overall strength and durability in high-temperature environments, at temperatures above 900°C, calcium silicate hydrate completely decomposes **(Demirel, Keleştemur, 2010).**

Fire can induce the loss of concrete's load-bearing capacity and heighten the risk of collapse due to the evaporation of entrapped water at high temperatures. Fires in residential and public buildings can reach temperatures up to 1000-1200℃, and over 1300℃ in industrial structures, persisting for several hours, leading to concrete chipping and flaking. Fire temperatures are often calculated indirectly by melting concrete materials **(Du, Wei, Lv, 2018).**

2.5.1 Spalling of Concrete under Fire Exposure

The occurrence wherein vapor pressure within concrete surpasses its tensile strength, leading to the detachment of concrete fragments from the surface, is known as fire-induced spalling. This phenomenon has the potential to diminish the load-bearing capability and fire resistance of concrete elements, as noted by **(Dwaikat, & Kodur, 2010).**

Phan (2007) indicated that the extent of spalling is impacted by a range of variables. These include factors like load magnitude, fire intensity, aggregate composition, relative humidity, the presence of silica fume, other additives, as well as properties such as strength, porosity, and density, all contributing to the overall effect.

Dwaikat and Kodur,(2009) pointed out that spalling is a property that, in addition to thermal, mechanical, and deformation qualities, has a major effect on the fire performance of a concrete structural part. This characteristic is specific to concrete and may be used to determine the fire resistance of a reinforced concrete structural part.

Dwaikat and Kodur, (2009) categorized fire-induced spalling in concrete members into three main stages: early spalling, intermediate spalling, and late spalling.

2.5.1.1 Mechanisms of Spalling

Moisture plays a crucial role in a classical approach known as the Moisture Clog Theory, which was formulated by **(Harmathy, 1993)**. According to this theory, when a concrete specimen is subjected to heating, the steam pressure within its pores increases near the surface. The pressure difference inside the specimen drives moisture towards thinner and colder areas, resulting in the condensation of steam when it encounters colder layers. This process continues, creating a fully saturated region of significant thickness, known as the "moisture clog," which hinders the inward movement of steam towards colder regions. Figure (2-5) illustrates this situation. The crucial point to note is that the inward experiences the highest pressure.

Pore pressure is a critical factor that can contribute significantly to the occurrence of explosive thermal spalling (**Bazant et al., 1997)** conducted an investigation into the hypothesis of restrained thermal dilatation of concrete. The spalling phenomenon occurs due to the constrained expansion of concrete near the heated surface, resulting in the formation of compressive stresses aligned with the surface, as illustrated in Figure (2-6).As these compressive stresses reach their limit, they are released through brittle fractures in the concrete, leading to the phenomenon known as spalling.

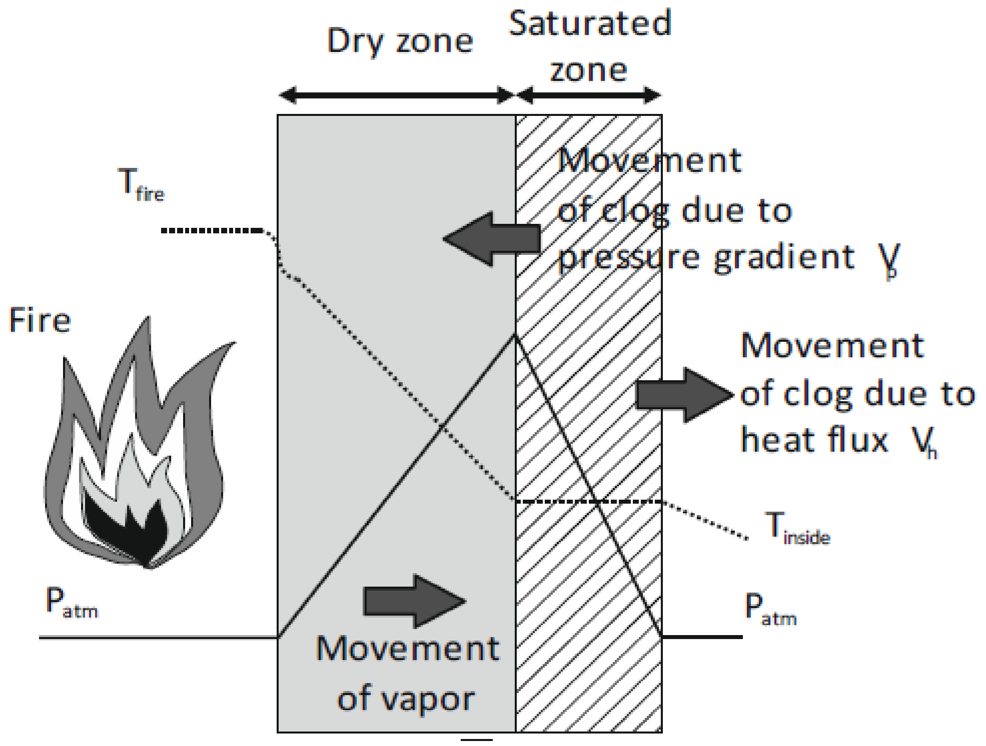

Figure (2-5): Moisture Clog Model for Spalling of Concrete **[Harmathy 1993]**

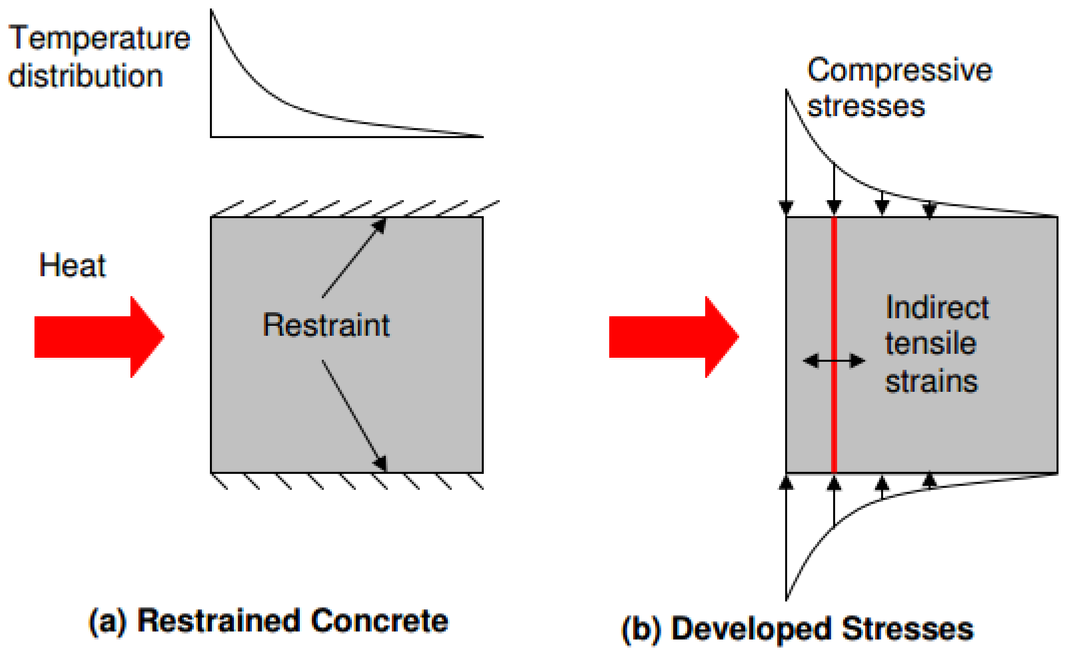

Figure (2-6): Illustration of Thermal Dilation Mechanism for Fire Induced Spalling **[Bazant et al., 1997]**

Ozawa et al., (**2012**) conducted research into mechanisms in high-strength concrete exposed to elevated temperatures. As the concrete surface temperature increases, it establishes a temperature gradient within the material, leading to the formation of compressive stresses parallel to the surface and concurrent development of perpendicular tensile stresses. Explosive spalling occurs when these tensile stresses exceed the concrete's tensile strength, as demonstrated in Figure [2-7a].

The second process encompasses the flow of liquid phases, which consist of liquid water, vapor, and dry air. As the temperature of the concrete surface increases, alterations in moisture content occur at varying depths from the surface, as illustrated in Figure [2-7b]. This causes vapor pressure to elevate, particularly at the interface between the vapor and humid zones, surpassing that in the dry and moist zones. At the pinnacle of vapor pressure, the heightened pressure within the concrete results in significant tensile stress. Consequently, this elevated tensile stress has the potential to trigger the phenomenon of concrete spalling. The concrete spalling happens due to the tensile stresses exceeding the material's tensile strength, causing it to crack and spall away. This phenomenon is particularly evident at and humid zone, where the vapor pressure reaches its highest level, triggering the potential for explosive spalling in the concrete **Ozawa et al., (2012).**

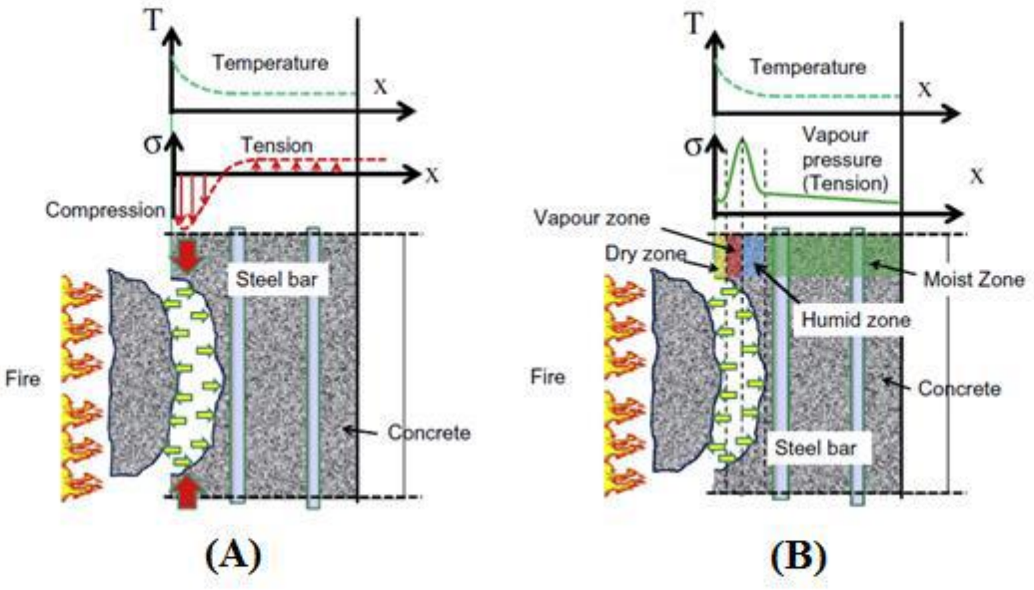

Figure (2-7) : Mechanisms of Spalling**[Ozawa et all 2012].**

2.5.1.2 Spalling Types

Concrete spalling at high temperatures can be categorized as follows, as proposed by **(Klingsch, 2014):**

a) Explosive spalling: violent breaking-off of concrete fragments at high temperatures.

b) Surface spalling: violent breaking-off of concrete layers at high temperatures.

c) Aggregate spalling: splitting of aggregates due to their decomposition or changes at high temperatures

d) Corner spalling: removal of concrete cover from corners, at high temperature due to the temperature impact from two sides.

e) Post-cooling spalling: non-violent breaking-off of concrete fragments during cooling.

f) Sloughing off spalling: non-violent breaking-off of concrete fragments after longer exposure to high temperatures.

2.6 Properties of Light Weight Concrete and Self compacting – Lightweight Concrete Exposed to Elevated Temperature

Lightweight aggregates are often produced by volcanic eruptions or cremation. Consequently, due to their low heat conductivity and high heat resistance, concrete incorporating these aggregates is expected to exhibit superior mechanical properties at elevated temperatures compared to concrete made with regular aggregates **(Jiang et al., 2013; Sancak et al., 2008; Turkmen & Findik, 2013; Yoon et al., 2015).**

Significant advancements have been made in understanding the high-temperature performance of SCLWC, particularly concerning spalling and residual mechanical properties, in a literature survey conducted by **(Lindgard and Hammer, 1998)** on the fire resistance of SCLWC, it was found that SCLWC poses a greater risk of spalling when compared to normal concrete (NC). This increased risk is attributed to SCLWC's elevated moisture content resulting from aggregates.

Lightweight concrete offers enhanced fire resistance compared to normal weight concrete due to its lower thermal conductivity, lower coefficient of thermal expansion, and the inherent fire stability of lightweight aggregates. However, when lightweight concrete, which includes fly ash and lightweight aggregates, is exposed to extreme temperatures of up to 800°C, its compressive strength experiences a significant drop **(Tanyildizi, Coskun, 2008).**

Akcaozoglu, (2017) conducted an experimental study on the effect of high temperature on lightweight concrete produced by expanded clay aggregate and calcium aluminate cement. The residual strength of the mixtures produced by the expanded clay aggregates was higher than that of the concrete produced by the natural aggregates.

According to **Tang, (2020)** in recent years, the usage of lightweight concrete has grown in popularity in concrete constructions. Fire is a devastating threat that may destroy concrete structures. This study assesses the influence of elevated temperatures on lightweight aggregate concretes. To conduct this analysis, three unique mixes of lightweight aggregate concrete were utilized to create a total of 81 cube-shaped specimens. After undergoing wet curing periods lasting 3, 7, and 28 days, these samples were subjected to ambient and elevated temperatures of 450°C and 650°C for duration of 2 hours. Alterations in sample weights before and after exposure to extreme temperatures were documented, and the resulting residual strength measurements were contrasted. The results highlight that increased temperatures lead to a reduction in strength and a noteworthy decrease in weight for lightweight aggregate concrete**.**

The researchers investigated the characteristics of LWC composed of cinder and LECA in 2015 (**Kumar& Prakash, 2015).** There was a reduction in weight and, respectively, a reduction in compressive strength by trying to replace coarse aggregate with mixed lightweight aggregates such as cinder and LECA, but they were able to use cinder and LECA as a replacement for normal coarse aggregate to reduce cost, while the compressive strengths were close to the strengths of NC. The average compressive strength for samples containing the previously indicated LWA was 39.2 N/mm2, whereas the average compressive strength for NC was 43.4 N/mm2. The LWC density ranged from 1800 to 1950 kg/mm3, whereas the NC density was 2637 kg/m3.

2.7 Effect of Fibers on SCC, LWC and SCLWC under Elevated Temperature

Choumanidis et al., (2016) investigated the flexural behavior of hybrid fibers -reinforced concrete. Their finding showed that combining fibers significantly increases residual tensile strength and toughness at elevated temperature, and the existence of steel fibers appears to offer the best post –cracking behavior.

Eldan et al., (2017) investigated the PPF concrete' s residual mechanical properties after being exposed to elevated temperatures. In that article , experimental findings on the residual mechanical characteristics of fiber reinforced concrete specimens exposed to high temperatures are presented .The study encompassed various parameters such as compressive and tensile strength, elastic modulus, and cracking modes. Seven sets of concrete mixes were investigated, comprising six series of PPF-reinforced concrete and one series of plain concrete samples. Following exposure to varying heating temperatures, the results revealed that PPF concrete demonstrated superior performance in comparison with plain concrete at elevated temperatures.

Uysal and Tanyildizi, (2012) conducted research on the impact of polypropylene fibers in high-temperature conditions on SCC mixed with various fillers like granulated ground blast furnace slag, fly ash, and limestone powder. They observed that SCC with polypropylene fibers exhibited reduced weight loss. However, a greater decrease in ultrasonic pulse velocity for SCC with polypropylene fibers indicated the generation of more microcracks after exposure to high temperatures.

Tang, (2020) investigated the impact of single and mixed fibers on the mechanical properties of lightweight aggregate concrete (LWAC) after being exposed to elevated temperatures. The research considered four test parameters, namely concrete type, concrete strength, fiber type, and target temperature. Following exposure to 400 °C, the residual mechanical properties of all samples remained unimpaired due to the drying effect of the higher temperatures and the more effective cement wetting reaction. However, after being exposed to 800 °C, there was a significant reduction in the mechanical residue characteristics. Generally, the fiber-reinforced mixed LWAC exhibited better resistance to the loss of mechanical properties caused by high temperature. It was observed that the flexural strength was relatively more affected compared to the compressive strength loss.

Aslani et al., (2019) conducted a study to investigate the utilization of lightweight aggregates known as scoria, for enhancing the strength-to-weight ratio and cost efficiency of SCLWC. In this research, SCLWC was produced by incorporating fibers, specifically polypropylene and steel, in varying proportions. The effects of different fiber types and ratios were examined concerning unique properties such as slump flow and J loop. Mechanical performance after hardening (compressive and tensile strength at 20 °C), and at high-temperature (compressive and tensile strength, mass loss, and spalling) were examined. The study determined the optimal fiber ratios to be 0.25% for polypropylene fiber and 0.75% for steel fiber, offering a balanced combination of new properties along with high-temperature resistance and improved hardening properties**.**

It has been proposed that incorporating 1.5 kg/m^3 of 12.5 mm- long PPF could prevent spalling with a low water-to-cement (w/c) ratio in concrete. Moreover, the compressive strength of SCC was notably improved by using 0.1% PPF, and the optimal results for splitting tensile strength, impact resistance, and heat resistance were achieved with 0.3% PPF (**Karimipour et al., 2020).** The combination of fibers significantly boosts residual tensile strength and toughness at elevated temperatures, whereby the presence of steel fibers appears to provide the best post cracking behavior **(Bozkurt, 2014).**

Zween, (2008) studied the performance of LWC containing fibers exposed to high temperatures. The results showed that after exposure to 600°C, the residual compressive strength of LWC was about (50-72) percent of the room temperature strength.

2.8 Mineral Admixtures

Mineral admixtures are finely divided materials added to cement mortar and concrete to achieve specific engineering properties of concrete. They serve multiple essential purposes, including obtaining desired properties, economic benefits, and environmentally safe recycling of industrial and other waste by-products. Unlike chemical admixtures, mineral admixtures are used in relatively larger quantities, often replacing cement and/or fine aggregates in concrete.

In the past, natural pozzolans, such as volcanic earths, tuffs, trass, clays, and shales, in either raw or calcined form, have been successfully utilized in the construction of various structures, including aqueducts, monuments, and water-retaining structures. These mineral admixtures have proven to be valuable in improving the performance and durability of concrete while also contributing to sustainable and eco-friendly construction practices.

While natural pozzolans continue to be utilized in certain regions, industrial waste by-products like fly ash, slag, silica fume, red mud, and rice husk ash have increasingly become the primary sources of mineral admixtures for cement and concrete in recent years **(Concrete Admixtures Handbook, 1996).**

The incorporation of mineral admixtures also eliminates the need for viscosity-enhancing chemical admixtures. The lower water content of the concrete leads to higher durability, in addition to better mechanical integrity of the structure. It is also known that some mineral admixtures may improve rheological properties and reduce thermally-induced cracking of concrete due to the reduction in the overall heat of hydration and increase the workability and long-term properties of concrete **(Dinakar P et al., 2008).**

2.8.1 Fly Ash

Fly ash (FA) is a residual product derived from the incineration of coal powder within thermal power plants. Through the combustion of coal, it undergoes exposure to elevated temperatures within the furnace. During this heightened thermal state, a majority of metal impurities like quartz, clay, and feldspar dissolve, while the carbon undergoes combustion. Subsequently, the resultant molten substance is swiftly moved to a region of lower temperatures, where it undergoes rapid cooling and solidification into spherical glassy particles.

One of the key characteristics of fly ash is its very smooth, spherical, and small particle size compared to cement particles. The diameter of fly ash particles typically ranges between 10 to 25 μm, while cement particles range between 10 to 100 μm. The smoothness of fly ash particles enhances the fluidity and workability of concrete mixes, making the mixing process faster and easier.

Furthermore, fly ash exhibits pozzolanic properties, It has the capability to interact with Ca(OH)2, an undesired secondary compound formed during cement hydration, resulting in the creation of (C-S-H), a favorable cementitious compound. This fly ash and calcium hydroxide enhances the strength and longevity of concrete, rendering it a valuable addition to the cement hydration process.

Fly ash is renowned for its significant physical characteristics, including the pozzolanic reaction, hardness, fineness, uniformity, and alkali reactivity. These properties play a crucial role in engineering research when selecting and accepting fly ash, as they ensure that the chosen fly ash will deliver the desired and predictable performance in concrete. The pozzolanic reaction of fly ash is particularly essential, as it enables the material to react with calcium hydroxide produced during cement hydration, forming calcium silicate hydrate, which contributes to the strength and durability of the concrete **(Helmuth, 1987)**.

Increasing the percentage of cement replacement with fly ash doesn't increase the required mixing water for the desired slump in concrete due to the higher surface area of fly ash particles. Instead, fly ash enhances workability by introducing glassy spherical particles that act as lubricants, reducing the need for additional water. This leads to a more cohesive and easier-to-work-with concrete mix. Incorporating fly ash or materials with fine particles in the mix results in a sticky and workable concrete, observed in research by **(Tikalsky et al., 1989).** The glassy and spherical nature of fly ash particles reduces water demand, improving the workability and manageability of the concrete mix.

Adding of FA to SCC mixes leads to improve its workability with reducing water demand due to small spherical shape of FA **Koehler and Fowler (2007)**. FA can disperse the agglomeration of cement particles because of its spherical shape (**Nehdi et al., 2004)**.

According to **Lane and Best ,(1982),** the pozzolanic reaction of FA can take one year to increase compressive strength 50% with compared to 30% for concrete without FA. **Bouzoubaa and Lachemi, (2001)** reported that using of FA generally improves workability and delays strength development in SCC and reduces superplastisizer amount to obtain slump flow, when it compared with concrete made with plain cement only. Figure (2-8) depicts the scanning electron microscope of fly ash.

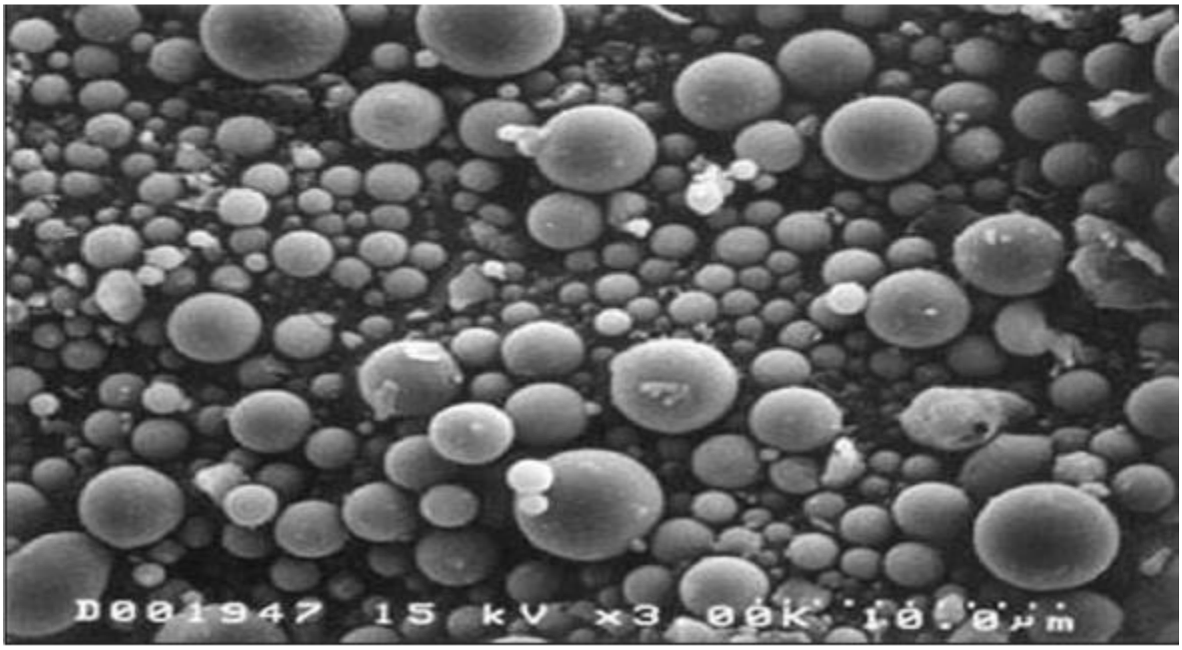

Figure (2-8) Scanning Electron Microscope Micrograph of Fly Ash Particles at 2000X **(Federal Highway Administration 2006)** .

2.8.2 Metakaolin

Kaolin is a fine, white clay material. That has been traditionally used in the manufacture of porcelain **(Chiad, 2009)**. Kaolin is primarily the mineral Kaolinite, a hydrous aluminum silicate having the chemical formula (Al2O3.2SiO2.2H2O). Under normal environmental condition, kaolin is quite stable, when kaolin is heated in the range of 650 to 850, it is converted to metakaolin (Al2O3.2SiO2), and it loses 14% of its mass, because this heat treatment or calcination destroys the structure of kaolin so that the alumina and silica layers lose their long-range order and water is driven off, and metakaolin exhibits pozzolanic properties (**Al-Soadi, 2002)**.

$$AL_2O_3.2SiO_2.2H_2O \xrightarrow{\text{Heating}} AL_2O_3.2SiO_2+2H_2O \quad ....(2\text{-}1)$$

According to ACI 232.1R-00, the amount of kaolinite included in the original clay material specifies the reactivity of metakaolin .

Using of metakaolin which it has plate-like particles increases the inter-particles friction, thereby decreasing the slump flow **(Justice, 2005)**. Figure (2-9) illustrates electron microscope micrograph of metakaolin particles at 2000X.

Hooton et al., (1997) used metakaolin with replacement percentages of 8 to 12% by weight of cement at 0.4 to 0.3 water-cementitious materials ratio (w/cm), the researchers noticed that this greatly improved the compressive strength at all ages.

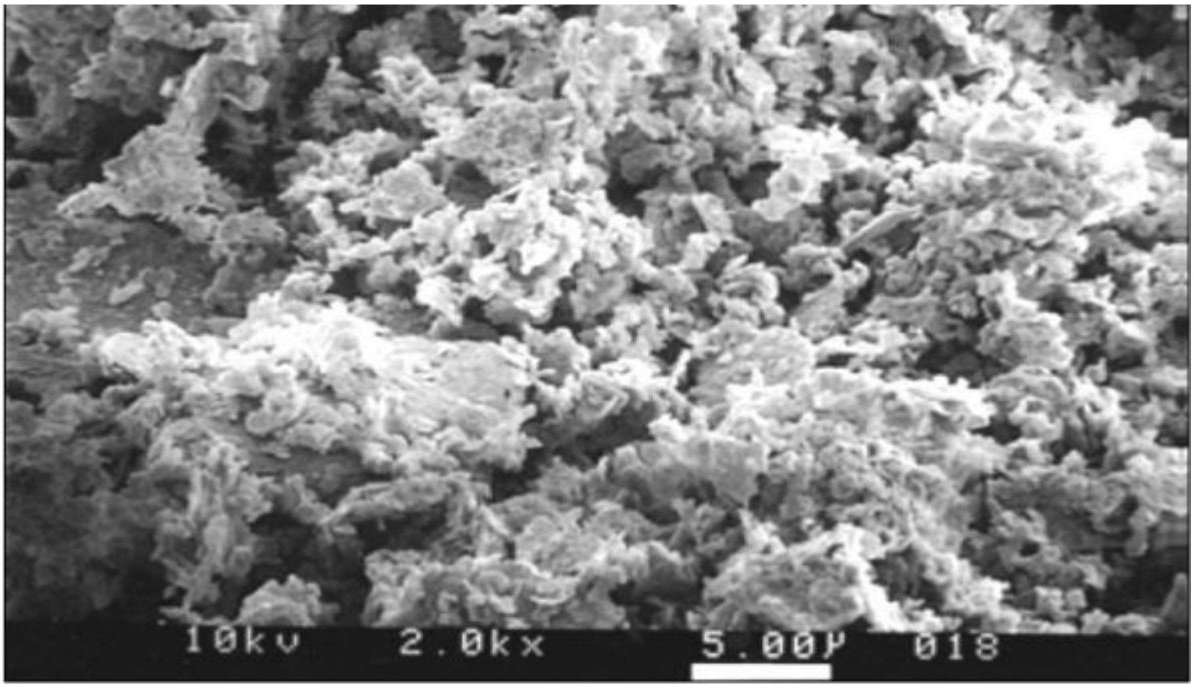

Figure (2-9) Scanning Electron Microscope Micrograph of Metakaolin Particles at 2000X **(kosmatka et, al 2003)**

2.8.3 Silica Fume

Referred to as condensed silica fume or microsilica, silica fume is an ultra-fine pozzolanic substance obtained as a by-product during the manufacture of silicon or ferro-silicon alloys. Typically, silica fume comprises around 5 to 10 percent of the overall cementitious components employed in concrete. The incorporation of silica fume can be stipulated in accordance with the **ASTM C 1240 (AASHTO M307)** guidelines.

When enhanced durability is a priority, incorporating silica fume in concrete can effectively reduce the permeability of the material, leading to a slower penetration rate of aggressive chemicals such as deicing salts. As a result, the use of silica fume has been shown to yield rapid chloride permeability values of less than 500 when tested in accordance with **ASTM C1202 (AASHTO T277)** guidelines.

Benefits are:

• Reduce permeability,

• Improve bonding within the concrete,

• Improve resistance to corrosion,

• Can reduce alkali-silica reactivity (ASR),

• Increase compressive and flexural strengths, and

Applications are:

• High-strength structural columns,

• Low permeable parking garage decks, and

• Abrasion resistant hydraulic structures.

2.9 Effect of Pozolanic Material on Concrete under Elevated Temperature.

Abdelmelek and Lublog (2020) investigated the impact of temperature increases up to 900 °C on the mechanical characteristics of high strength cement paste at the age of 90 days . Using different metakaolin replacement percentages (by weight of cement) up to 15%. Each temperature was set for two hours . Results have shown that matakaolin improve the properties of high strength cement paste' s resistance to temperature elevation.

Yigang et al., (2000) researched the impact of fly ash and curing methods on the properties of high temperature concrete. Their findings suggest that concrete samples manufactured with fly ash have a higher residual strength at temperature more than 650 °C.

In the cited study by **Abed Al-wahab, (2011),** SCC with high-reactivity metakaolin (MK) as a partial replacement for cement exhibited superior residual compressive strength compared to regular SCC when exposed to 800 °C. The residual compressive strength of MK-enhanced SCC at that temperature was 73.2% of the original strength, while regular SCC only retained 65% of its original strength. Moreover, the reduction in the modulus of rupture (a measure of flexural strength) at 800 °C was more significant than the reduction in compressive strength. This highlights the potential advantage of incorporating high-reactivity MK in SCC, as it improves its resistance to high temperatures and helps maintain its mechanical properties, particularly in terms of compressive strength.

Poon et al., (2001) conducted a study on high-strength concrete (HSC) incorporating up to 20% silica fume (SF) and examined its performance after exposure to elevated temperatures. They observed that SF concrete experienced a more severe loss of compressive strength and reduced durability related to permeability compared to FA concrete and normal concrete after exposure to high temperatures .This led to the conclusion that the presence of pores is the primary weakness in the hardened properties.

According to **Syed KAZ, (2020)** Mineral admixture-containing concretes are widely utilized across the world because to their great performance, and the impacts of high temperatures on such concrete are also attributable to its characteristics. As a result, an experimental investigation was conducted to investigate the compressive behavior and physicochemical properties of concrete subjected to high temperatures. The tests were carried out on regular Portland cement concrete cubes that had been added with 10% and 20% fly ash by weight of the concrete. The cubes were therefore subjected to raised temperature in a furnace with a temperature range of 100-600 °C and tried before heating by ultrasonic testing and direct compression testing. The cubes tests were performed using a differential calorimeter to observe the progressions under various elevated temperatures. The outcome

Hertz KD, (2003) investigated concrete with SF replacements comprising 14-20% of the cement mass and found that such concrete is highly susceptible to spalling and cracking at high temperatures. The findings revealed that the relative residual compressive strength at 450 °C and 600 °C was 88% and 73%, respectively, which is approximately twice as high as that of pure ordinary Portland cement pastes

2.10. Concluding Remarks

From the previous researches, it can be easily noted that there are considerable experimental studies that have studied the mechanical properties of self-compacted lightweight concrete at elevated temperatures and some of them concern the mechanical properties of hybrid fiber reinforced SCLWC exposed to elevated temperatures. However, the previous studies of the properties of lightweight self-compacting concrete reinforced with fibers under the influence of a fire flame according to the ISO-834 standard fire curve are very limited, and the study of the impact of replacing pozzolanic materials as percentages of cement weight on the performance of lightweight self-compacting concrete after exposure to a real fire flame has not been investigated so far.

This study endeavors to interrogate the fire resistance properties of self-compacting lightweight concrete (SCLWC) made with lightweight expanded clay aggregate (LECA) as coarse aggregate reinforced with Steel Fibers (S) and Polypropylene Fibers (PPF) with different type of mineral admixtures.

CHAPTER THREE

EXPERIMENTAL WORK

3.1 INTRODUCTION

In this chapter, an elaborate account is presented regarding the experimental design and the materials employed in this study. Furthermore, comprehensive elucidation is provided concerning the techniques employed for fabricating specimens of Self-Compacted Lightweight Concrete (SCLWC), encompassing their blending, molding, conditioning, and examination. The chapter also encompasses comprehensive insights into the testing apparatus utilized in this research, along with their methodologies, contributing to a comprehensive perspective on the testing protocols. To achieve appropriate concrete production, stringent measures in material selection, control, and proportion of the overall material have been used. The experimental study extensively elaborates on the origins of materials, their characteristics, and their physical attributes. These materials were subjected to necessary tests within the laboratories of the Civil Engineering Department at Babylon University's Faculty of Engineering.

3.2 Experimental Program of the Research

This research's experimental exploration comprised two phases. During the initial stage, the process encompassed the selection and preparation of materials, along with the conduction of physical and chemical tests on the materials employed in this study. This was carried out to ascertain their viability as potential replacements for cement in concrete mixtures. Afterward this stage also explains the concrete mix proportions of materials, mixing method, casting, curing and laboratory tests method, for SCLWC. Laboratory testing was carried out to show the difference in behavior that occurs in the fresh and hard state.

Among the tests that were carried out in the fresh state are (slump flow (D (mm), and T500), L-box test, and V-funnel tests), after that the concrete mixtures were poured into molds prepared for this purpose and cured in water for (28, 56) days. After reaching the required ages, the hardened testes were made the concrete samples, represented by dry density, compressive strength, splitting tensile strength, flexural strength and ultrasonic pulse velocity (UPV).

The second stage consists of the burning process to study the impact of high temperatures on the SCLWC specimens without and with mineral admixtures as a substitution material 10% by weight of cement in SCLWC encompass (silica fume(SF), fly ash(FA) and metakaolin(MK)) as well as containing micro steel fibers in the percentages of (0.25%) and (0.5%), and hybrid fibers (steel + polypropylene) in different proportions (0.25+0.15) and (0.5+0.15) for fire exposure at (60 minutes) after reaching the required ages (28,56 days).The outline of the experimental work is summarized in Figure (3-1).

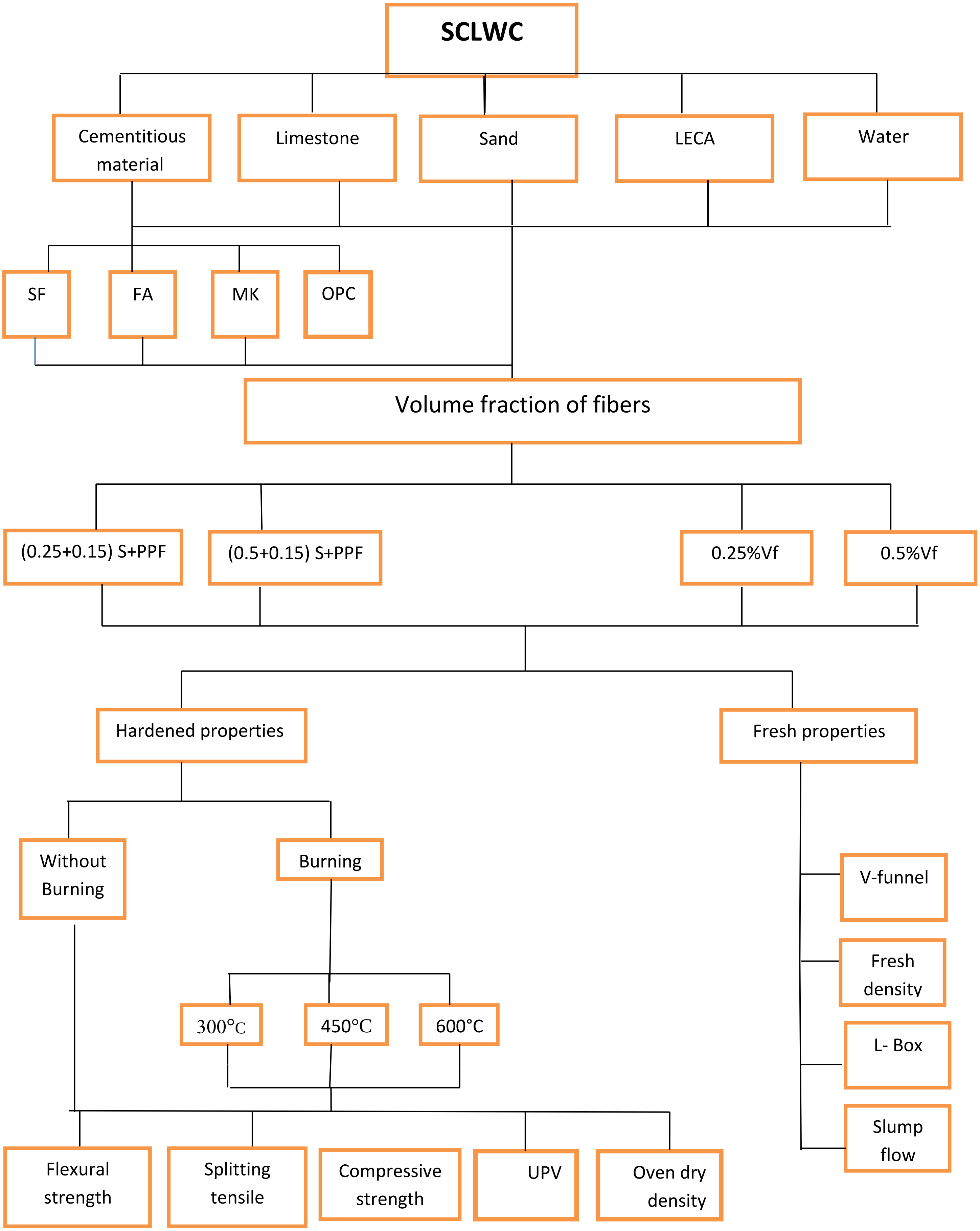

Figure. (3-1) Flow chart for experimental work program

3.3 Selection of Materials and Basic Characteristics

Comprehending the attributes and qualities of the constituent elements within concrete holds significant importance. As a composite substance, concrete comprises a variety of constituents including. These individual components possess unique traits like, gradation, and moisture content. To ensure optimal concrete production, a meticulous process is employed for material selection, precise control, and proportioning of the entire mixture. This experimental investigation provides comprehensive insights into the supplies, physical attributes, and chemical compositions of the utilized materials. The fundamental features of these components are outlined as follows:

3.3.1 Cement

In this research, ordinary Portland cement type 1(AL MASS), conforming to **(IQS 5/2019)** standards, with a high early strength class 42.5R (IQS5-CEM1 42.5R) was employed. To shield the cement from fluctuating atmospheric conditions, it was kept in a dry setting. The chemical analysis and physical results conducted on the cement in use are detailed in Table (3-1) and (3-2) respectively.

Table (3-1): Chemical Composition and Main Compounds of Al Maas Cement.

Chemical Composition	**Percentage %**	**Limit of IQS No.5/2019**
CaO	64.78	----
SiO_2	22.1	----
Al_2O_3	4.78	----
Fe_2O_3	3.19	----
MgO	1.76	$\leq$ 5%
SO_3	2.45	2.8 % if C_3A › 5%
L.O.I.	1.78	$\leq$ 4%
I.R.	0.21	$\leq$ 1.5%
L.S.F	0.94	(0.66-1.02)%
Main compounds (Bogue's equation)		
(C_3S)	53.57	---
(C_2S)	23.01	---
(C_3A)	7.28	---
(C_4AF)	9.70	---

* The experiment was conducted in the laboratories of the Civil Department at Babylon University, College of Engineering.

Table (3-2): Physical Properties of Al Maas Cement.*

Physical Properties	Test result	Limit of IQS No. 5: 2019
Specific Surface Area (Blaine Method) cm^2/g	3250	≥ 2800
Setting Time (Vicat's Apparatus)		
Initial Setting, (min)	185	≥ 45
Final setting, (min)	235	≤ 600
Compressive strength at:		
2 days (MPa)	24.0	≥ 20
28 days (MPa)	42.6	≥ 42.5

* The experiment was conducted in the laboratories of the Civil Department at Babylon University.

3.3.2 Fine Aggregate

There are important factors that should be taken into consideration when producing self-compacting concrete, which are the amount of fine aggregate, grading, and the shape of the particle. In this study, natural sand available locally from the Al-Akhaider area was used. The grading of fine aggregate used is shown in Table 3.3 and Figure 3.2, while the physical properties of fine aggregate are shown in Table 3.4. Through the results, it was found that the used fine aggregate is located within the third gradient zone, and conforms to Iraqi standards **(IQS No. 45/1984)** and has fineness modulus (2.4).

Table (3-3): Fine Aggregate Test Result

Sieve size(mm)	Passing %	IQS No.45/1984, zone 3
9.5	100	100
4.75	97	90-100
2.36	85	85-100
1.18	76	75-100
0.6	60	60-79
0.3	18	12-40

0.15	0	0-10

*test was conducted by the construction material laboratory in civil Engineering University of Babylon

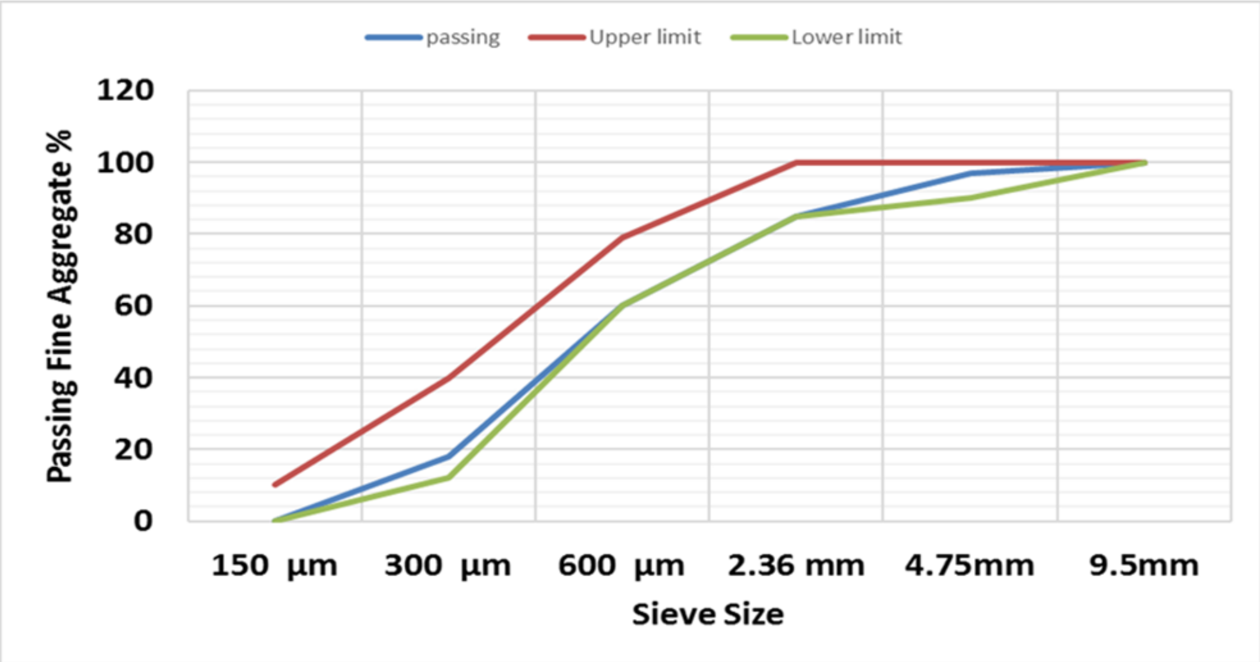

Figure (3-2): Sieve Analysis of Fine Aggregate Zone (3).

Table 3-4: The physical and chemical properties of fine aggregate

Physical Properties		
Properties	**Test results**	**Iraqi specification No. 45/1984**
Specific gravity	2.65	---
Absorption	0.92%	---
Fine material passing from sieve (75µm)	2.5%	≤ 5.0%
Fineness modulus	2.4	---
Chemical properties		
Sulfate content	0.352%	≤ 0.5%

3.3.3 Lightweight Expanded Clay

Lightweight expanded clay aggregate (LECA) was utilized with regular sizes of between 0.475 cm and 1 cm, which was brought from the north of Tehran, Iran. This type of lightweight aggregate is characterized by porous ceramic materials with uniform, small, closed-cell pores, as well as tightly sintered and strong exterior surfaces. LECA is made from raw materials of clay minerals which are burned in rotary kilns at a temperature ranging between 1100 and 1200° C thus leading to an increase in the volume of particles significantly as a result of swelling. Table (3-5) provides requirements for (**ASTM C330,2017)** for gradation of lightweight aggregate along with the test results of LECA used herein while Table (3-6) describes its chemical and physical characteristics. Lightweight expanded clay (LECA) are illustrated in Plate (3-1)

Table 3-5: Grading of LECA Course Aggregate.

Sieve Size (mm)	Cumulative passing %	Limits of ASTM C330, 2017
12.5	100	100
10	100	80-100
8	79	-
6	46	-
4.75	5	5-40
2.36	2	0-20
`1.18	0	0-10

Table 3-6: Physical and Chemical Properties of LECA*.

Physical Properties	
Specific Gravity	**1.26**
Absorption	**12%**
Bulk density Kg/m3	**700**

Table 3-7: Chemical Composition of LECA

CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	L.O.I.	TiO_2	MnO_2	Na_2O	K_2O
3.78	61.58	16.99	7.62	2.56	2.45	0.2	0.8	0.1	1.03	2.34

*Chemical tests were conducted from LECA factory, IRAN.

As shown in Plate (3-1a) LECA was immersed in water for at least 48 hours, in order to prevent absorbing water by LECA during mixing because of its high-water absorption capacity. As in Plate (3-1b), the LECA spread in laboratory conditions until the surface became dry so that the aggregate had the saturated and surface dry condition (SSD).

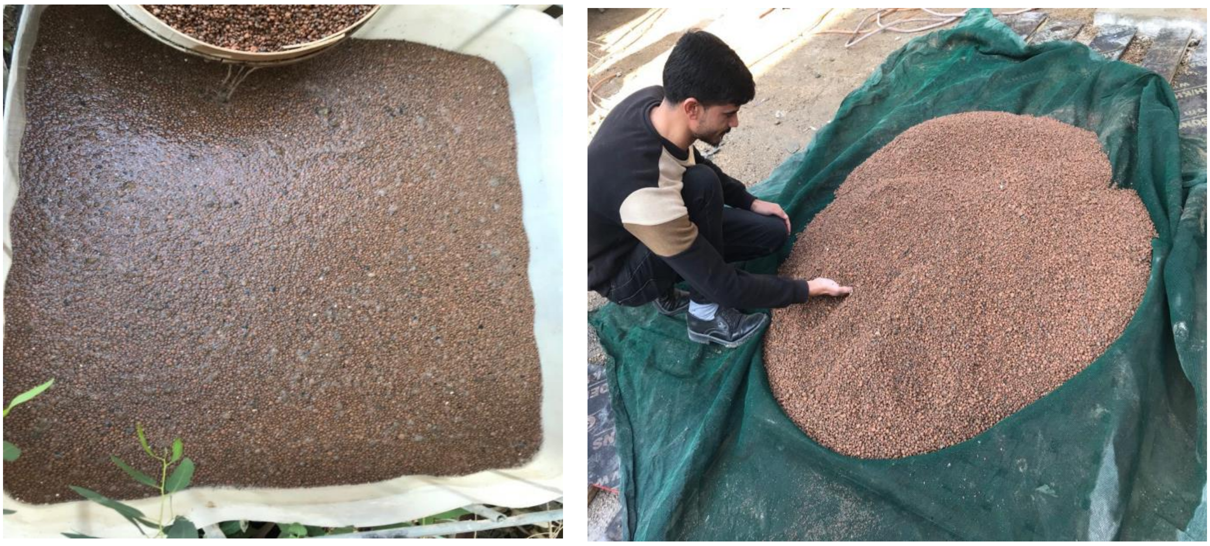

Plate (3-1): (a) LECA was soaked in water; (b) LECA was drained in the laboratory air.

3.3.4 Limestone Powder (LSP)

Limestone powder, known locally as "Al-Gubra" was brought from the 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 avaılable in Iraq. A fine powder of limestone utilized in this research was ground by blowing method so that the particle size was smaller than 0.0125 cm as recommended by **EFNARC (2005).**

Table (3-7): Chemical Analysis of the limestone powder

Oxide	Content (%)
CaO	54.6
Fe_2O_3	0.16
Al_2O_3	0.03
SiO_2	3.20
MgO	0.56
SO_3	0.64
L.O.I	43.6

*Chemical analysis was conducted by the Karbala construction laboratory.

3.3.5 Mineral Admixtures

3.3.5.1 Silica fume (SF)

Silica fume is a finely textured, non-crystalline form of silica that is generated as a by-product during the production of elemental silicon or alloys in electric arc furnaces. Emerging from the furnace gases, this possesses a notably high concentration and comprises minuscule spherical particles typically falling within the diameter range of 0.1 to 0.2 μm. Originally seen as a cement replacement, silica fume has evolved to become a key player in formulating high-performance concrete, where its incorporation enhances the properties of the concrete. Currently, the foremost application of silica fume is in the creation of concrete. With augmented compressive strength and exceptional levels of durability, as underscored by **ACI 234R (2006).**

Plate (3-2) displays the silica fume applied in this study, commercially identified as Mega Add MS (D) and procured from the chemical firm (CONMIX). In this research, it was employed as a partial replacement, constituting 10% of the cement's weight. Silica fume imparts greater durability to the cement paste's microstructure, bolstering its resistance to diverse. The chemical composition of the employed is documented in Table (3-8), while its physical specifications are outlined in Table (3-9). The findings affirm that the

SF utilized in this investigation aligns with the stipulations of **(ASTM C1240, 2015).**

Plate (3-2): silica fume

Table 3-8: Silica Fume Chemical Analysis*.

Oxide composition	Oxide content %	ASTM C1240-15 limitations
SiO_2	89.31	Min. 85%
Al_2O_3	0.62	-
Fe_2O_3	0.46	-
CaO	0.81	< 1
SO_3	0.88	< 2
K_2O+Na_2O	1.36	-
L.O.I.	4.12	Max. 6%
CI	0.19	-
CaO (free)	2.15	-

Table 3-9: Physical properties of silica fume used.

properties	**Result**
Strength activity index at 7 days	135%
Percent retained on 45 µm (No.325) sieve, max, %	1.4
specific surface area (m^2/g).	24

3.3.5.2 Metakaolin(MK)

In contrast to mineral admixtures like fly ash, silica fume, and slag, metakaolin distinguishes itself by not being a result of an industrial process. Instead, it is deliberately manufactured for specific purposes within closely monitored conditions. The production of metakaolin involves subjecting kaolin, a naturally abundant clay mineral, to temperatures ranging between 650-900°C. This controlled heating process, known as calcination, leads to the structural breakdown of kaolin. This process leads to the elimination of bound hydroxyl ions and introduces disarray within the alumina and silica layers, resulting in an exceptionally responsive and non-crystalline material exhibiting both pozzolanic and latent hydraulic reactivity. Such attributes render it suitable for various cementing applications. Obtained from Al-Mohandis Technical scientific Bureau Baghdad/Iraq. The chemical analysis of the MK used is depicted in Table (3-10). Plate (3-3) shows the MK utilized in the present study.

Table (3-10) Chemical analysis of Metakaolin

Chemical Composition	Percentage By Weight
$SiO2$	51.2%
Al_2O3	45.3%
Fe_2O3	0.60%
MgO	—
CaO	0.05%
Na_2O	0.21%
K_2O	0.16%

SO3	—
LOI	0.51%
Activity	
7d activity index	84
28d activity index	94

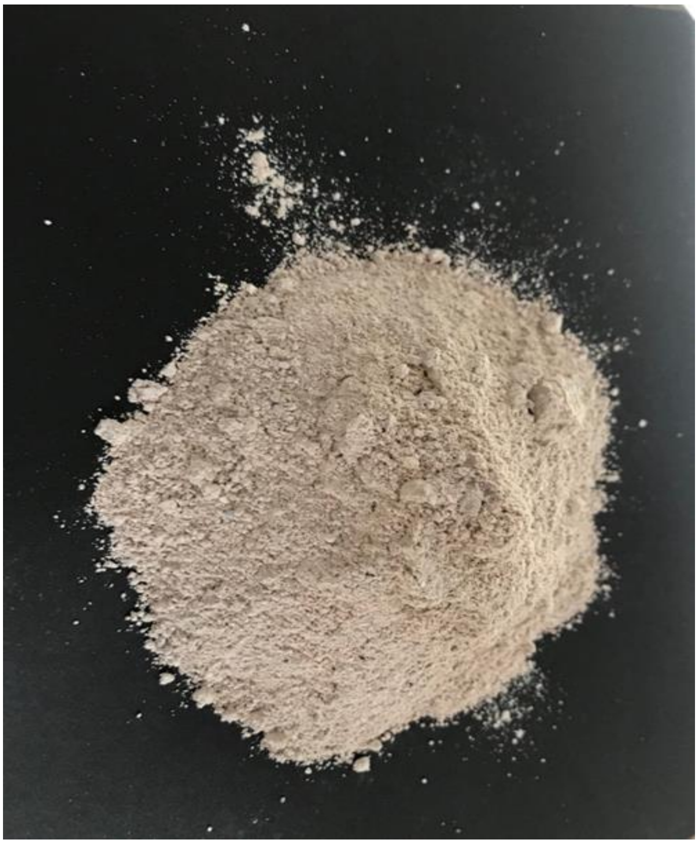

Plate (3-3) Metakaolin used in this study

3.3.5.3 Fly Ash

Fly ash that utilized in this study was an imported material, it was imported from chain, fly ash was classified according to **ASTM C 618 (2015)** as type F fly ash where, the sum of SiO_2+ Al_2O_3+Fe_2O_3 is greater than 70% as well as CaO content is lower than 10%. Tables (3-11) and (3-12) depict physical properties and chemical composition of imported fly ash utilized throughout this study.

Table (3-11) Physical Properties of Fly Ash

Property	Result	Limits of ASTM C 618-03
Specific gravity*	2.4	-
Specific surface, m2/kg*	685	-
Percentage of material remaining after wet sieving through a 45µm (No. 325) .*sieve	16.2	<34
strength activity index , % , at age 7 days 28 days	126.5 135.82	≥ 75 ≥ 75

Table (3-12) presents the Chemical Characteristics of Fly Ash.

Oxide Composition	Oxide Content %
SiO_2	61.3
CaO	2.21
MgO	2.3
SO_3	0. 31
Al_2O_3	25.68
Fe_2O_3	4.64
L.O.I	3.32

3.3.6 High-Range Water Reducing Admixture (Super-Plasticizer) (SP)

GLENIUM® 54 from Basf Company was used throughout this study. Distinguishing itself from typical superplasticizers, it stands out as it relies on an exclusive carboxylic ether polymer featuring extended side chains. This distinctive characteristic greatly improves the distribution of cement. During the initial stages, it elevates on the cement particle's surface, aiding in the cement dispersion through electrostatic repulsion. GLENIUM 54 demonstrates exceptional performance due to the lateral chains attached to the polymer's core, creating steric hindrance that enhances the stability of the cement particles, enabling effective separation and dispersion. It satisfies the requirements of **ASTM C494 (2017) F**

Table (3-13): Technical Description of GLENIUM® 54 *

Chemical Basis	Water-based solution of altered polycarboxylate.
Boiling	100°C
Products of potentially harmful decomposition (Reactions with hazards).	No hazardous reactions known.
Odor	None
Colour	Whitish to straw colored liquid
Relative density	1.07 kg/It.
pH	5-8
Level of chloride.	None
Storage	Shielded from direct sunlight and safeguarded from freezing at temperatures ranging from +5°C to +35°C.

*Manufacturer Properties

3.3.7 Fibers

3.3.7.1 Steel Fiber

Dramix straight-shape steel fibers shown in Plate (3-4) were used in this study. Tables (3-14) and (3-15) show the characteristics of these fibers as given by the manufacturer.

Table (3-14) Displays the Composition of Chemicals of the Micro Steel Fiber.

Composition of chemicals.	Composition (%)
Carbon	(0.80)
Manganese	(0.75)
Phosphorus (P)	(0.035)
Sulfur	(0.045)

*Characteristics of the manufacturer.

Table (3-15) presents the properties of Micro Steel Fibers.

Density	7825 Kg/m3
Tensile Strength	2400MPa
Melting Point	1500°C
Length	13 mm
Diameter	0.2mm
Aspect ratio (L/D)	65

*Characteristics of the manufacturer.

3.3.7.2 Polypropylene Fiber

Micro polypropylene fibers were also utilized throughout the experimental program as shown in Plate (3-4). The properties of the used micro polypropylene fibers are presented in Table (3-16).

(a)Polypropylene fiber **(b) steel fiber**

Plate (3-4): (a, b) Sample of Micro steel and polypropylene fibers used in this study

Table (3-16) The characteristics of polypropylene fibers.

Shape	Straight
Length	12 mm
Diameter	0.018 mm
Aspect ratio (L/D) Density	666.66 910 kg/m3
Tensile strength	300-400 MPa
Melting point	165C°

3.3.8 Water

The mixing water used for mixing and curing was normal tap water from the domestic water supply. So it was clear of residual and organic materials that could have impacted the concrete properties.

Table (3-17) Mix Proportion of SCLWC Material kg/m3 – SP by wt. of cement

Mix. Code		Cement	Lime stone	Water	SP	Sand	W/c Ratio	LECA	Silica Fume	Fly ash	Meta Kaolin	Fibers S	PP
SCLWC	Normal SCLWC	480	70	175	1.45	820	0.36	373	-	-	-	0	0
SCLWC0.25S		480	70	175	1.45	820		373	-	-	-	19.56	0
SCLWC0.5S		480	70	175	1.9	820		373	-	-	-	39.1	0
SCLWC(0.25S+0.15PP)		480	70	175	1.6	820		373	-	-	-	19.56	1.36
SCLWC(0.5S+0.15PP)		480	70	175	2	820		373	-	-	-	39.1	1.36
10SFSCLWC	10%Silica fume	432	70	175	1.6	820	0.36	373	48	-	-	0	0
10SFSCLWC0.25S		432	70	175	1.6	820		373	48	-	-	19.56	-
10SFSCLWC0.5S		432	70	175	2	820		373	48			39.1	0
10SFSCLWC0.25S+0.15PP		432	70	175	2	820		373	48			19.56	1.36
10SFSCLWC0.5S+0.15PP		432	70	175	2.4	820		373	48			39.1	1.36
10FASCLWC	10%Fly ash	432	70	175	1.4	820	0.36	373		48		0	0
10FASCLWC0.25S		432	70	175	1.4	820		373		48		19.56	0
10FASCLWC0.5S		432	70	175	1.6	820		373		48		39.1	0
10FASCLWC0.25S+0.15PP		432	70	175	1.6	820		373		48		19.56	1.36
10FASCLWC0.5S+0.15PP		432	70	175	1.9	820		373		48		39.1	1.36
10MKSCLWC	10% Metakaolin	432	70	175	1.6	820	0.36	373			48	0	0
10MKSCLWC0.25S		432	70	175	1.6	820		373			48	19.56	0
10MKSCLWC0. 5S		432	70	175	2	820		373			48	39.1	0
10MKSCLWC0.25S+0.15PP		432	70	175	1.9	820		373			48	19.56	1.36
10MKSCLWC0. 5S+0.15PP		432	70	175	2.4	820		373			48	39.1	1.36

3.4 Mixtures Proportion for Self-Compacting Lightweight Aggregate.

Because there is no standard procedure for designing such materials, achieving the fresh and hardened qualities of self-compacting lightweight concrete (SCLWC) needed several experimental mixes with varied proportions of components. The finest plain combinations were chosen from these trails' blends based on fresh qualities and compressive strength

As shown in Table (3-17), twenty SCLWC mixes were produced in this study. SCLWC mixes were divided into four groups according to the type of mineral admixtures which is replaced by (10%) of the mass of cement namely, without, silica fume, fly ash and metakaoline respectively. Each group contains five mixes. First mix was without fibers, second and third mixes were reinforced with steel fibers with percentages of (0.25% and 0.5%) by volume respectively. Fourth and fifth mixes were reinforced with hybrid fibers (steel + polypropylene) with percentages of (0.25% +0.15%) and (0.5%S+0.15 %) by volume of concrete.

A code was given for each mixture, as an example the code for the fourth mix in the second grope is 10SFSCLWC0.25S+ 0.15PP where SCLWC designate lightweight self-compacting concrete, 0.25S and 0.15PP represent the volume fraction proportion of steel and polypropylene fibers respectively, and 10SF represent the percentage replacement of silica fume by weight of cement.

3.5 Mixing Procedure

Depending on the previous mixing methods in global research, **(Güneyisi, E., 2015)** the mixing procedure steps were done as follows: Initially, the dry components comprising cement, limestone powder, sand, and coarse aggregate (LECA) were blended until a uniform dry mixture was attained. Subsequently, one-third of the required mixing water was introduced and re-mixed for approximately one minute. The remaining portion of the mixing water was subsequently added, along with the entire quantity of superplasticizer.

Finally, micro steel or polypropylene fibers if any were added gradually as seen in Plate (3-5). While mixing and the process continued for about 3 minutes more. The mix was left for 2 minutes to rest before pouring fresh concrete into the molds

3.6 Specimens of Concrete.

Criterion specimens of concrete were cast to investigate the properties of SCLWC before and after exposure to fire flame. Subsequently the details of samples clarified in points

1- Three cubes (100×100×100 mm) were cast in the same manner as for each mix to test Compressive strength, ultrasonic pulse velocity, and oven dry density
2- To test Splitting tensile strength of concrete were cast (cylinder of100mmx200mm)
3- To test Flexural tensile strength were cast (prisms of 100x100x400mm)

3.7 Casting and Curing of Specimens

The molds and the interior surface were cleaned and oiled to avoid cohesion after the hardening of the concrete. Then the samples were wrapped with a sheet of polypropylene in the lab for about 24 hours and then the samples were demolded accurately and soaked in water of curing for 27 and 55 days. These processes are shown in Plate (3-6).

Plate (3-5) add Micro- steel fiber (after adding all ingredients of concrete mixture) gradually during mixing

A **B**

(C)

plate (3-6): A: Molds, B: casting, C:de-molding process.

3.8 Test Methods for Fresh Concrete

3.8.1 Slump flow

The slump test is used to assess the deformability of SCC in the absence of obstacles. This test serves the purpose of assessing filling ability by gauging the horizontal flow diameter, as well as determining mix viscosity by measuring the duration required for SCC to achieve a 500 mm flow distance. Because of the simplicity of this test, segregation resistance can be detected visually. The slump test can be done with an inverted or upright Abram's cone either in situ or in the laboratory. The cone is put on flat steel has a leveled and non-absorbing surface with at least 900 mm x 900 mm plane area, filled with SCC, and lifted to a height of 15 to 30 mm in 2 to 4 sec; under the influence of gravity, SCC flows out.

The recorded values are for two diameters, d1 and d2, which are both perpendicular and horizontal to each other as shown in Figure (3-3). The average diameter of flow spread, SF, is then computed using the equation provided below:

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)

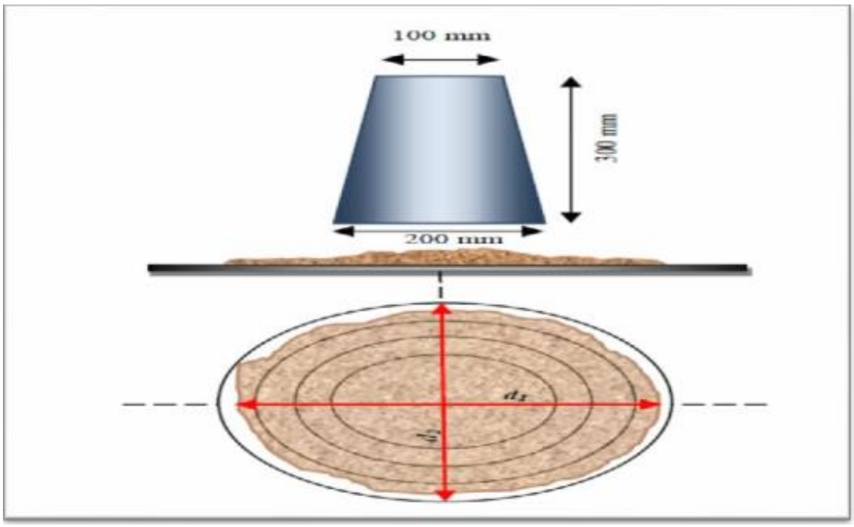

Figure (3-3) Slump Flow Test

Plate (3-7) Slump Flow and T50cm Tests Performance in Study.

3.8.2L-BoxTest

The test is used to evaluate the capacity of SCC to stream through narrow holes such as spaces between reinforcement and other obstacles without separation or blockage. This was performed by the process outlined at **EFNARC,(2005)**, using an L-shaped box with a gate at the vertical part and 3 ϕ12 smooth bars as shown in Fig. (3-4) and plate (3-8).

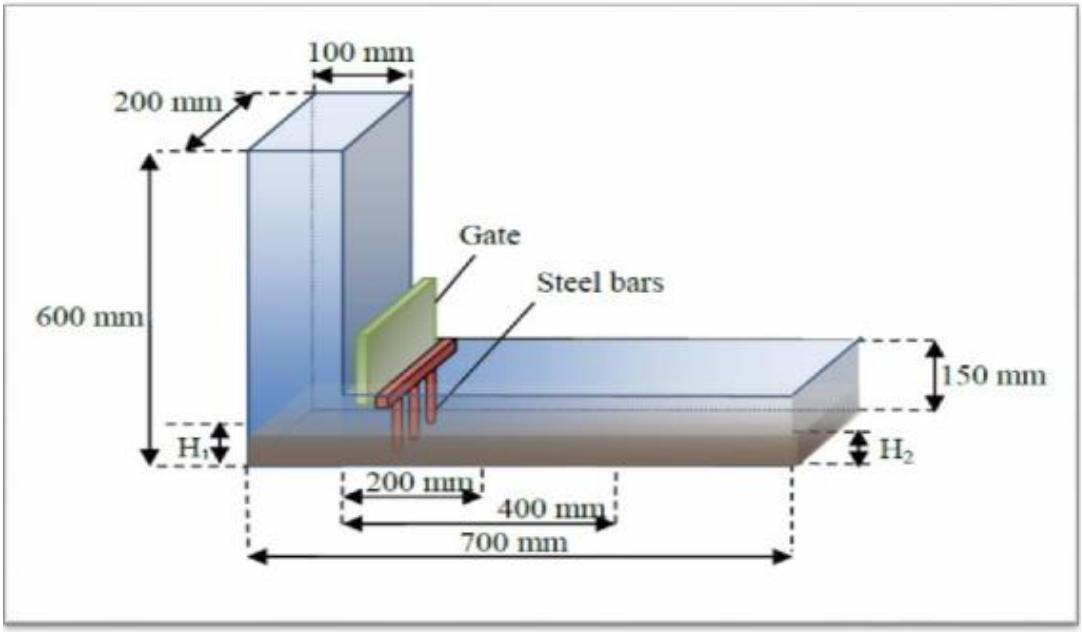

Figure (3-4) L-box

Once the box was moistened, the fresh concrete was poured into the vertical segment of the L-box and allowed to settle for duration of 1 minute. Subsequently, the slide gate was raised, enabling the concrete to flow through the horizontal section of the L-box. The concrete's height was then measured at two distinct positions: firstly, at the commencement of the horizontal segment (H1), and secondly, at the termination of the same segment (H2).

Plate (3-8) L- Box Test Performance

3.8.3 V-funnel Test

The V-funnel test is designed to evaluate the filling ability and viscosity of SCC. The test was performed according to (EFNARC, 2005), by means of apparatus having the dimensions shown in Fig. (3-5) and Plate (3-9)

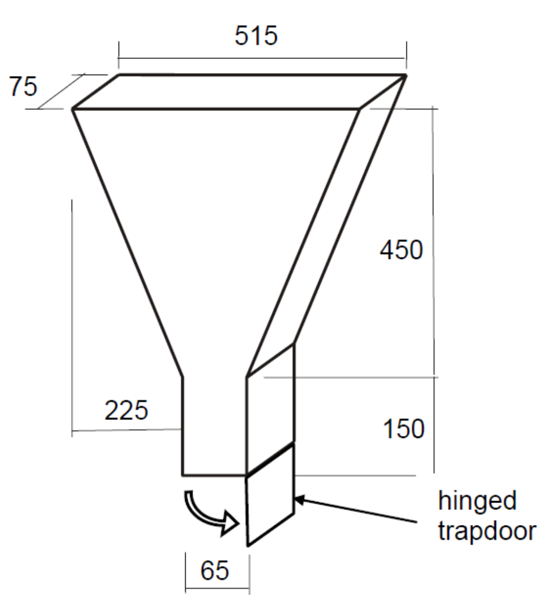

Figure (3-5) v-funnel

Plate (3-9) V-funnel test performance.

3.8.4 Fresh Density

Fresh density, also known as unit mass or unit weight in air is calculated by dividing the total mass of all the fresh constituents of concrete by the volume occupied by the concrete. The measurement of fresh unit weight is typically taken immediately after pouring, as depicted in Plate (3-10).

Plate (3-10) Fresh Density Measuring

3.9 Testing of Hardened of Self-Compacting Lightweight Concert

3.9.1 Compressive Strength Test

The compressive strength was an established measure that represents one of the important concrete engineering properties that could provide an overall picture of the quality of concrete. In order to measure the compressive strength, three cubes (100×100×100 mm) were cast in the same manner as for each mix of SCLWC and the average value of these cubes were attained according to **(BS EN12390-Part 3:2019).** The testing machine for compressive strength is shown in Plate (3-11). The compressive strength test was determined by crushing three cubes at the ages of 28 and 56 days using a digital testing.

Plate (3-11) Compressive Strength Testing.

3.9.2 Splitting Tensile Strength

Splitting tensile strength test was conducted following the guidelines of **ASTM C 496/C 496M – 2004.** For every mixture, three cylindrical concrete specimens measuring (100x200 mm) were prepared at the ages of 28 and 56 days. These specimens were subjected to continuous loading until failure. Two plywood bearing strips, each measuring 3 mm in thickness, 25 mm in width, and 200 mm in length, were positioned above and below the specimen. Positioned within the bearing blocks of an electrical testing apparatus with a capability of 2000 kN, the specimen was placed, as illustrated in plate (3-12). Each mix's average splitting tensile strength was determined based on three cylinders. The computation of splitting tensile strength was accomplished by employing the subsequent formula:

$$T = \frac{2P}{\pi l d} \quad \text{--------------------} \quad (3\text{-}2)$$

where:
T: Tensile strength in splitting (MPa),
P: Peak load in splitting test (N),
d: Cylinder diameter (mm),
L: Cylinder length (mm).

Plate (3-12) Test for Tensile Strength in Splitting.

3.9.3 Flexural Strength

The flexural tensile strength of concrete was measured on prisms of 100x100x400) mm using a digital testing machine of 2000kN capacity. The flexural strength of the prisms was tested using the third point loading according to the ASTM specification **ASTM C78/C78M – 2018** at the ages (28 and 56) days as shown in Plate (3-13). The average flexural strength of three prisms for each mix and age was recorded.

The modulus of rupture is determined using the straightforward formula for beam bending:

a. When the fracture originates on the tension surface within the middle third of the span length, the calculation is as follows:

$R = PL / bd^2$ -------------------- (3-3)

Where:

R = modulus of rupture, (in MPa)

L = span length, (in meters)

P = maximum applied load, (in N)

d = average depth of the specimen, (in mm)

b = average width of the specimen, (in mm)

b. If the fracture occurs on the tension surface beyond the middle third of the span length, but within a margin of 5% of the span length, then:

$R= \frac{3Pa}{bd2}$ ------------- (3-4)

a= average distance between line of fracture and the nearst support measured on the tension surface of the prism (mm).

Plate (3-13): Flexural Test.

3.9.4 Ultrasonic Pulse Velocity Test (U.P.V)

The ultrasonic pulse velocity (UPV) method involves assessing the propagation of stress waves by measuring the travel time of ultrasonic pulse waves across a predetermined path length. These pulses are introduced into the concrete using a piezoelectric transducer, and a similar transducer functions as a receiver, detecting the surface vibration generated by the pulse's arrival **(Bissonnette, et al., 2018).** A timing circuit (t) is employed to gauge the duration taken for the pulse to journey from the transmitting to the receiving transducers along the material path (L). Calculating the pulse velocity (V) involves dividing the path length (L) by the transit time (t). The presence of low-density or cracked concrete prolongs the travel time, resulting in a decreased pulse velocity

(Camara, et al., 2019). This procedure was carried out following the **ASTM C597 (2002)** standard.

Plate (3-14): Ultrasonic Pulse Velocity Test.

3.10 Fire Test Furnace Description

This furnace is designed to generate typical conditions, such as temperature and heat transfer, to which concrete might be exposed during an actual fire incident. The furnace possesses internal measurements of 2200 mm in length, 450 mm in width, and 650 mm in height. The furnace's floor and wall insulation consist of a tri-layer configuration comprising distinct refractory materials, as depicted in Figure (3-6). This configuration guarantees accurate thermal insulation and consistent conditions within the furnace **(Ahmed .H 2022).**

The wall thickness in all sides is fixed at 136 mm, the main structure is made of thermal bricks and mortar with a small opening to provide the necessary fresh oxygen for the burners, and the furnace cover is made of an insulator plate with thickness of 8 mm to keep the temperature constant as described in Figure (3-6). The burner network consists of three lines, one in the bottom and one in each lateral side. All methane burners were connected together to an electrical regulator which connected to two valves controlling the discharge of gas coming from oxygen and methane bottles. The aim of the fire-flame bars was to simulate the heating condition in a realistic fire. The full details of the burning process and burning furnace with all connections are shown in Plate (3-15).

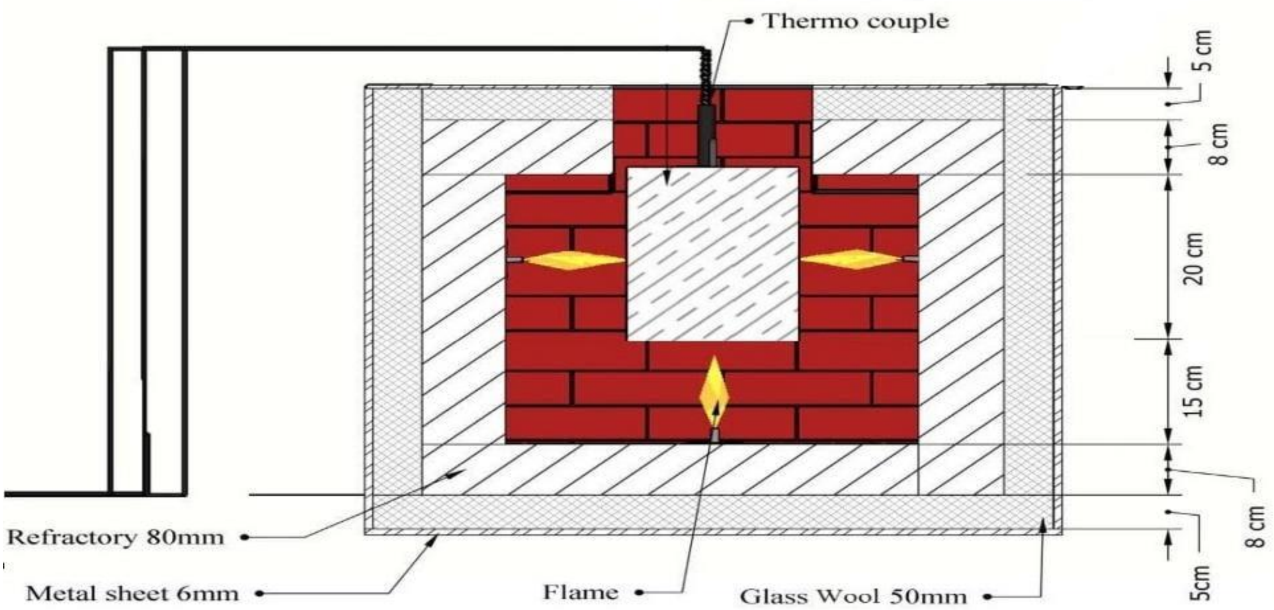

Figure (3-6) Furnace Floor and Wall Insulation.

Plate (3-15) Site Burning Furnace Details

The main goal of the fire flame stove is to raise the temperature of concrete specimens to the required degree and sustain this temperature consistently for the needed duration. To manage fire exposure along with axial pre-loading, the combustion process involves employing the following apparatus:

1. Brick furnace.
2. Network of methane burners.
3. Thermocouple.

4. Electrical gas regulator control.
5. Digital gauge.
6. Electric power supply.
7. Gas connections and pipelines.
8. Cover made of steel for the furnace.
9. Ignition tool.

3.10.1 Thermocouple

A thermocouple functions as a temperature-sensing component made up of two wire legs constructed from dissimilar metals. These wire legs are enclosed within a metal tube, known as the thermocouple cover. They are joined together at one end to create a junction where temperature is measured. When this junction is exposed to temperature variations, it generates a voltage, which can then be translated into a temperature reading. Typically, a thermocouple is linked to a thermometer or a compatible thermocouple device (in this particular study, a digital gauge was used). This connection is established through a thermally insulated electrical wire designed to withstand high temperatures during the heating process. Plate (3-16) offers comprehensive specifications for both the thermocouple and the digital gauge.

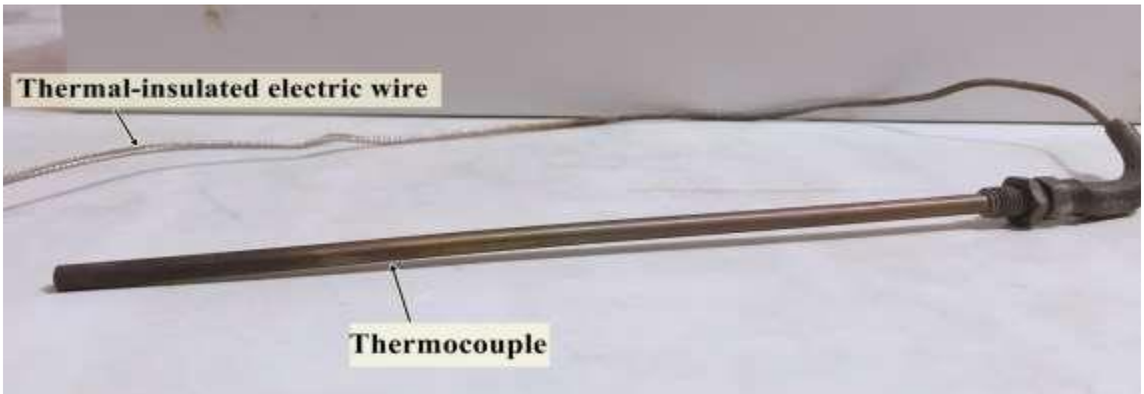

Plate (3-16) Thermocouple Details

3.10.2 Digital Temperature Controller

This device manages the internal temperature of the oven by directing the gas regulator to open and close in response to the temperature detected within the oven by the sensor. This adjustment aligns with the temperature degree set by the user upon installation. Initially, the gas valve is opened before turning on the electricity for the purpose of opening the burners; the existing flame in the burners is controlled by this valve manually for the purpose of keeping the flame existing inside the burners. Then electricity is turned on to start the firing, as the regulator feeds the oven with the amount of gas needed to ignite.

If the temperature inside the oven is higher than the desired temperature value, the control output is de-energized (regulator gas is turned off). If the temperature inside the oven is smaller than the desired temperature value, the control output is energized (regulator gas is turned). Plate (3-17) shows the digital temperature controller, the upper reading represents the current temperature while the lower reading represents the desired temperature.

Plate (3-17): Digital Temperature Controller Details.

3.10.3 System for Electric Gas Regulation and Ignition-Burning.

The gas regulator device, an electronic valve meticulously designed for precise and rapid control of gas flow to furnace burners, operates through a sophisticated mechanism. An electronic circuit continuously evaluates gas injection pressure in relation to a predefined temperature reference, thereby regulating gas flow to uphold the desired temperature. This modulation is achieved by manipulating the gate's position, either opening or closing it. The electronic gas regulator is linked to a digital gauge, ensuring gas delivery harmonizes with the specified temperature parameters. These interconnections empower the burners to maintain a consistent ignition system, ensuring the flames endure throughout the firing process. The ignition apparatus remains active even during instances of gas locking, ready to reignite combustion once the temperature falls below the set threshold. Plate (3-18) visually represents the electrical gas regulator and ignition combustion system.

Plate (3-18) The Electrical Gas Regulator

The study involved subjecting the samples to different temperatures (300, 450, and 600 °C) for a duration of 1 hour. The ultrasonic pulse velocity ,compressive strength, and oven dry density were tested using three cubes, while the splitting tensile strength was tested using three cylinders and flexural tensile strength was tested using three prisms at each temperature level and for each mix. Additionally, three reference samples were used for each test in each mix, which were maintained at room temperature (25 °C).

The furnace temperature closely adheres to the ISO 834 fire curve, showing minimal variation of under 10% until the desired temperature (600 °C) is attained. To regulate the digital temperature controller, an electric gas regulator equipped with thermocouples was linked to a digital gauge.

The initial segment of the fire curve in Figure (3-7) exhibits a resemblance to the standard fire curve up to 600°C. Following this, the specimens were subjected to one-hour duration at the maximum temperature (300, 450, and 600°C). Subsequently, the samples underwent controlled cooling within the laboratory environment. It is important to note that the experimental curve's heating rate and the peak temperature of fire exposure are lower compared to the ISO-834 recommendations, attributed to the constraints of the available equipment. Plate (3-19) visually displays the specimens before the combustion process, while the burning process of specimens is illustrated in Plate (3-20).

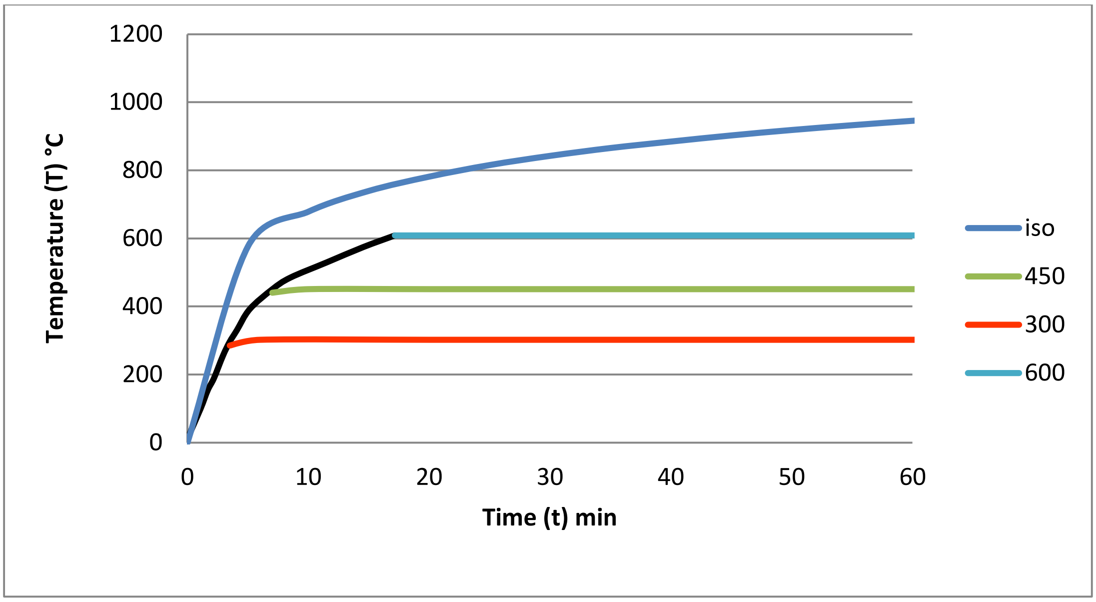

Figure (3-7) Displays the Temperature-Time Curves Recommended by the ISO-834 Standard and Those Obtained Experimentally.

A B

Plate (3-19) Specimen Before Burning Process

Plate (3-20): The Burning Process of SCLWC Specimen.

3.11 Oven Dry Density

The oven dry density of SCLWC was determined according to **ASTM C1754 / C1754M – 12**. The oven dry density was determined by drying the specimens at 100±2 0C for 24 hrs. Then they were weighed (W0). So, the value of such property was calculated from Eq. (3-5). W0=**ρ**dry/V--------------------(3-5)

Where**:** ρ dry (kg/m3)

W0:dry weight(kg)

V: Volume (m3)

CHAPTER FOUR

EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the experimental outcomes obtained through testing the specimens. The examined experimental parameters included the fiber type and quantity utilized in each mixture. The volume dosages of steel fibers (SF) and polypropylene fibers (PPF) were (0.25%, 0), (0.5%, 0), (0.25%, 0.15%), (0.5%, 0.15%) respectively and mineral admixtures (silica fume, fly ash and metakaolin) were used at the same replacement percentage by weight of cement 10%. Which were also making comparisons to conventional plain concrete, the comparison of properties and behavior includes workability, unit weight, spalling, weight loss, compressive strength, splitting strength, flexural strength and ultrasonic pulse velocity. Discussion and results obtained from the experimental tests are introduced.

4.2 Fresh Properties of Self-Compact Light Weight (SCLWC)

4.2.1 Slump flow

The slump flow of the mixes examined in this study is influenced by the dosage of superplasticizer (SP). This is due to the fact that the concrete paste is formulated with various types of fibers and mineral admixtures, each exhibiting distinct morphology and rheological behavior. Thus, maintaining a consistent dosage of SP becomes a complex task. A uniform SP dosage can lead to insufficient spreading in one mixture while causing segregation in another. As an alternative, the design of SCLWC mixes aimed to achieve a consistent target slump flow value of 700-725 mm. According to **(EFNARC 2005)** guidelines, a deviation of ±80mm from the target slump flow value is permissible. The specific SP dosages and the results of the slump flow test for all mixes are detailed in Table (4-1) and visualized as a histogram in Figure (4-1).

Table (4-1) Fresh Properties Results of Mixtures.

Mixes	Slump flow(mm)	SP% by weight of cement	T500 mm	V-funnel sec	L-box hight ratio	Fresh density Kg/m^3
SCLWC	725	1.45	3.5	18	0.94	1890
SCLWC0.25S	718	1.45	3.65	21	0.92	1903
SCLWC0.5S	711	1.9	3.9	22	0.9	1921
SCLWC(0.25S+0.15PPF)	716	1.6	3.75	22	0.91	1905
SCLWC(0.5S+0.15PPF)	709	2	4	23	0.88	1922
10SFSCLWC	715	1.6	4.2	20	0.92	1849
10SFSCLWC0.25S	707	1.6	4.5	22	0.91	1861
10SFSCLWC0.5S	701	2	4.7	24	0.9	1879
10SFSCLWC0.25S+0.15PP	700	2	4.2	22	0.9	1863
10SFSCLWC0.5S+0.15PP	702	2.4	4.5	25	0.87	1881
10FASCLWC	725	1.4	3.65	19	0.95	1865
10FASCLWC0.25S	720	1.4	3.8	21	0.93	1880
10FASCLWC0.5S	715	1.6	4	23	0.91	1894
10FASCLWC0.25S+0.15PP	720	1.6	3.8	21	0.92	1881
10FASCLWC0.5S+0.15PP	717	1.9	4	24	0.9	1897
10MKSCLWC	720	1.6	3.9	20	0.93	1872
10MKSCLWC0.25S	713	1.6	4.2	21	0.92	1888
10MKSCLWC0. 5S	707	2	4.5	23	0.9	1903
10MKSCLWC0.25S+0.15PP	710	1.9	4	22	0.9	1890
10MKSCLWC0. 5S+0.15PP	705	2.4	4.5	24	0.88	1904

Based on Figure (4-2), it can be observed that mixes with fibers have less slump flow results in comparison with the reference mix without fibers. Actually, to maintain a slump flow within the range of 700-725mm a higher dosage of SP was used for mixes with fibers. For example, the dosage of SP used in plain SCLWC mix was 1.45% by weight of cement to get a slump flow of 725 mm, while for SCLWC (0.5S+0.15PP) mix, the dosage of SP was 2% by weight of cement to get a slump flow of 709 mm. This is because, during the mixing process, the movement of aggregates caused the fibers to disperse and open up into a network of linked filaments, which were then mechanically anchored to the cement paste, as reported in the literature **(Karimipour . A et al., 2020).** For the 10SFSCLWC and 10MKSCLWC mixes, the dosage of SP increased to (1.6%) by weight of cement compared with the SCLWC mix (1.45%) , because they have plate-like particles with a high surface area, which increased water requirement to get the same slump flow. While the dosage of SP in 10FASCLWC reduced to 1.4% by weight of cement. The spherical shape of fly ash (FA) particles contributes to their lower surface area and water absorption, which makes it easier for them to slide over each other. As a result, a lower dosage of SP is required to achieve the same slump flow target value compared to the SCLWC mix. The values of slump flow for the mixtures that contained mineral admixture and fibers together ranged between (702-715, 717-725 and 705-720) mm respectively, for mixes containing SF, FA and MK respectively.

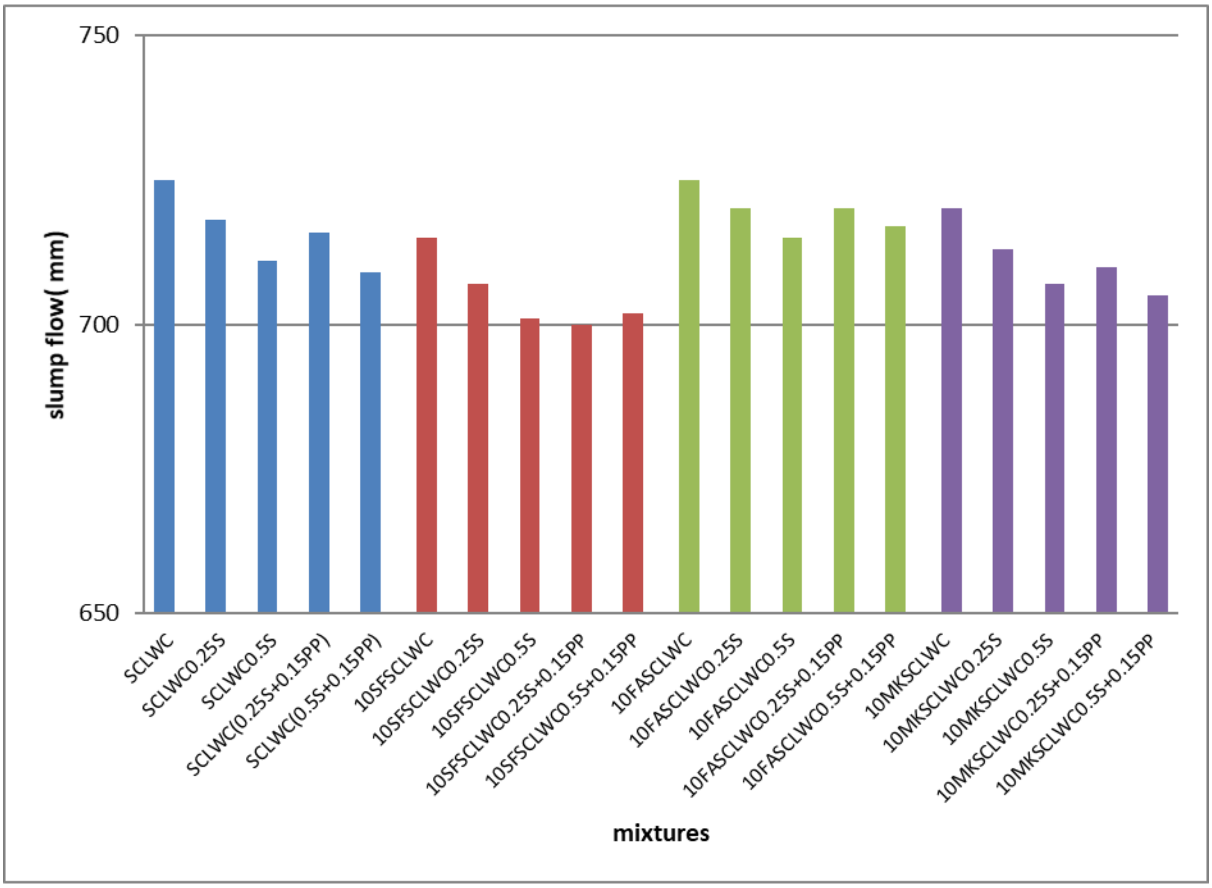

Figure (4-1) Slump Flow for SCLWC Mixes

4.2.2 T500 mm

This test gives an indication about flow ability and viscosity of SCLWC mixes. High viscosity of SCLWC reduces segregation and bleeding and makes SCLWC more stable, while low viscosity leads to segregate its ingredients. The outcomes for T500 mm are presented in Table (4-1), unequivocally demonstrating that all findings fall within the stipulated acceptance standards of EFNARC 2005. Figure (4-2) presents the values of T50cm of all mixtures. It can be observed from this figure that the addition of fibers increased the T50cm values, indicating an increase in the viscosity of the SCLWC. For instance, the SCLWC (0.5SF+0.15PPF) mixture had a T500mm value of 4 s; compared with the plain SCLWC mixture which had a value of 3.5 seconds. This increase in viscosity can be attributed to the greater interlocking and friction that occurs between particles in mixtures containing fibers, as reported by **(Liu, X., Wu et al., 2019).** Mixtures incorporating mineral admixtures exhibited a greater T500 mm value compared to the reference mix (SCLWC) because all these mineral admixtures have a lower density than cement, so adding them to concrete as a partial replacement percentage by weight of cement led to increase paste volume. Accordingly, the cohesiveness and viscosity of paste will increase (ACI 232.1 -96). The highest value noticed for mix 10SFSCLWC was (4.2sec) while for mixes 10FASCLWC and 10MKSCLWC were 3.7 and 3.9 sec respectively, because of lower density causes a high increase in paste.

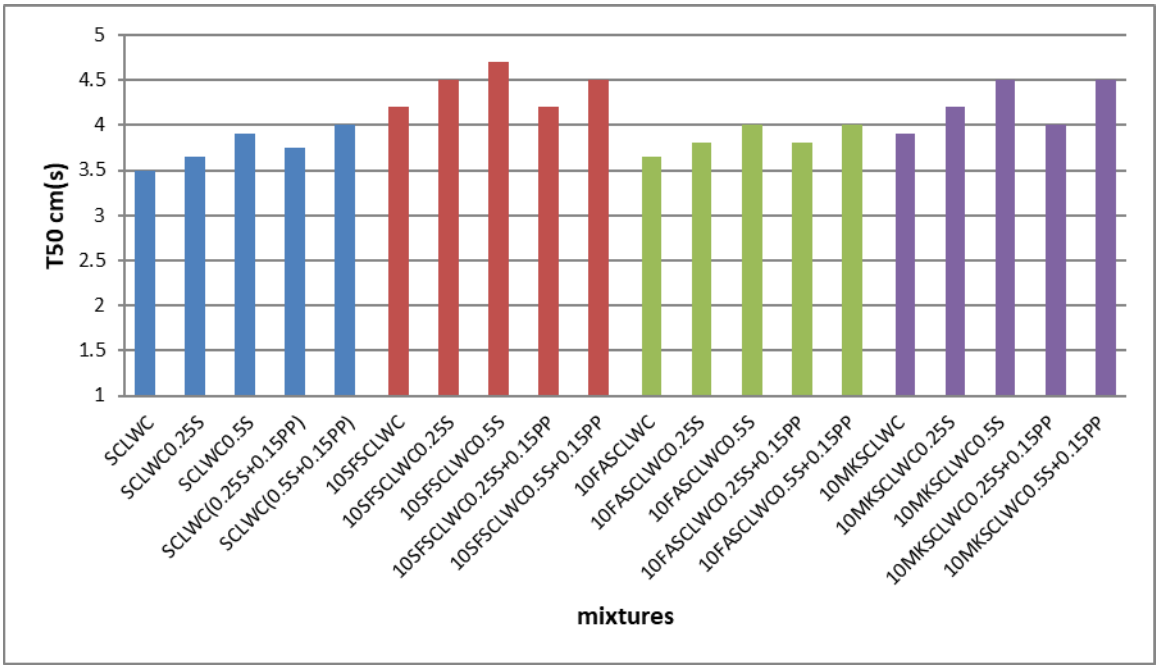

Figure. (4-2) T500 mm for SCLWC Mixes

4.2.3 V-funnel

This test is used to give an indication about the viscosity and flow ability of SCLWC. The data in Table (4-1) displays that every V-funnel time result conforms to the acceptance standards set by EFNARC 2005. Figure(4-3) demonstrates that the SCLWC mixes with micro steel and hybrid fibers had longer V-funnel flow times compared to those without fibers, where the range of(21-23) comparison with plain SCLWC was (18 s), with longer times corresponding to higher fiber percentages. This trend is due to an increase in viscosity, resulting in a more cohesive and interlocked concrete mixture due to fiber reinforcement, which delays the flow of SCLWC from the V-funnel apparatus **(Ting, H., et al., 2019)**. Also using mineral admixtures increased V-funnel time, because SCLWC containing mineral admixtures had a higher viscosity than (reference mix) for the same reason mentioned in the previous section.. Larger values of v-funnel flow time were observed in the mixtures that contained mineral admixture and fibers together. For example, the mixture (plain SCLWC) had a v-funnel of (18), while this value increased to (25, 23 and 24) seconds when fibers and mineral admixtures were incorporated in the mixes (10SFSCLWC0.5S+0.15PP), (10FASCLWC0.5S+0.15PP) and (10MKSCLWC0.5+0.15PP) respectively. This trend is due to an increase in viscosity, resulting in a more cohesive and interlocked concrete mixture due to fiber reinforcement, which delays the flow of SCLWC from the V-funnel apparatus. According to **(Ting et al., 2019)** the addition of fibers generally leads to an increase in V-funnel flow time due to fiber blockage within the confined area of the V-funnel.

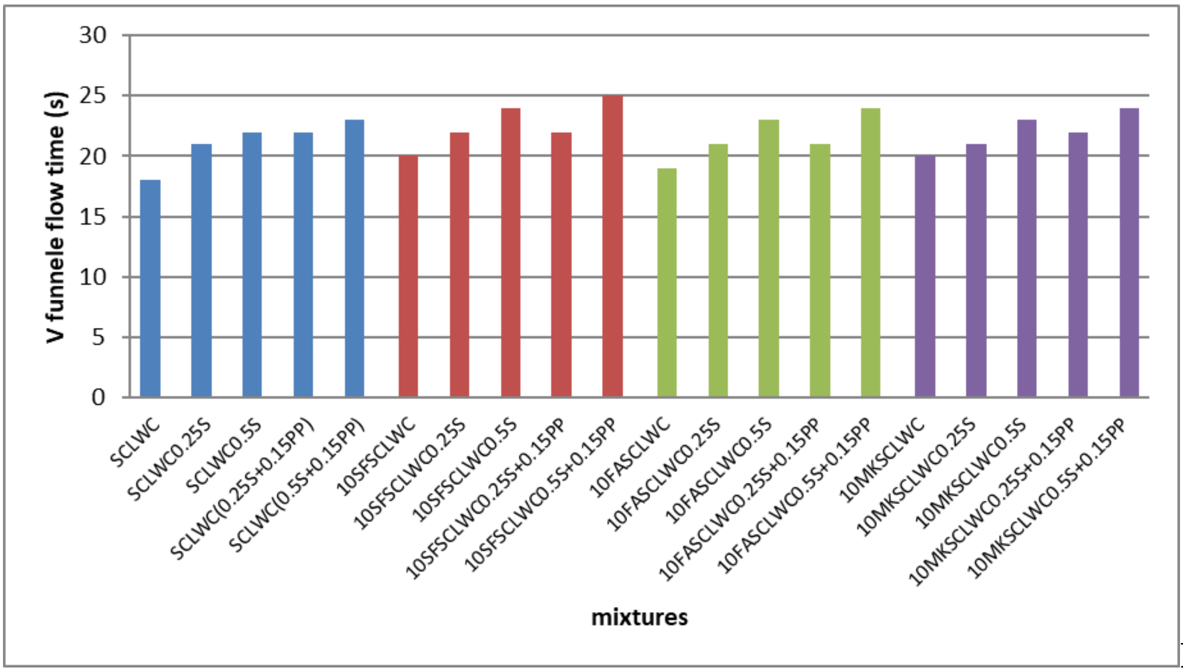

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Figure (4-3) V- funnel Flow for Mixes

Figure (4-4) shows the relationship between V-funnel flow time and T500mm for all mixes. Obviously, most mixes were in the category of VS2/VF2 (9- 25) sec. according to EFNARC classification (2005).

It is worth noting that the SCLWC which is classified as VS2/ VF2 viscosity class with SF2 slump flow diameter can be applicable for constructing ramps and walls/columns **(EFNARC, 2005).**

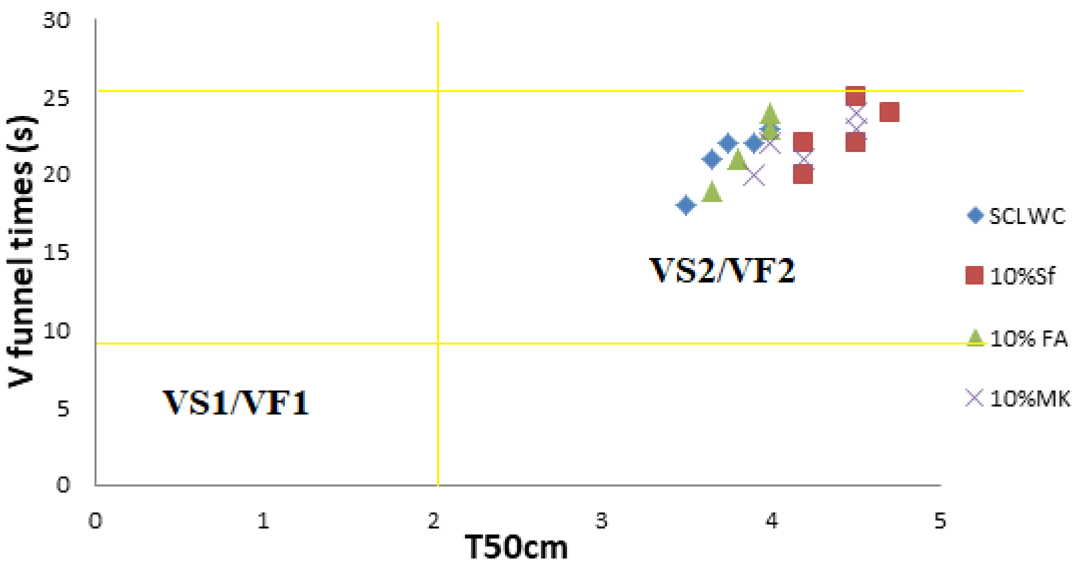


Figure (4.4) Relationship between V-funnel Times and T500mm.

4.2.4 L-box

This test is used to assess passing ability which it can be visually estimated. The results of L Box are depicted in Table (4-1) and Figure (4-5) which reveal that all results are within the acceptance criteria of **(EFNARC, 2005).** High H2/H1 depends on the viscosity and flowability of SCLWC, so a lower H2/H1 value means lower passing ability. With approaching this value from 1, higher passing ability can be obtained. Increasing micro-steel and hybrid fibers percentages diminished the value of L-Box height ratio. It can be seen that incorporation fibers in SCLWC indeed decreases its workability, however the results of these tests still met the limitations recommended by EFNARC committee and in line with **(Schneider. H et al., 2002)**. Figure (4-6) also shows that the value of H_2/H_1 for mix containing FA recorded, the highest value was 0.95, this is attributed to its superior flowability, which can be attributed to the spherical morphology of FA particles.

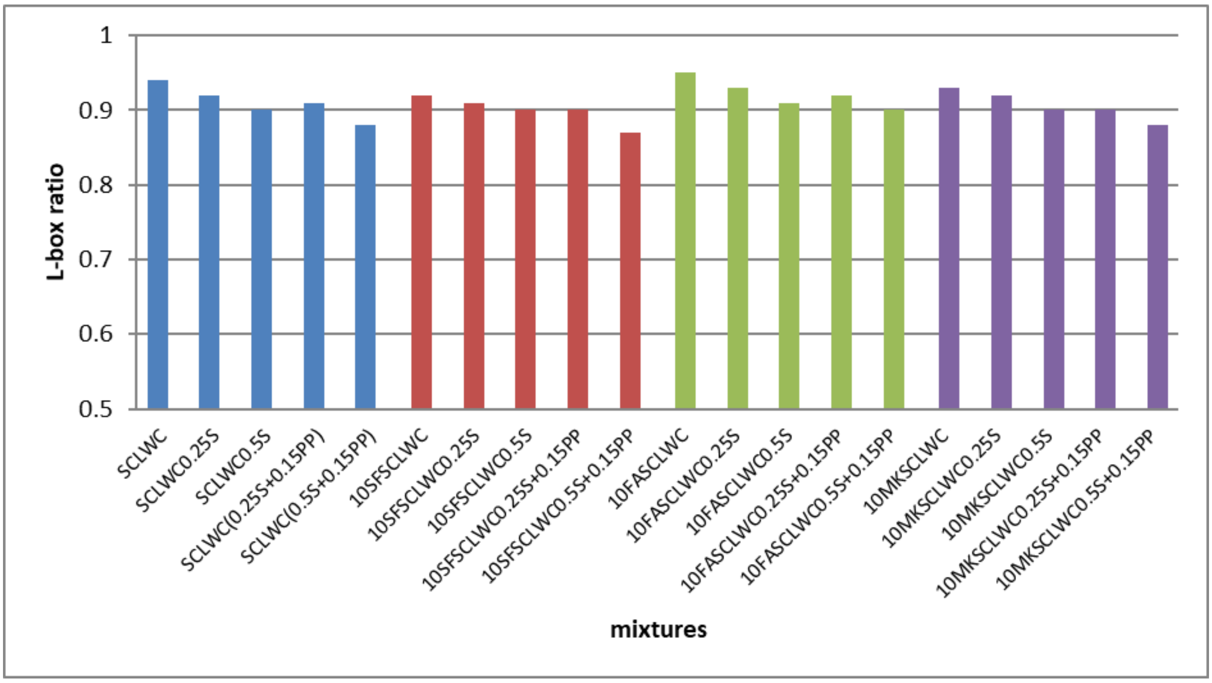


Figure (4-5) L- box Ratio for SCLWC Mixes

4.2.5 Fresh Density

Following casting, the immediate measurement of the fresh density of SCLWC was conducted as per ASTM C138, 2017 guidelines. The fresh density values for all SCLWC mixtures are presented in Table (4-1) and depicted graphically in Figure (4-6). The observed range for fresh density was between (1849 - 1922) kg/m^3. Notably, Figure (4-6) indicates a marginal rise in the fresh density of SCLWC upon the incorporation of micro steel fibers, consistent with findings by **(Nahhab, A. H., and Ketab, A. K. 2020).** While in the hybrid mixes, the polypropylene fibers have very little effect on the fresh density. This may be due to the fact of the low specific gravity of polypropylene fibers **(Liu, X., Wu et al., 2019).**The results show that fresh density is reduced when mineral admixtures are used and the reduction value depends on their type and density (specific gravity). Lower fresh density value was noticed with mixes content SF, because SF has lower density, so when it was replaced with cement by the same weight that led to increase mixes volume, while its weight remained constant. On the other hand, when incorporating fibers and mineral admixture in mixes the fresh density was ranged from 1861-1881, 1880-1897, and 1888-1904, kg /m3 for mixtures with SF, FA, and MK respectively.

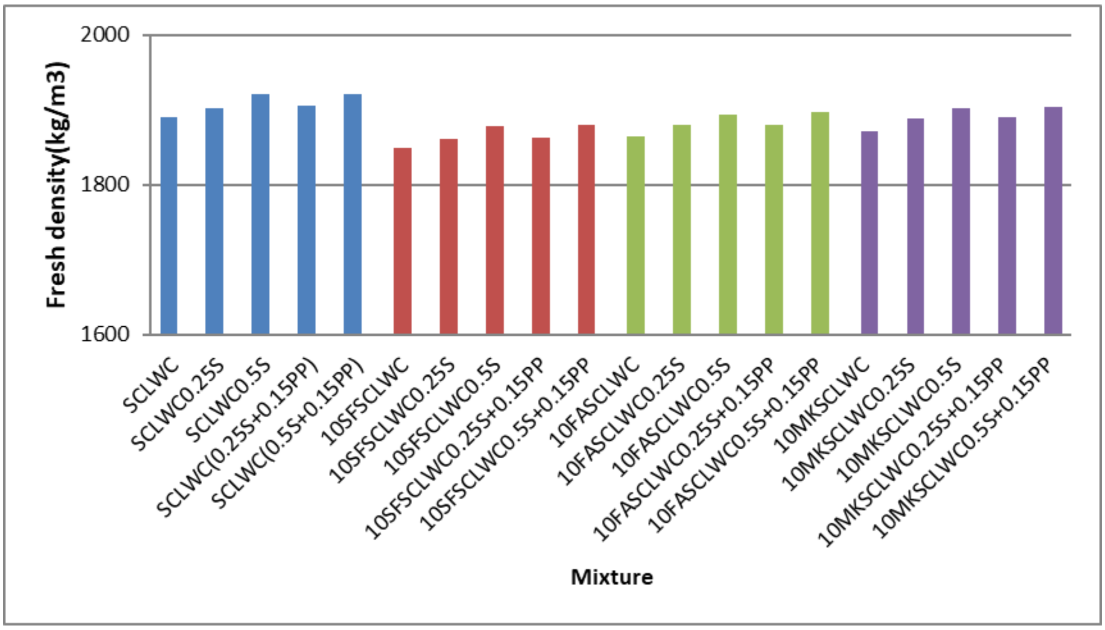


Figure (4-6) Fresh Density of SCLWC Mixes

4.3 Weight loss

Weight loss is associated with the processes of evaporation of water from SCLWC and chemical hydrates decomposition. The impact of fire flame temperature on the weight loss of all SCLWC mixes at the age of 28 days is depicted in Figure (4-7). The weight loss was in the range of (3-9.5) % when fire flame temperatures increased from (300 to 600) °C. The decrease in weight affirms the loss in mass caused by the concrete material and the rise in the percentage of air voids **(Bingol (2009) and Janotka (2005)).**

It can be noticed from Figure (4-8) that steel fibers reinforced SCLWC mixes have similar weight loss compared with reference mix , while SCLWC mixes , which contain hybrid fibers (steel +polypropylene), reveal a slightly higher weight loss than reference mixes (plain SCLWC mixes) . Also the concrete samples containing silica fume suffered higher weight loss than the other corresponding mixes **(Sancak et al., 2008)** have also found similar results.

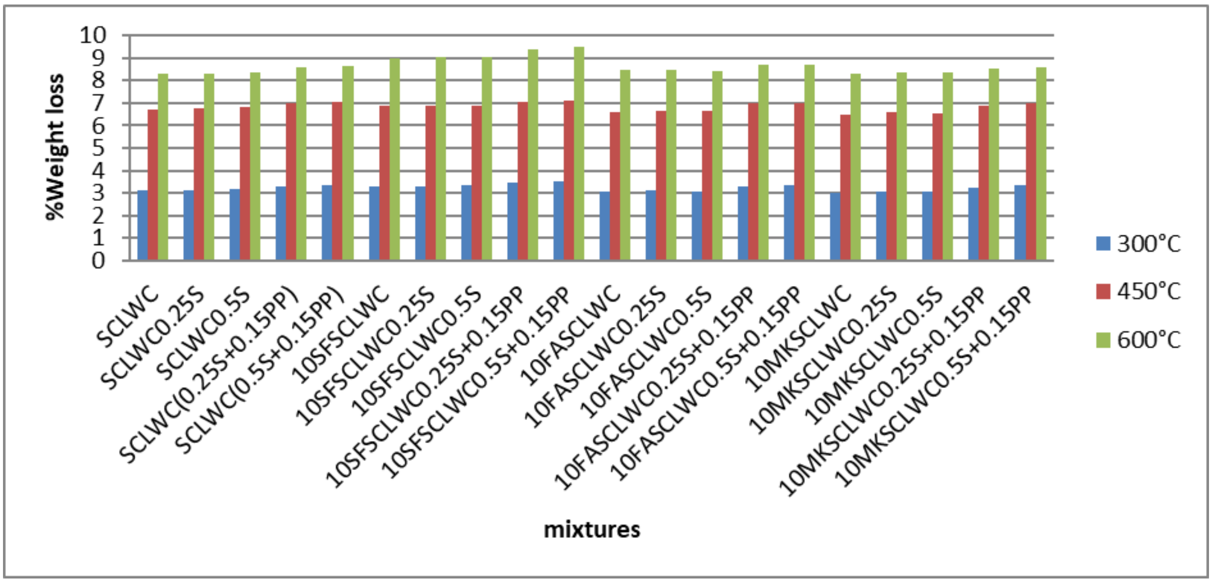


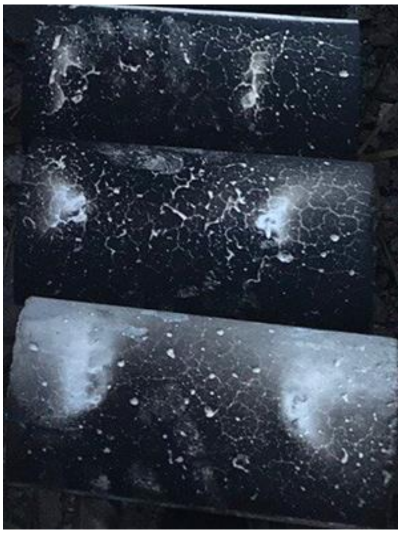
Figure (4-7) Weight Loss of SCLWC at Different Temperatures

4.4 Spalling Characteristics

According to **Hertz KD(2003)** the spalling may be occurs due to the accumulation of pore pressure during heating. Due to the dense nature of concrete, it becomes challenging for the elevated water vapor pressure to escape. As a consequence, when the pressure within the pores surpasses the tensile strength of the concrete, it causes the detachment of concrete fragments from the structural element, resulting in spalling. This pore pressure drives progressive failure. Initially, spalling was considered insignificant when only surface pitting occurred. However, if spalling exposes the core and reinforcing steel or tendons to a rapid temperature rise, it can affect the fire resistance and load-bearing capacity of structural or non-structural elements. Plate (4-1) depicts the partial spalling occurred in mixture containing SF because it has a finer particle size compared to FA and MK . Due to the high powder content required to develop SCLWC, concrete with SF becomes denser, more compact, and less permeable. However, at high elevated temperatures, water vapor cannot escape easily from the concrete with SF, leading to increased pore pressure and eventual spalling. This is highlighted in reference (**Sideris KK, 2007)** Regarding the effect of incorporating FA and MK on high-temperature resistance to spalling, a clear positive effect was observed at 600 °C this is in line with **(Aydin S ,2007).**For the SCLWC specimens incorporating 0.25% and 0.5% micro steel fibers by volume, spalling was observed when they were subjected to fire flame 600 °C see Plate (4-1). This confirmed the findings of previous investigations that showed that the steel fiber was not effective enough to totally prevent spalling during the fire test even with large quantities **(Kodur et al., 2003).** This may be attributed to the differential thermal expansion, resulting from a combination of the thermal gradient and differences in expansion coefficients.

While the polypropylene and micro steel fibers in hybrid mixes were resist the risk of spalling of SCLWC sample after exposure to fire flame, as shown in plate (4-1). The particular characteristics of PPF help to enhance the durability of concrete and make it more resistant to fire damage. When exposed to high temperatures, these fibers create empty spaces within the concrete, allowing moisture in both liquid and vapor forms to escape more easily. This lowers internal pressure and prevents the surface of the concrete from cracking or flaking due to the build-up of moisture **(Karimipour et al., 2020).** In summary, the main cause of spalling in concrete at elevated temperatures is the buildup of internal pore pressure resulting from the vaporization of free and chemically bound water, as indicated in the research **(Schneider, H et al., 2002).**

10%Silica fume **0.25S (10%SF)** **0.5S(10%SF)**



0.25S+0.15PP (10SF) **0.5S+0.15PP(10%SF)** **0.5S (10%SF)**

10%MK

Plate (4-1) Spalling Characteristics

4.5 Mechanical Properties of Hardened Concrete

Analyzing the mechanical characteristics of concrete is essential for comprehending the response of concrete specimens. The mechanical properties evaluated in this research for hardened concrete encompass compressive strength, splitting tensile strength, flexural strength and UPV. These properties were investigated in order to estimate the resistance and capability of single and hybrid fibers reinforced SCLWC under fire exposure. The burning process of the SCLWC samples was under fire duration (60) minutes.

4.5.1 Compressive Strength

Tables (4-2) and (4-3) present the pre- and post-burning compressive strength data for SCLWC mixes. Each value in these tables represents the average value of three cubes. Also, the impact of fire flame at different fire temperature levels on the residual compressive strength of specimens without and with fibers is depicted in Figures (4-9) and (4-10). The results demonstrate that the compressive strength of each of the SCLWC mixes without fibers or with fibers decreased with the increase in the fire flame temperature, and that the percentage of the added fibers and their type affected the extent of the compressive strength loss. This is because the elevated temperatures weaken the bond between cement paste and aggregate, and cause the breakdown of the cement gel structure, which leads to a consequent loss in the load bearing capacity, (**Ahmad et al., 2019).**

The utilization of various mineral admixtures in SCLWC produces dense microstructure with less amount of calcium hydroxide, which ensures a beneficial impact on compressive strength at room temperature as reported by (**Chan YN et al., 2000)**. However, this dense microstructure can increase impermeability, posing a concern when the concrete is exposed to elevated temperatures. Under high temperatures, moisture retention within the impermeable microstructure can lead to pore pressure accumulation and microcrack development, ultimately causing a rapid deterioration in concrete strength and potential spalling, as reported by (**Poon et al., 2001).**

Table (4-2) Compressive Strength Values for All Mixture at 28 days

Mixes	Period of exposure (hour)	Compressive strength (MPa)				Residual compressive strength %		
		Temperatures °C						
		25 A	300°C B	450°C C	600°C D	300 °C	450 °C	600 °C
SCLWC	1.0	31.8	26.4	24.5	18.4	83	77	58
SCLWC0.25S		32.35	27.17	25.6	21.7	84	79	67
SCLWC0.5S		33.02	28.07	26.56	23.44	85	80	71
SCLWC(0.25S+0.15PP)		32	24.32	22.7	20.48	76	71	64
SCLWC(0.5S+0.15PP)		32.5	25.35	23.7	21.7	78	73	67
10SFSCLWC	1.0	36	31.53	26.64	18.36	87.6	74	51
10SFSCLWC0.25S		36.8	32	27.6	22.44	87	75	61
10SFSCLWC0.5S		37.1	32.6	28.19	24.5	88	76	66
10SFSCLWC0.25S+0.15PP		36.5	29.57	24.8	21.9	81	68	60
10SFSCLWC0.5S+0.15PP		37	30.7	26.27	23.68	83	71	64
10FASCLWC	1.0	31.7	26.6	24.9	19.24	84	78.5	60.7
10FASCLWC0.25S		32.93	28	26.5	23.58	85	80.5	71.6
10FASCLWC0.5S		33	28.05	26.73	23.76	85	81	72
10FASCLWC0.25S+0.15PP		31.8	24.8	22.8	20.67	78	71.7	65
10FASCLWC0.5S+0.15PP		32.3	25.5	23.9	21.6	79	74	67
10MKSCLWC	1.0	35.4	31.1	28.08	21.6	88	79.3	61
10MKSCLWC0.25S		36.1	31.4	28.9	24.9	87	80	69
10MKSCLWC0.5S		35.9	31.7	29.8	25.95	88.5	83	72.3
10MKSCLWC0.25S+0.15PP		35	27.3	25.5	23.8	78.4	73	68
10MKSCLWC0.5S+0.15PP		35.2	28.1	26	24.2	80	74	69

Table (4-3) Compressive Strength Values for All Mixture at 56 day

Mixes	Period of exposure (hour)	Compressive strength (MPa)				Residual compressive strength %		
		Temperatures °C						
		25 A	300 B	450 C	600 D	300 °C	450 °C	600 °C
SCLWC	**1.0**	33.1	28.33	26	19.6	85.6	78.7	59.4
SCLWC0.25S		34	29	27.54	23.46	85.3	81	69
SCLWC0.5S		34.9	30.4	28.27	25.61	87.1	81	73.4
SCLWC(0.25S+0.15PP)		33.5	26.13	24.35	22.44	78	72.7	67
SCLWC(0.5S+0.15PP)		35	28	26.18	24.04	80.2	74.8	68.7
10SFSCLWC	1.0	37.01	33.3	27.83	19.84	90	75.2	53.6
10SFSCLWC0.25S		37.5	33.3	28.8	23.78	88.8	76.8	63.4
10SFSCLWC0.5S		40.33	36	31.05	27.42	89.3	77	68
10SFSCLWC0.25S+0.15PP		36.9	29.29	25.83	23.02	79.4	70	62.4
10SFSCLWC0.5S+0.15PP		39	31.98	28.23	25.86	82	72.4	66.3
10FASCLWC	1.0	36	31.14	29.12	22.86	86.5	80.9	63.5
10FASCLWC0.25S		36.83	32.04	30.57	25.78	87	83	70
10FASCLWC0.5S		37.4	32.6	31.27	28.05	87.2	83.6	75
10FASCLWC0.25S+0.15PP		35	28	25.55	23.48	80	73	67.1
10FASCLWC0.5S+0.15PP		37	30.1	27.75	25.53	81.4	75	69
10MKSCLWC	**1.0**	36.28	32.65	29.31	23.21	90	80.8	64
10MKSCLWC0.25S		37.08	32.63	30.55	26.54	88	82.4	71.6
10MKSCLWC0.5S		39.34	35.52	33.4	29.19	90.3	85	74.2
10MKSCLWC0.25S+0.15PP		37	29.6	27.38	25.53	80	74	69
10MKSCLWC0.5S+0.15PP		38.7	32.12	29.4	27.6	83	76	71.3

It is clear from the results of Figure (4-8), that the [10SFSCLWC and 10MKSCLWC] mixes gain compressive strength at an early age (at 28 days) , Due to its reaction with calcium hydroxide during cement hydration, because

SF reacts with calcium hydroxide ($Ca(OH)_2$) during the hydration of cement resulting in the formation of fine calcium silicate hydrate (C-S-H) , which acted as a filler together with very fine particles of SF **(Demirel, B., & Keleştemur, O. 2010)**. Nonetheless, the increase in strength persists throughout the curing period, albeit at a diminished rate of progress by the 56th day. These findings align with observations made by other scholars. While the results of the 10FASCLWC mix showed that its early compressive strength was reduced compared to the reference mix, this is attributed to the lower CaO content of class F fly ash. At 56 days, the compressive strength of the mix containing FA increased; this may be obtained due to slow pozzolanic reactivity, which begins after cement hydration. According to **(Lane and Best, 1982)** the pozzolanic reaction of FA can take one year to increase compressive strength by 50% compared to 30% for concrete without FA. The same conclusions were reached by **(Fathi 2013). (Liu 2009). (Lal and Kumar 2015), (Thomas 2007) and (Skazlic and Vujica 2012).**

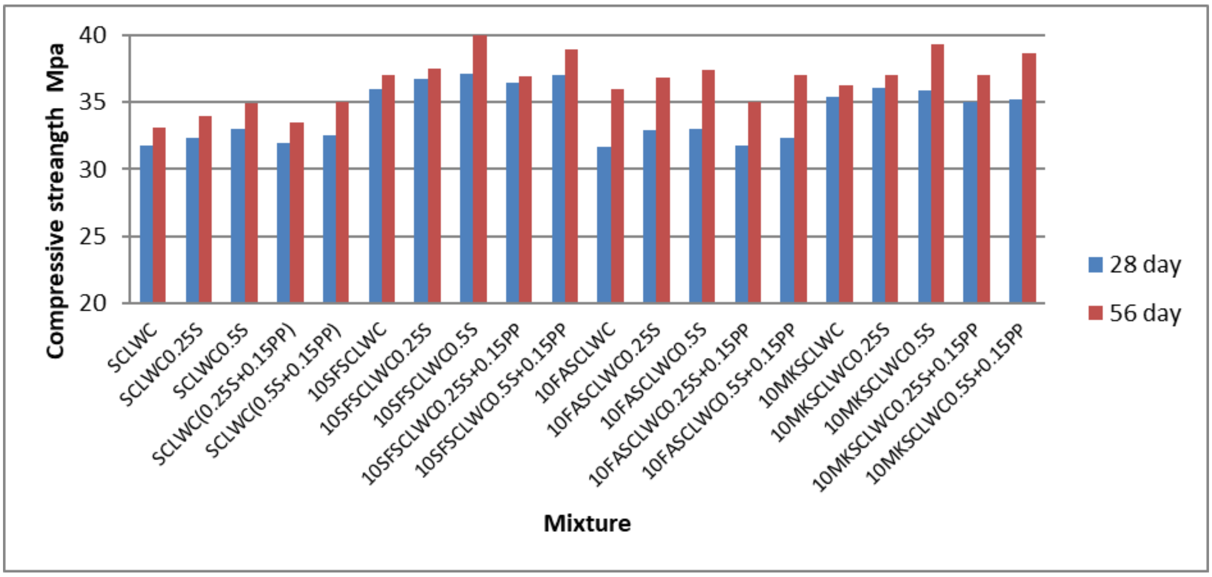
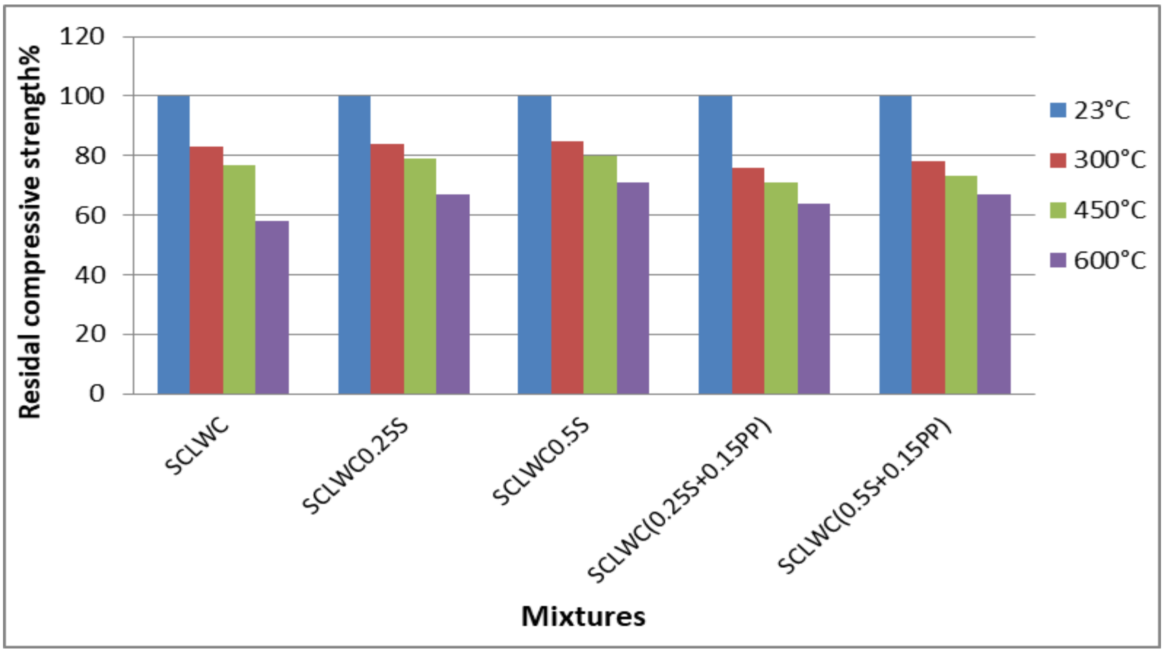


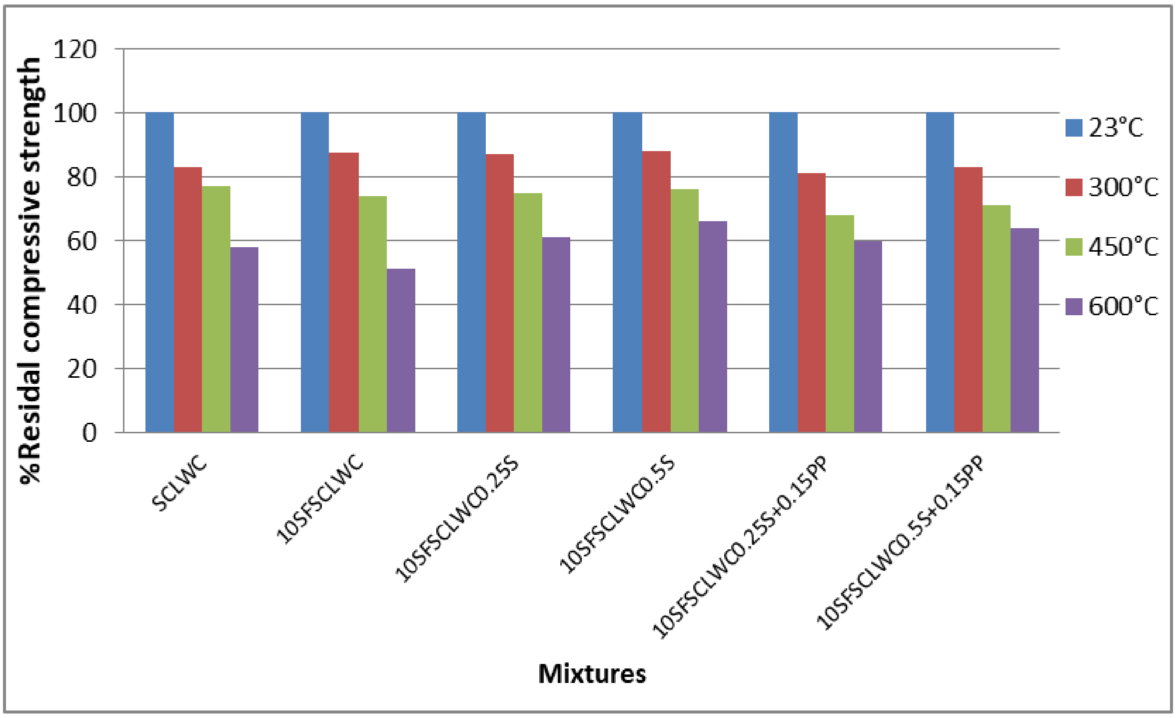
Figure (4-8) Compressive Strength Results for SCLWC Mixes Before Exposure to Fire Flame

The finding of the test revealed that when the samples were exposed to temperature below 450 °C , the presence of steel fibers had negligible effect on the fluctuation of compressive strength .However , as the temperature reached 600 °C , the residual compressive strength of steel fibers reinforced SCLWC increased with the increase in amount of fibers , As shown at 600 °C the residual compressive strength of (SCLWC0.25S) and (SCLWC0.5S) mixes were higher than values corresponding to the reference mix (the SCLWC mix) by[(9%) , (13%)] and [(9.6%),(14)] respectively at 28 and 56 day. This can be imputed to the fact that the existence steel fibers in the concrete help limit crack growth and propagation in this temperature range, the same conclusion was reached by [28].However for the mixes with hybrid fibers the behavior is changed . At 300°C of fire flame exposure, the residual compressive strength of SCLWC(0.25S+0.15PP) and SCLWC(0.5S+0.15PP) mixes were less than the residual strength of SCLWC mix by (7% , 5%], [7.6% , 5.4%] at 28 and 56 days respectively. Whereas at 450 °C the residual compressive strength of these mixes were less than those on SCLWC mix by (6% and 4%], [6% and 3.9%] at 28 and 56 days respectively. On the other hand at 600°C the residual strength of these mixes were higher than of those mix by about [6% and 9%] , [7.6% and 9.3%] at 28 and 56 days respectively this is in line with **(Schneider, H and Wille, K., 2002)** .

(At 300 °C of fire flame exposure, the residual compressive strength [10SFSCLWC, 10FASCLWC and 10MKSCLWC] mixes was higher than residual compressive strength of (SCLWC mix) reference mix by [4.6%, 1% and 5 %] and [4.4%, 0.9% and 4.4%] respectively at 28 and 56 days. At 450°C the residual compressive strength of [10MKSCLWC and 10FASCLWC] mix was higher than residual compressive strength of (SCLWC) mix by [2.3% and 1.5%] ,[2.1% and 2.2%] respectively at 28 and 56 days .While the residual compressive strength for [10SFSCLWC] mix was lower than that of residual compressive strength of SCLWC mix by [3% and 3.5%) respectively at 28 and 56 days. On the other hand at 600°C the residual compressive strength of [10MKSCLWC and 10FASCLWC]mixes was higher than those of SCLWC mix by [3% and 2.7%], [4.6% and 4.1%] at 28 and 56 days respectively, while for 10SFSCLWC was lower than those of SCLWC mix by [7% and_5.8%]_at 28 and 56 day respectively . This due to the fact that MK samples showed less content of $Ca(OH)_2$, and in the counterpart, high content of C-S-H is identified. This outcome leads to an advantageous agreement for the positive contribution of MK. Consequently, MK mixes lead to achieving high residual strength values **(Abdelmelek and Lubloy, 2020)**.

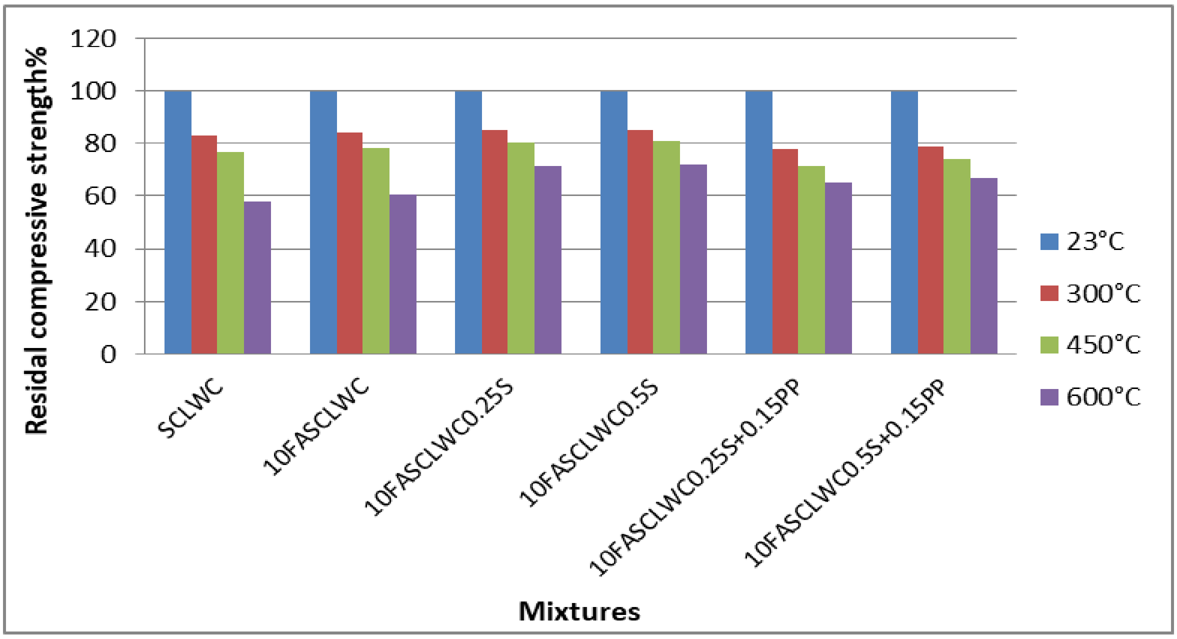


(a)



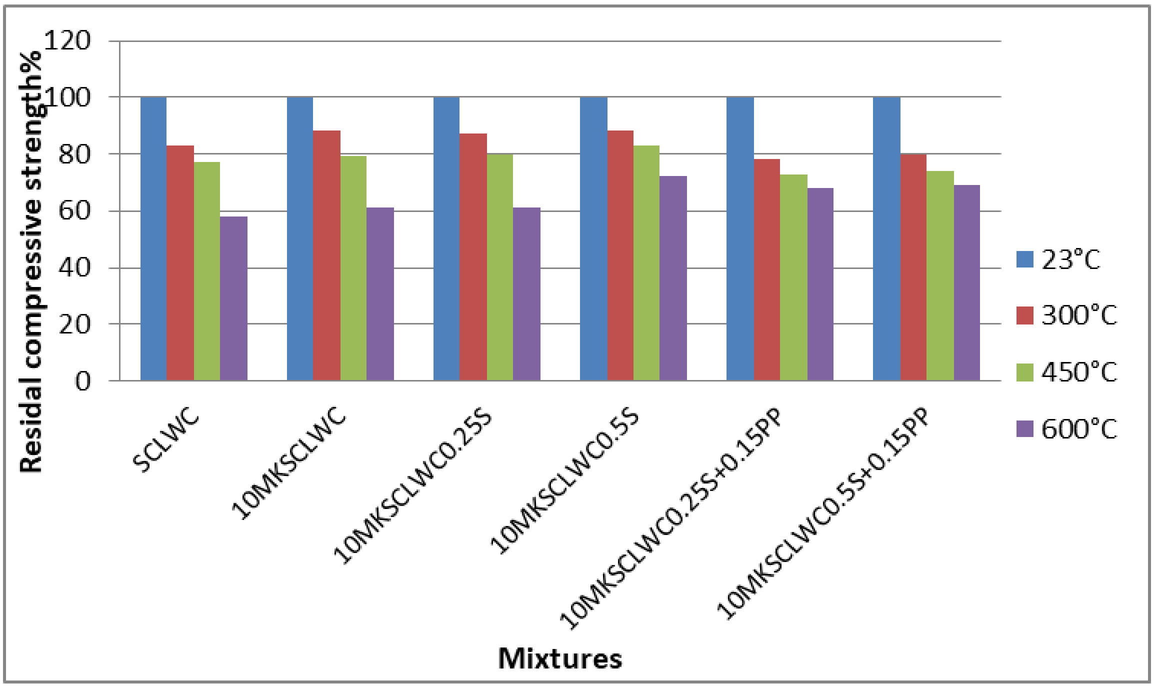
%Residal compressive strength
120
100
80
60
40
20
0
SCLWC
10SFSCLWC
10SFSCLWC0.25S
10SFSCLWC0.5S
10SFSCLWC0.25S+0.15PP
10SFSCLWC0.5S+0.15PP
Mixtures
23°C
300°C
450°C
600°C

(b)



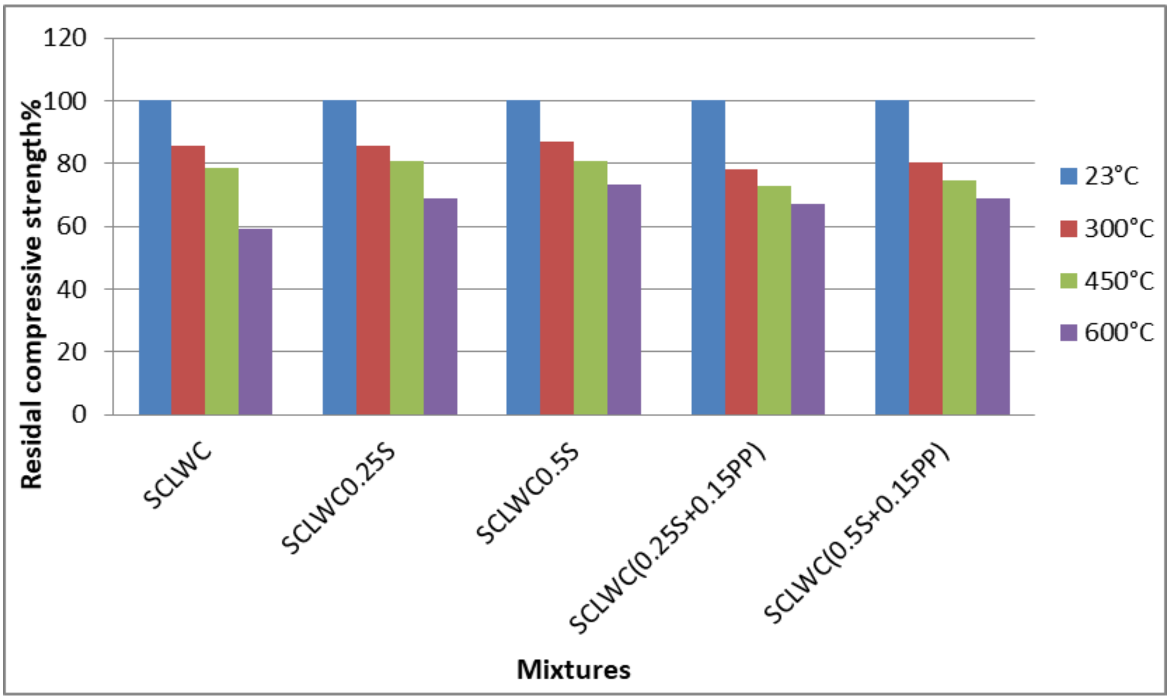
Residal compressive strength%
120
100
80
60
40
20
0
SCLWC
10FASCLWC
10FASCLWC0.25S
10FASCLWC0.5S
10FASCLWC0.25S+0.15PP
10FASCLWC0.5S+0.15PP
Mixtures
23°C
300°C
450°C
600°C

(c)

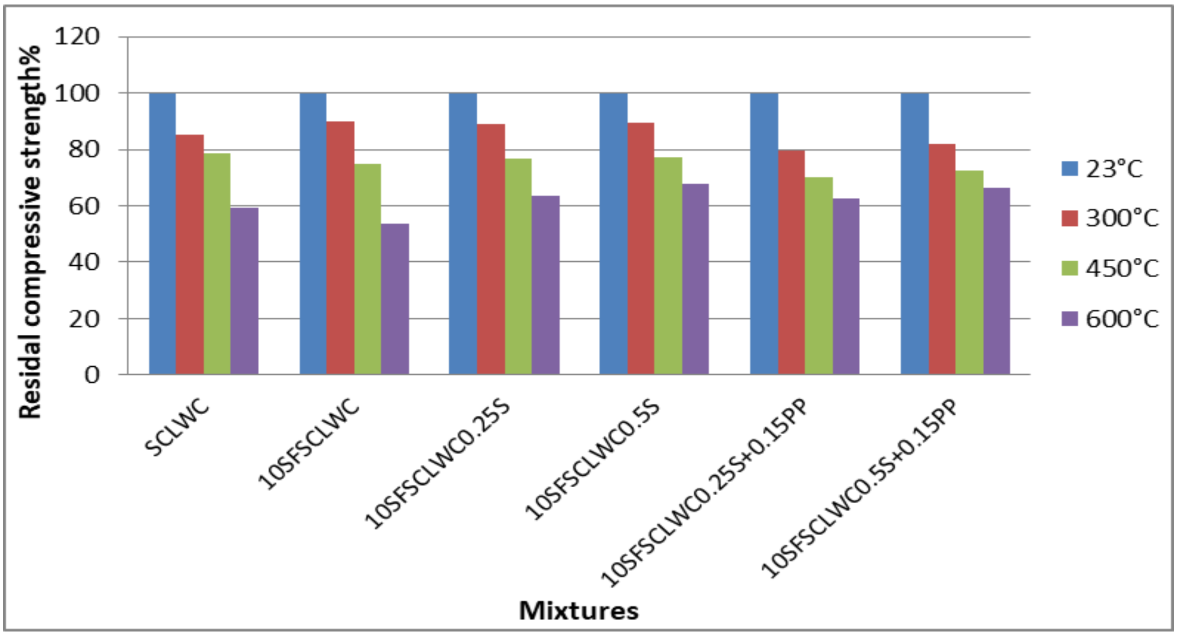


(d)

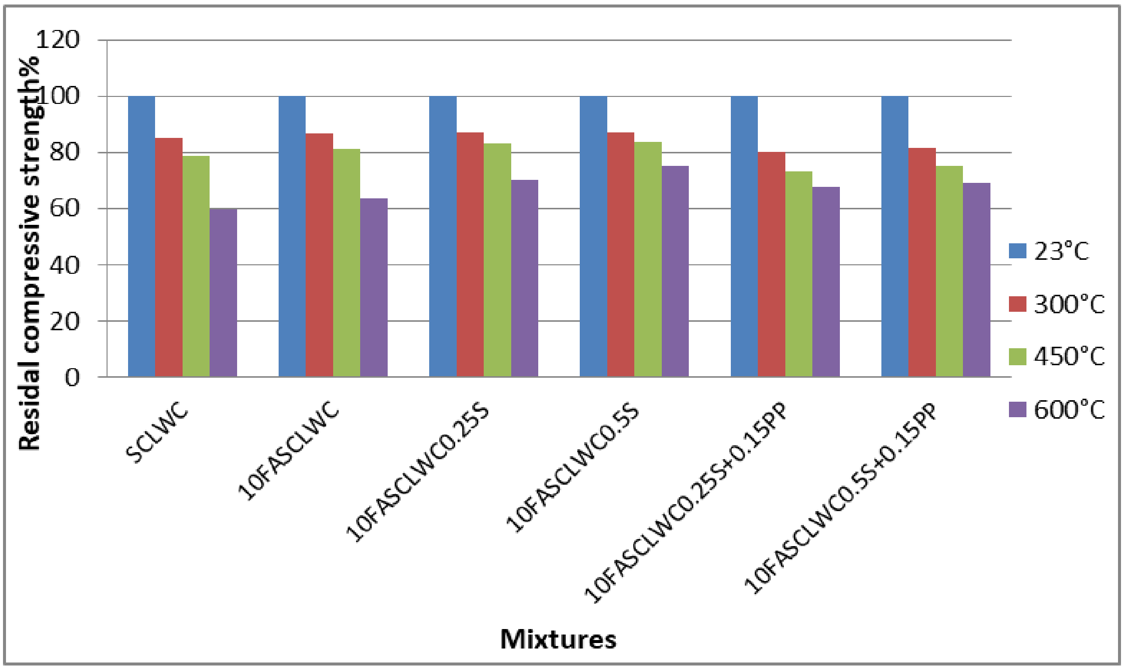
Figure (4-9) (a, b, c, d) Residual compressive strength at 28 day after fire flame exposure as a percentage of that at room temperature (at 25 °C). a) Without mineral admixture, b) SF=10%, c) FA=10%, d) MK=10% .



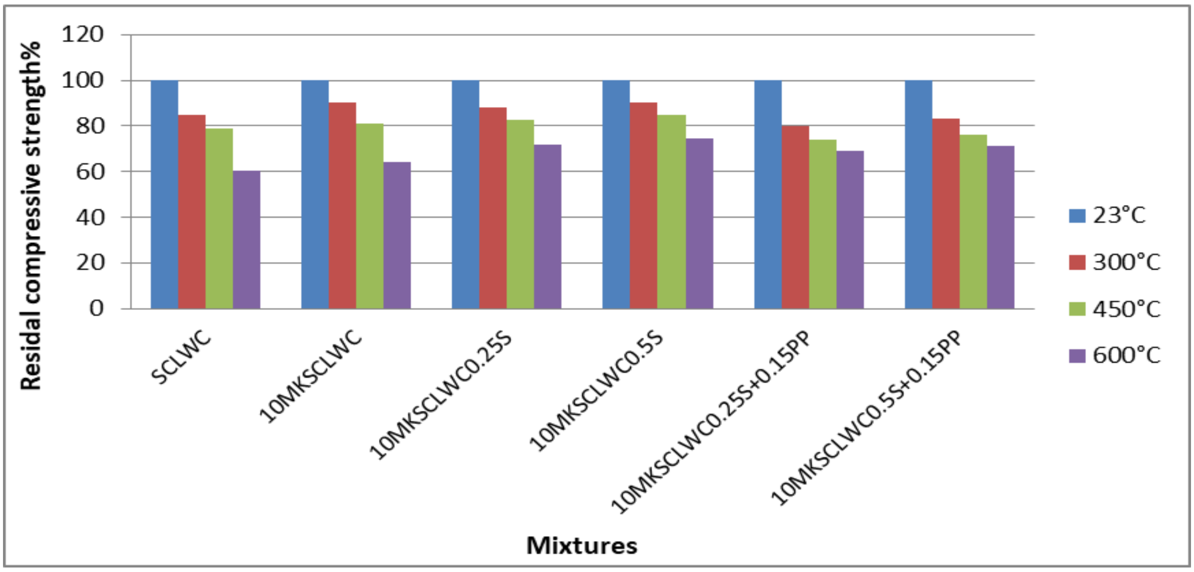
(a)


Residal compressive strength%
120
100
80
60
40
20
0
SCLWC
10SFSCLWC
10SFSCLWC0.25S
10SFSCLWC0.5S
10SFSCLWC0.25S+0.15PP
10SFSCLWC0.5S+0.15PP
Mixtures
23°C
300°C
450°C
600°C

(b)


Residal compressive strength%
120
100
80
60
40
20
0
SCLWC
10FASCLWC
10FASCLWC0.25S
10FASCLWC0.5S
10FASCLWC0.25S+0.15PP
10FASCLWC0.5S+0.15PP
Mixtures
23°C
300°C
450°C
600°C

(c)



(d)

Figure (4-10) (a, b, c, d) Residual compressive strength at 56 day after fire flame exposure as a percentage of that at room temperature (at 25 °C). a) Without mineral admixture, b) SF=10%, c) FA=10%, d) MK=10%.

4.5.2 Splitting Tensile Strength

The tensile strength of concrete is comparatively lower than its compressive strength due to the propensity for crack formation under tensile stresses. Particularly at elevated temperatures, the tensile strength of concrete is critical . It induces spalling in structural members as noted by **(Khaliq et al., 2011).** The cracks that emerge in heated concrete primarily stem from pore pressure surpassing the concrete's tensile strength. With an elevation in concrete grade or strength, there is a corresponding rise in both pore pressure and concrete tensile strength. Nevertheless, the escalation in pore pressure tends to surpass the increase in concrete's tensile strength. This disparity between pore pressure and tensile strength can pave the way for spalling, rendering concretes of higher grades more prone to thermal gradients, a conclusion in accordance with the observations made by **(Anand et al., 2014).**As anticipated, the impact of the steel and polypropylene fibers on the splitting tensile strength of concrete is considerably greater than their effect on the compressive strength of concrete.

This can be attributed to the behavior of concrete when it undergoes tensile cracking, wherein the fibers intersecting the crack plane become engaged and offer resistance against failure resulting from splitting **(Bošnjak, J., Sharma, A., & Grauf, K. (2019).**

Table (4-4) Splitting Tensile Strength Values at 28 day

Mixes	Period of exposure (hour	Splitting tensile Strength (MPa)				Residual splitting tensile Strength %		
		Temperatures °C						
		25 A	300 B	450 C	600 D	300 °C	450 °C	600 °C
SCLWC	**1.0**	2.52	2.19	2.01	1.31	87	80	52
SCLWC0.25S		3.83	3.4	3.03	2.3	90	79	60
SCLWC0.5S		4.45	4	3.6	2.66	90	81	66
SCLWC(0.25S+0.15PP)		3.94	3.3	2.48	2.3	84	63	59
SCLWC(0.5S+0.15PP)		4.61	3.82	3	2.81	83	66	61
10SFSCLWC	1.0	2.9	2.55	2.1	1.33	88	73	46
10SFSCLWC0.25S		4	3.6	2.96	2.08	90	74	52
10SFSCLWC0.5S		5.1	4.74	3.88	3	93	76	59
10SFSCLWC0.25S+0.15PP		4.3	3.65	2.53	2.24	85	59	52
10SFSCLWC0. 5S+0.15PP		5.4	4.53	3.4	3.07	84	63	57
10FASCLWC	1.0	2.51	2.19	2	1.34	87.3	81.5	53.5
10FASCLWC0.25S		3.7	3.25	2.98	2.25	88	80.5	61
10FASCLWC0. 5S		4.2	3.78	3.43	2.8	90	81.8	66.8
10FASCLWC0.25S+0.15PP		3.5	2.87	2.24	2.06	82	64	59
10FASCLWC0. 5S+0.15PP		4.3	3.48	2.88	2.7	81	67	63
10MKSCLWC	1.0	3.03	2.69	2.51	1.85	89	83	61
10MKSCLWC0.25S		4.2	3.69	3.36	2.9	88	80	69
10MKSCLWC0. 5S		4.9	4.41	4.06	3.54	90	83	72.3
10MKSCLWC0.25S+0.15PP		4.4	3.44	3.2	2.99	78.4	73	68
10MKCLWC0. 5S+0.15PP		5.3	4.24	3.9	3.66	80	74	69

Table (4-5) Splitting Tensile Strength Values at 56 Day

Mixes	Period of exposure (hour)	Splitting tensile strength (MPa)				Residual at splitting tensile Strength %		
		Temperatures °C						
		25 A	300 B	450 C	600 D	300 °C	450 °C	600 °C
SCLWC	**1.0**	2.81	2.48	2.3	1.49	88.2	81.8	53.1
SCLWC0.25S		4.1	3.69	3.32	2.55	90	81	62.2
SCLWC0.5S		4.8	4.39	3.95	3.26	91.4	82.3	67.9
SCLWC(0.25S+0.15PP)		4.23	3.6	2.75	2.56	85	65	60.7
SCLWC(0.5S+0.15PP)		4.9	4.15	3.3	3	84.8	67.3	62.6
10SFSCLWC	1.0	3.3	2.97	2.45	1.57	90.2	74.4	47.8
10SFSCLWC0.25S		4.2	3.84	3.22	2.23	91.5	76.7	53.3
10SFSCLWC0.5S		5.5	5.14	4.27	3.39	93.6	77.7	61.6
10SFSCLWC0.25S+0.15PP		4.66	3.97	2.84	2.52	85.2	60.9	54.1
10SFSCLWC0. 5S+0.15PP		5.9	4.97	3.81	3.47	84.2	64.6	58.8
10FASCLWC	1.0	3.1	2.75	2.54	1.75	88.8	82.2	56.6
10FASCLWC0.25S		4.1	3.69	3.39	2.54	90.2	82.8	61.9
10FASCLWC0. 5S		4.76	4.36	3.9	3.24	91.7	82.1	68
10FASCLWC0.25S+0.15PP		3.9	3.23	2.46	2.41	83	63.2	61.9
10FASCLWC0. 5S+0.15PP		4.78	3.97	3.28	3.03	83	68.7	63.4
10MKSCLWC	1.0	3.2	2.91	2.68	12	91.2	83.8	62.8
10MKSCLWC0.25S		4.4	3.9	3.6	3.1	88.7	82.2	70.6
10MKSCLWC0. 5S		5.1	4.58	4.23	3.77	89.8	84	74.1
10MKSCLWC0.25S+0.15PP		4.67	3.73	3.48	3.21	79.9	74.6	68.8
10MKCLWC0. 5S+0.15PP		5.71	4.68	4.32	4.01	82.1	75.7	70.3

As anticipated, in Figure (4-14) the impact of the steel and hybrid (steel + polypropylene) fibers on the splitting tensile strength of SCLWC is considerably greater than their impact on the compressive strength of concrete.

This is explained by how concrete behaves during tensile cracking, wherein the fibers intersecting the crack plane become engaged and offer resistance against failure resulting from splitting **(Bošnjak, J., Sharma, A., & Grauf, K. (2019).**

Also, Figure (4-11) reveals that using (SF, FA and MK) as replacement for 10% by weight of cement in SCLWC has a significant impact on increasing the splitting tensile strength (of mixes at room temperature), because of the high tendency of (SF,FA and MK) to consume high Ca(OH)2 from the interfacial transition zone (ITZ) and convert it to C-S-H, in addition to their physical effects in terms of packing of particles. Due to their lower density relative to Portland cement, mineral admixtures can increase paste volume when they are partially replaced by cement weight; consequently, the viscosity of the paste will increase. This increment in paste viscosity causes a reduction in ITZ porosity due to the reduction in bleeding water entrapped beneath coarse aggregate.

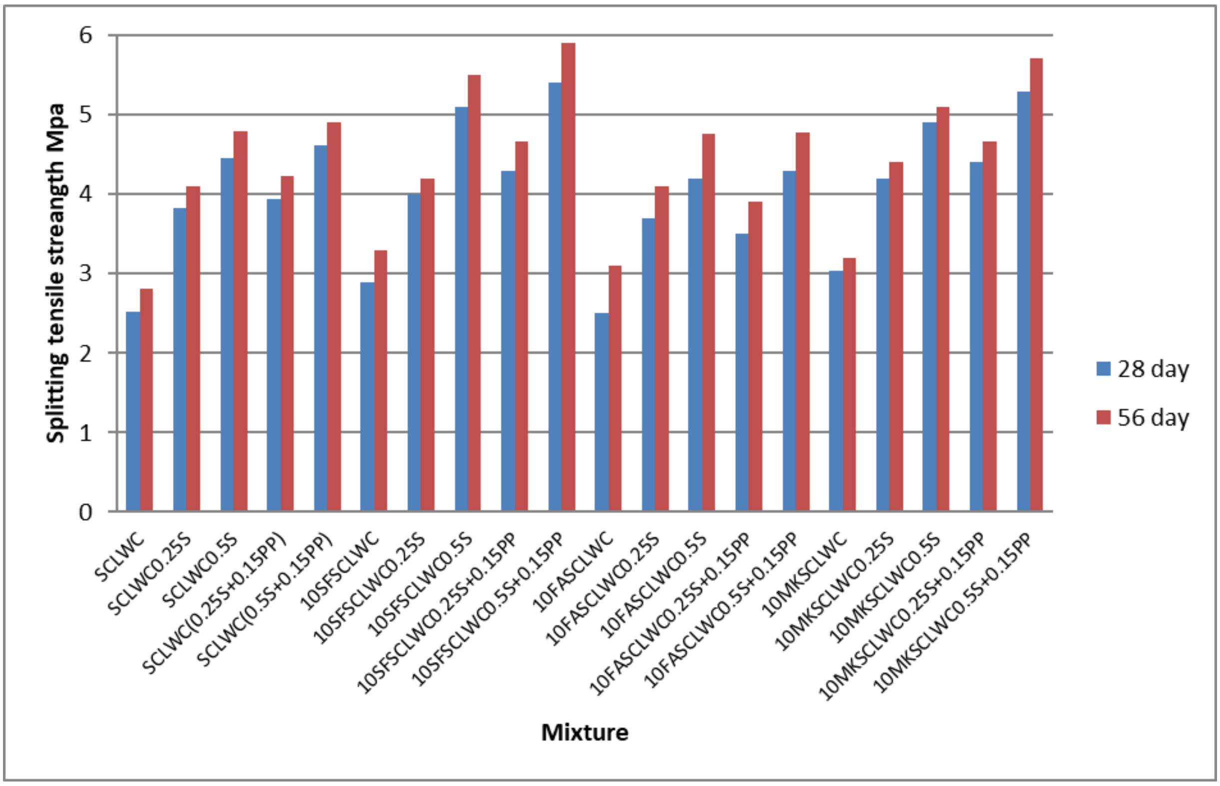


Figure (4-11) Splitting Tensile Strength Results for SCLWC Mixes before Exposure to Fire Flame

In the splitting tension test, the plain SCLWC cylinders exhibited a brittle failure, splitting into two parts. In contrast, the SCLWC cylinders reinforced with fibers retained their integrity, indicating a ductile failure. This difference in behavior is clearly illustrated in Plate (4-2). The plain SCLWC cylinders' brittle failure implies that they fractured abruptly without significant deformation or warning, while the fiber-reinforced SCLWC cylinders showed a more ductile response, with the ability to undergo deformation and resist fracture.

(a) (Brittle failure)

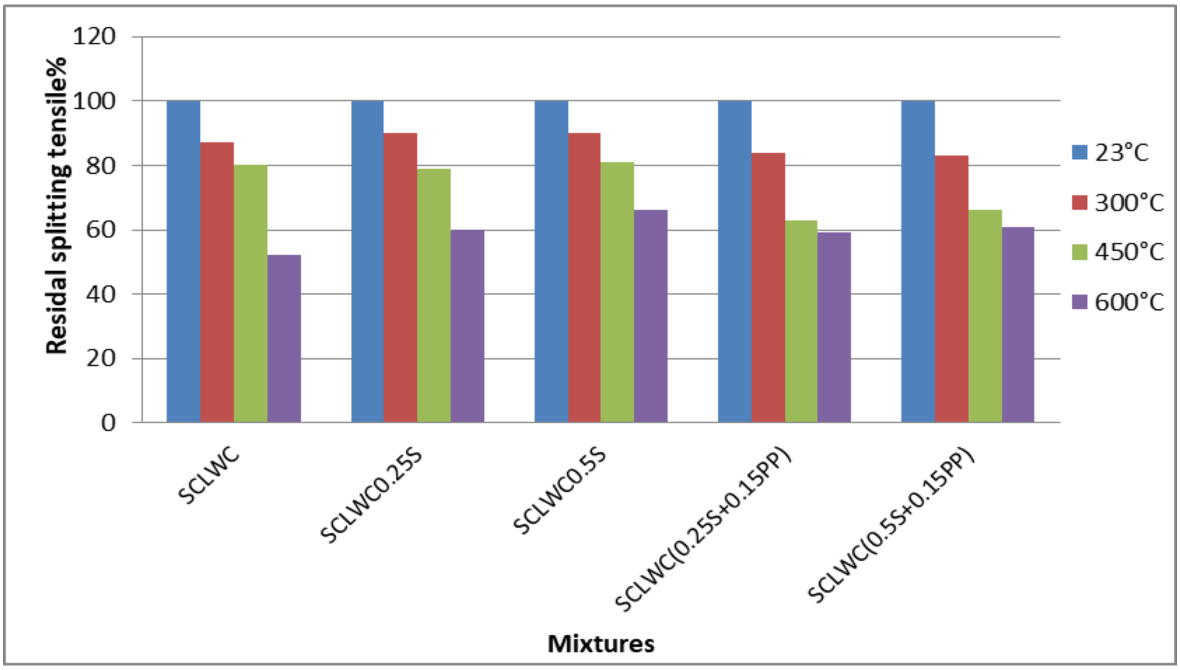
(b) (Ductile failure)

Plate (4.2) Mode of failure under splitting tension test (a) Without steel fiber, (b) With steel fiber.

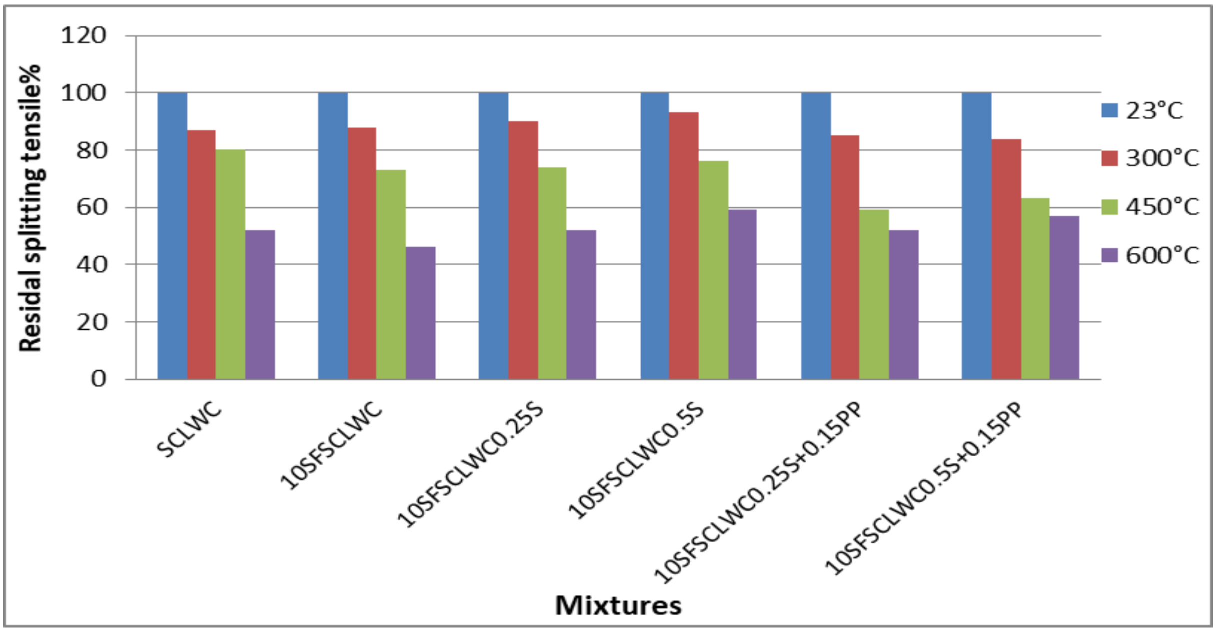
According to Figures (4-12) and (4-13) the presence of steel fibers did not significantly affect the residual splitting tensile strength of concrete when exposed to temperatures up to 450 °C. However, beyond this temperature, the splitting tensile strength of steel fiber-reinforced SCLWC increased as the steel fiber content increased, compared to the tensile strength of plain SCLWC at the same exposure temperature. The increase in fiber content led to an increase in the number of fibers, which improved the ability of fiber bridging and interception at the crack surface. At 600 °C, the residual splitting tensile strength of steel fibers reinforced SCLWC increased as the amount of fiber increases. Where the residual splitting tensile strength results of SCLWC0.25S and SCLWC0.5S mixes were higher than the residual splitting tensile strength of reference mix(the SCLWC mix) by [8% and 14%] ,[9.1% and 14.8%] at 28, 56 days respectively . The same conclusion was reached by **(Zween, A. 2008).**

At 300 °C of fire flame subjected, the residual splitting tensile strength of SCLWC(0.25S+0.15PP) and SCLWC(0.5S+0.15PP) mixes were less than the residual strength of SCLWC mix by [3% , 4%] and [3.2% , 3.4%] at 28 and 56 days respectively. Whereas at 450°C the residual splitting tensile strength of these mixes were less than those on SCLWC mix by [17%, 14][16.8%, 14.5%]at 28 and 56 days respectively. On the other hand at 600°C the residual strength of these mixes were higher than of those mix by [7%, 9%] and [7.6%, 9.5%] at 28 and 56 days respectively which is in agreement with **(Bošnjak et al., 2019)**

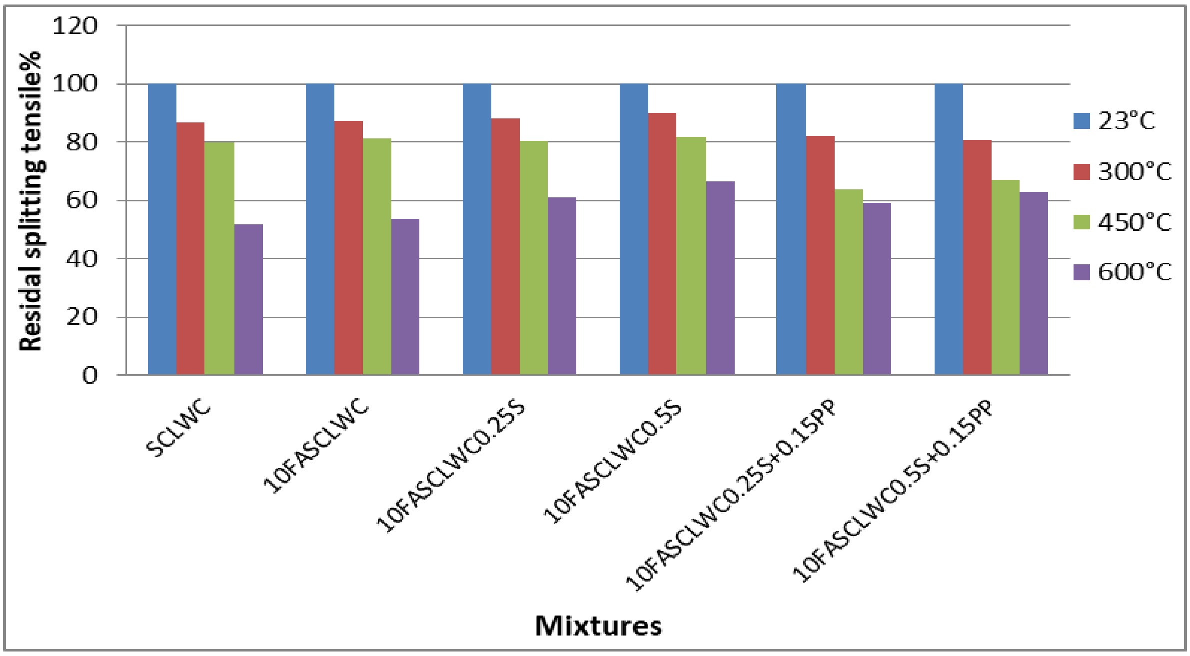
At temperature 300°C of fire flame subjected, The residual splitting tensile strength of [10SFSCLWC,10FASCLWC and 10MKSCLWC] mixes was higher than the residual splitting tensile strength of SCLWC mix by [1%,0.3%,2%] and [2%,0.6%, 3%] respectively, at 28 and 56 days .At temperature 450°C the residual splitting tensile strength of [10MKSCLWCand 10FASCLWC] were higher than that of SCLWC mix by [3% , 1.5%] and [2%, 0.4%] respectively, at 28 and 56 days, whereas for 10SFSCLWC was lesser than that of SCLWC mix by (7%), (7.4%) respectively. On the other hand at 600°C the residual splitting tensile strength of (10MKSCLWC and 10FASCLWC) were higher than those of the reference mix by [9%, 1.5%] and [9.7%, 3.5%] respectively at 28 and 56 days, whereas for 10SFSCLWC mix was lesser than that of SCLWC mix by [6% and 5.3%] at 28 and 56 day respectively. The presence of silica fume SF in concrete can hinder the escape of water vapor from the concrete. As a result, the pore pressure inside the concrete with SF increases, leading to the occurrence of spalling **(Hertz KD, 2003).**



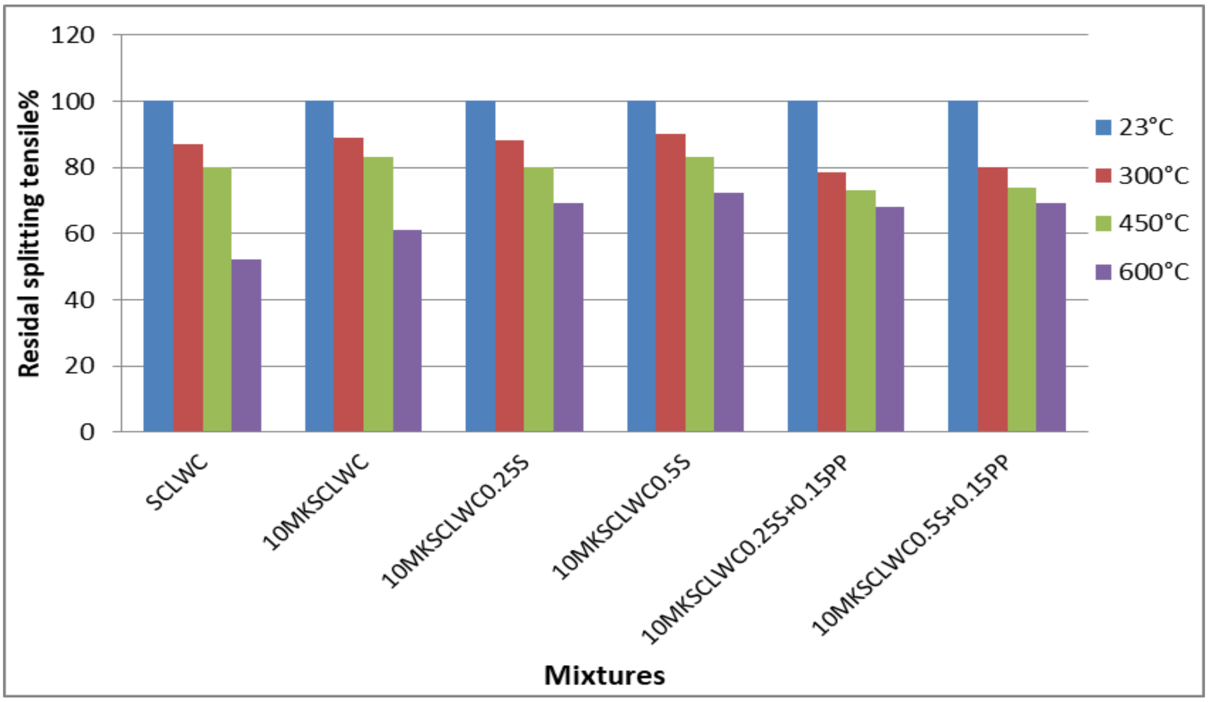
(a)



(b)

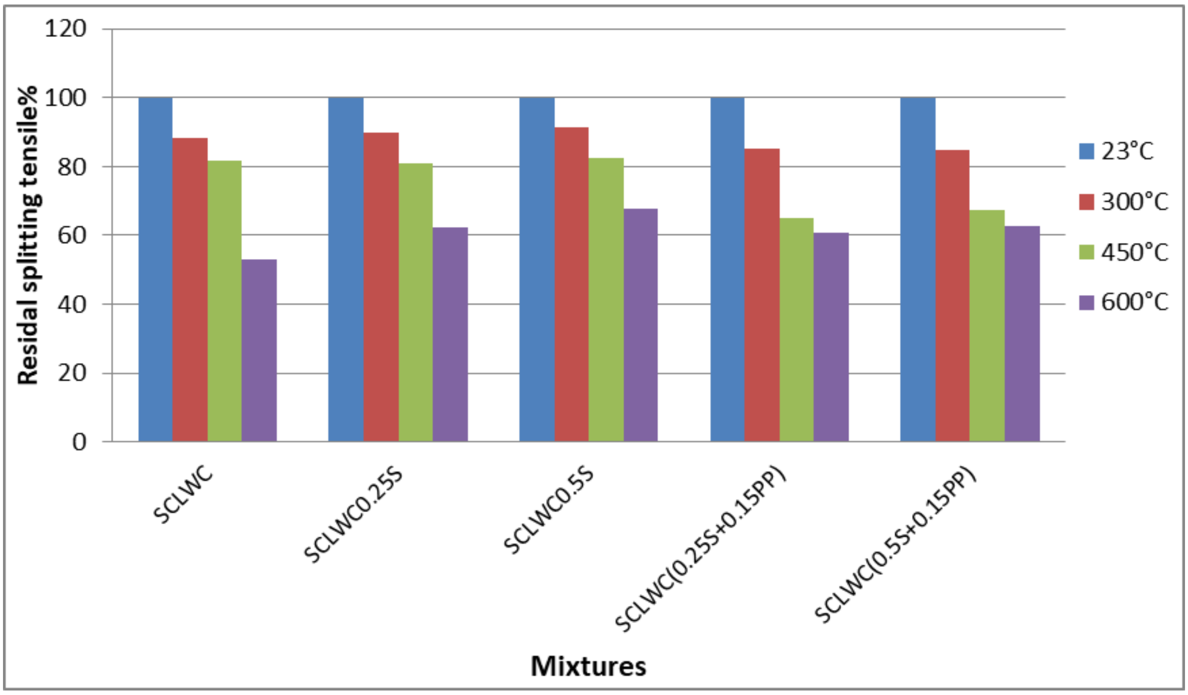


(c)



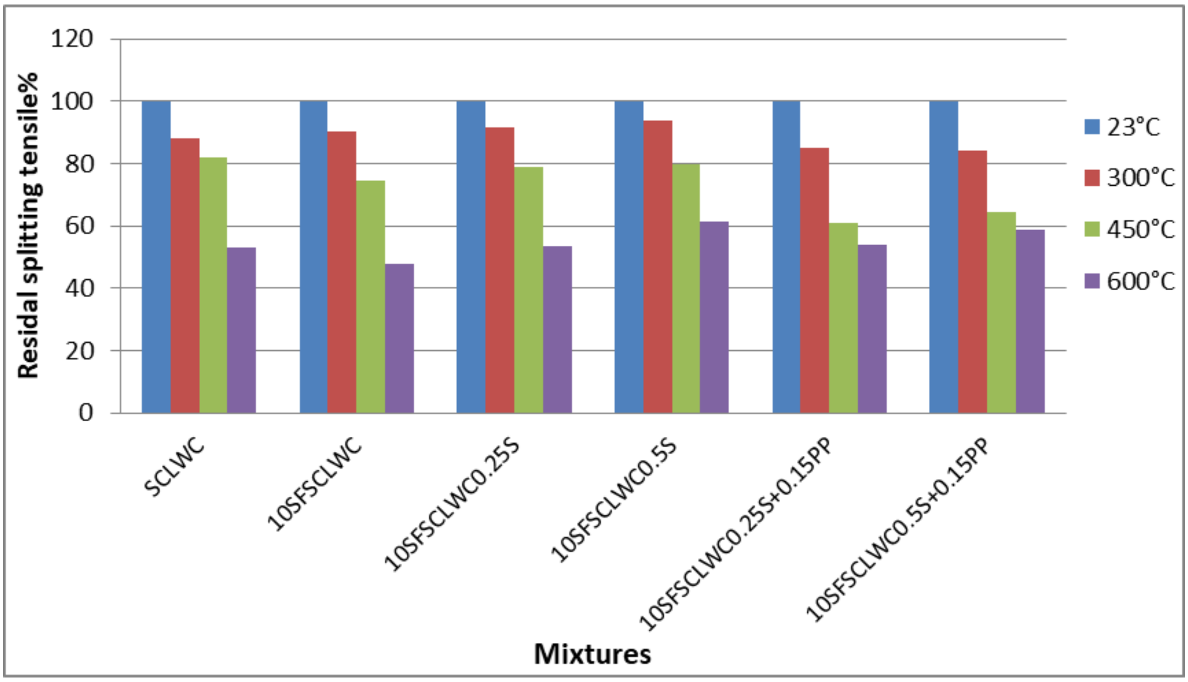
(d)

Figure (4-12) (a, b, c, d) splitting tensile strength at 28 day after fire flame exposure as a percentage of that at room temperature (at 25 °C). a) Without mineral admixture, b) SF=10%, c) FA=10%, d) MK=10%.



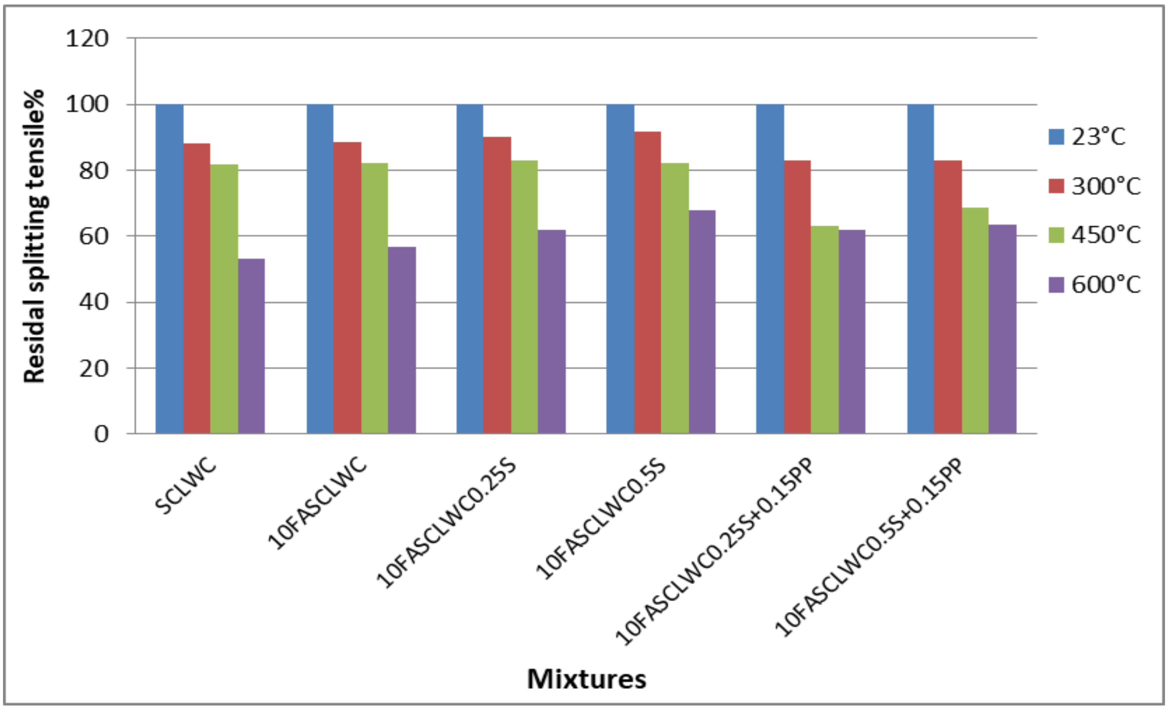
Residal splitting tensile%
120
100
80
60
40
20
0
SCLWC
SCLWC0.25S
SCLWC0.5S
SCLWC(0.25S+0.15PP)
SCLWC(0.5S+0.15PP)
Mixtures
23°C
300°C
450°C
600°C

(a)

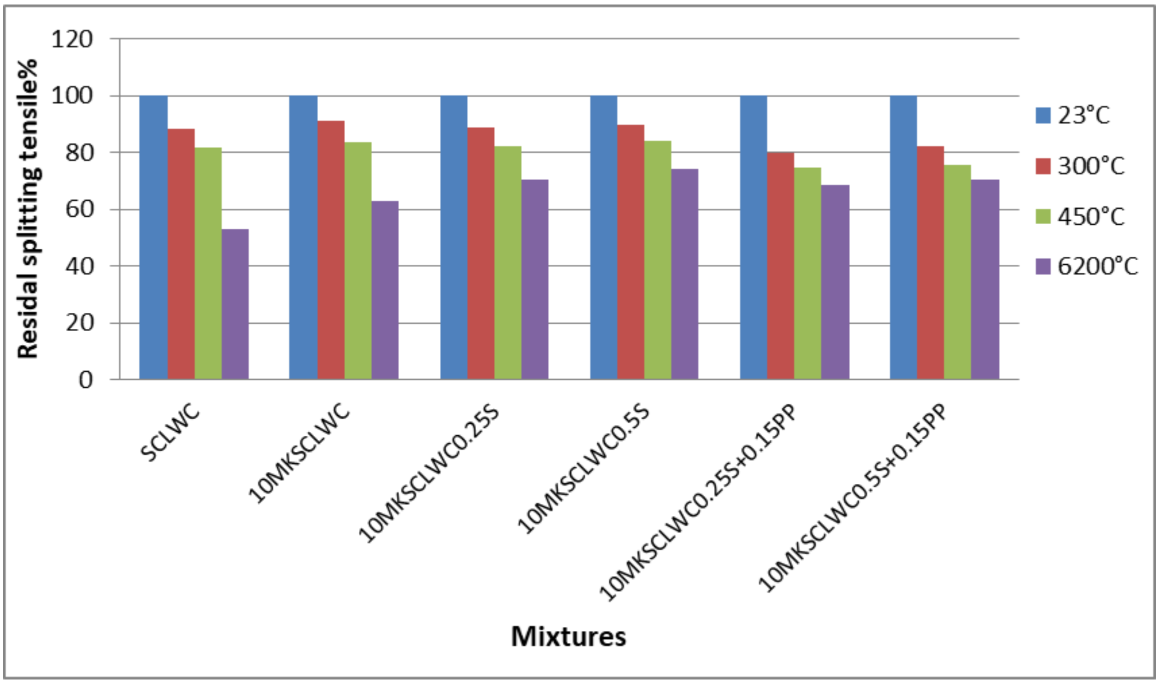


Residal splitting tensile%
120
100
80
60
40
20
0
SCLWC
10SFSCLWC
10SFSCLWC0.25S
10SFSCLWC0.5S
10SFSCLWC0.25S+0.15PP
10SFSCLWC0.5S+0.15PP
Mixtures
23°C
300°C
450°C
600°C

(b)



(c)



(d)

Figure (4-13) (a, b, c, d) splitting tensile strength at 56 day after fire flame exposure as a percentage of that at room temperature (at 25 °C). a) Without mineral admixture, b) SF=10%, c) FA=10%, d) MK=10%.

4.5.3 Flexural Tensile Strength

The mechanical properties of concrete are primarily assessed based on its flexural and compressive bearing capacities. Researchers often focus on evaluating the compressive property, given the importance of the material's flexural performance in construction applications. The significance of each mechanical property varies depending on the position of the structural element within the construction. In their study, **(Abdelmelek and Lubloy, 2021)** emphasized the evaluation of the compressive strength of concrete and its flexural performance, acknowledging the crucial role these properties play in determining the overall structural integrity and load-carrying capacity of concrete elements.

Table (4-6) Flexural Strength Values at 28 Day

Mixes	Period of exposure (hour)	Flexural tensile strength (MPa)				Residual flexural tensile strength %		
		Temperatures °C						
		25 A	300 B	450 C	600 D	300 °C	450 °C	600 °C
SCLWC	**1.0**	3.79	3.1	2.64	1.9	82.5	69.9	50
SCLWC0.25S		4.66	3.87	3.3	2.56	83	71	55
SCLWC0.5S		5.22	4.3	3.76	2.98	83	72	57
SCLWC(0.25S+0.15PP)		4.75	3.75	3.09	2.57	79	65	54
SCLWC(0.5S+0.15PP)		5.64	4.54	3.72	3.2	80.5	66	56
10SFSCLWC	1.0	4.12	3.5	2.76	1.93	85	67	47
10SFSCLWC0.25S		5.21	4.53	3.57	2.76	87	68.6	53
10SFSCLWC0.5S		6.08	5.35	4.25	3.59	88	70	59
10SFSCLWC0.25S+0.15PP		5.42	4.4	3.41	2.71	82	63	50
10SFSCLWC0. 5S+0.15PP		6.35	5.27	4.13	3.24	83	65	51
10FASCLWC		3.81	3.16	2.81	1.98	83	73.9	52
10FASCLWC0.25S		4.64	3.8	3.25	2.55	82	70	55

10FASCLWC0. 5S	1.0	5.53	4.53	3.93	3.1	82	71	56
10FASCLWC0.25S+0.15PP		4.77	3.76	2.96	2.58	79	62	54
10FASCLWC0. 5S+0.15PP		5.64	4.51	3.6	3.1	80	64	55
10MKSCLWC		4.1	3.44	2.99	2.26	84	72.9	55
10MKSCLWC0.25S		5.24	4.3	3.82	2.99	82	73	57
10MKSCLWC0. 5S	1.0	6	4.98	4.42	3.54	83	73.8	59
10MKSCLWC0.25S+0.15PP		5.5	4.45	3.68	3.03	81	67	55
10MKCLWC0. 5S+0.15PP		6.3	5.2	4.28	3.59	82	68	57

Table (4-7) Flexural Strength Values at 56 Day

Mixes	Period of exposure (hour)	Flexural tensile strength (MPa)				Residual flexural tensile Strength %		
		Temperatures °C						
		25 A	300 B	450 C	600 D	300 °C	450 °C	600 °C
SCLWC		4.4	3.68	3.14	2.28	83.7	71.4	52
SCLWC0.25S		5.22	4.41	3.81	2.93	84.6	73	56.2
SCLWC0.5S	**1.0**	5.89	4.94	4.37	3.49	84	74.2	59.3
SCLWC(0.25S+0.15PP)		5.34	4.36	3.54	2.95	81.7	66.3	55.3
SCLWC(0.5S+0.15PP)		5.97	4.91	4.11	3.4	82.3	68.9	57
10SFSCLWC		4.7	4.04	3.2	2.31	86	68.2	49.2
10SFSCLWC0.25S		5.77	5.1	4.13	3.07	88.4	71.6	53.2
10SFSCLWC0.5S	1.0	6.61	5.88	4.86	3.8	89	73.6	57.5
10SFSCLWC0.25S+0.15PP		5.96	5	3.98	3.16	83.9	66.8	53
10SFSCLWC0. 5S+0.15PP		6.72	5.7	4.62	3.56	85	68.8	52.2
10FASCLWC		4.52	3.86	3.39	2.51	85.4	75	55.6
10FASCLWC0.25S		5.36	4.51	4.04	3.04	84.3	75.5	56.8
10FASCLWC0. 5S	1.0	6.22	5.28	4.78	3.6	85	76.9	58

10FASCLWC0.25S+0.15PP		5.53	4.48	3.54	3.09	81	64.1	56
10FASCLWC0. 5S+0.15PP		6.34	5.22	4.16	3.63	82.4	65.6	57.3
10MKSCLWC	1.0	4.69	4.02	3.46	2.6	85.8	73.7	56.8
10MKSCLWC0.25S		5.85	4.91	4.3	3.45	84	74	59
10MKSCLWC0. 5S		6.57	5.51	4.92	4.02	84	75	61.2
10MKSCLWC0.25S+0.15PP		6.08	5	417	3.44	82.3	68.6	56.6
10MKCLWC0. 5S+0.15PP		6.61	5.51	4.56	3.89	83.4	69	58.9

As anticipated, in Figure (4-14) the influence of the steel and polypropylene fibers on the flexural tensile strength of concrete is considerably greater than their influence on the compressive strength of concrete .Also, Figure (4-14) demonstrates that the incorporation of mineral admixtures in SCLWC has a large impact on flexural tensile strength (before exposure to a fire flame) . This impact is attributed to the high affinity of mineral admixtures to consume calcium hydroxide within the ITZ and convert it into C-S-H. Additionally, the physical influences of mineral admixtures, particularly their influence on particle packing .

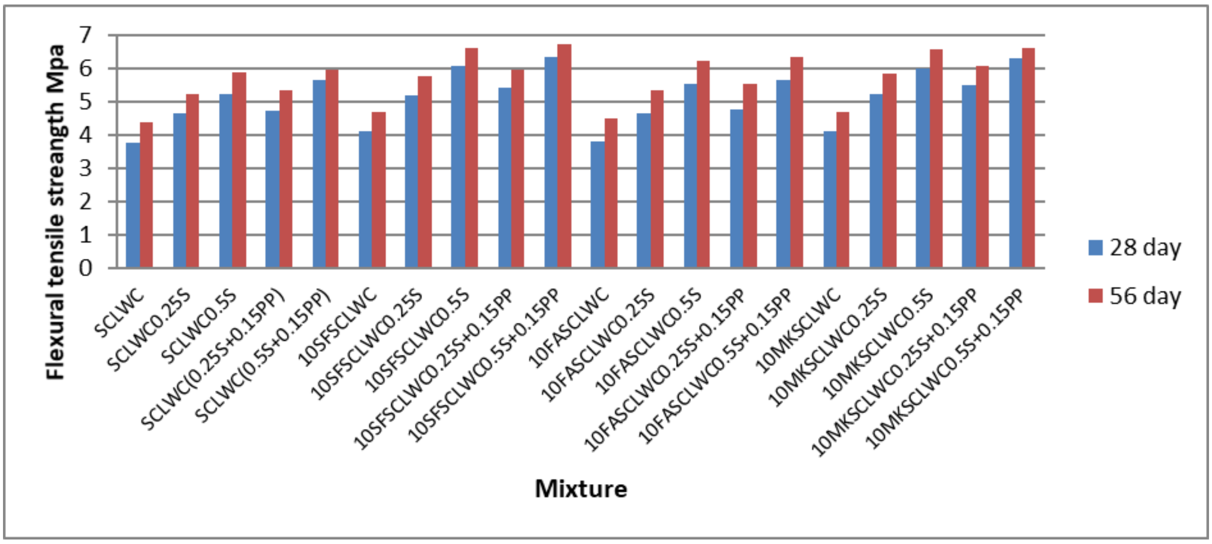
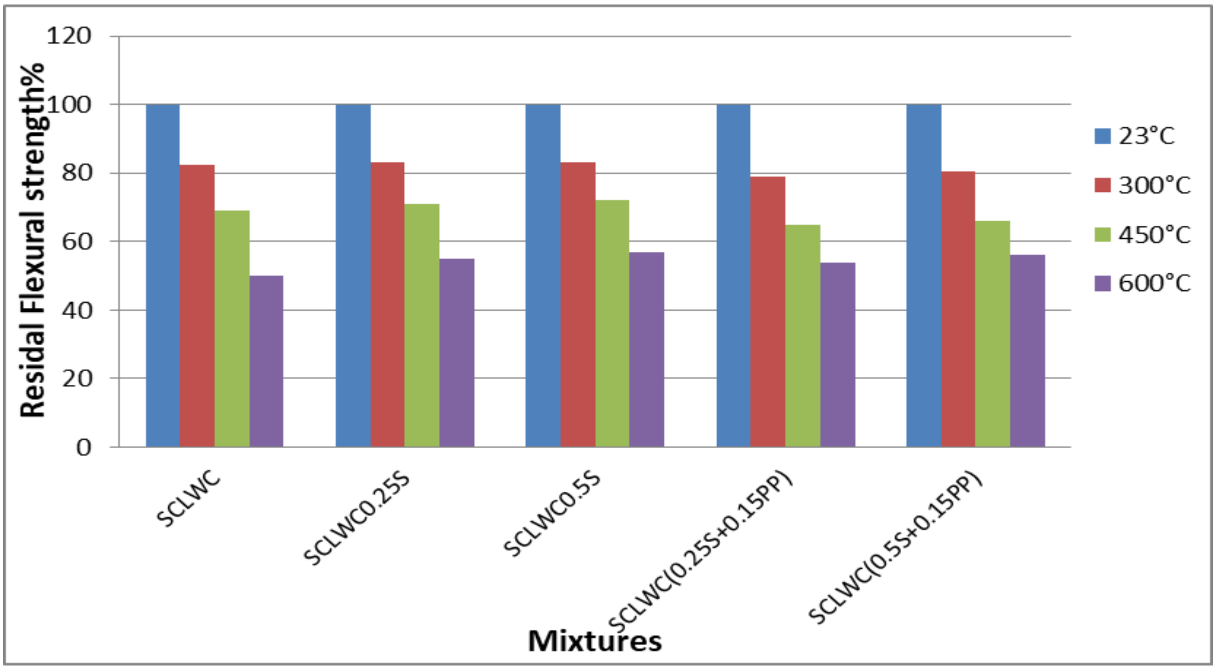


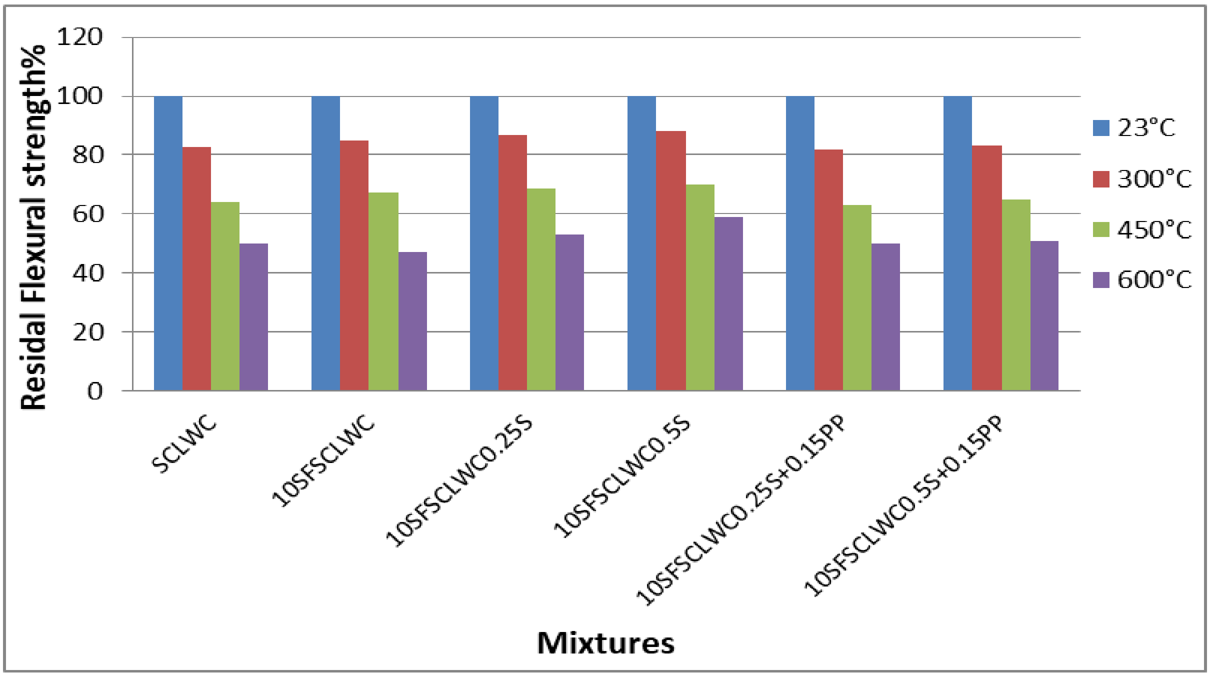
Figure (4-14) Flexural Tensile Strength Results for SCLWC Mixes Before Exposure to Fire Flame

According to Figures (4-15) and (4-16) the presence of steel fibers did not significantly affect the residual flexural strength of concrete when exposed to temperatures up to 450 °C. However, beyond this temperature, the flexural tensile strength of steel fiber-reinforced SCLWC increased as the steel fiber content increased, compared to the tensile strength of plain SCLWC at the same exposure temperature. The increase in fiber content led to an increase in the number of fibers, which improved the ability of fiber bridging and interception at the crack surface. At 600 °C, the residual flexural tensile strength of steel fibers reinforced SCLWC increased as the amount of fiber increases. Where the residual strength results of SCLWC0.25S and SCLWC0.5S mixes were higher than the residual flexural tensile strength of reference mix(the SCLWC mix) by [5%, 7%] and[4.2%, 7.3%]_at 28 and 56 day respectively . At 300°C of fire flame exposure, the residual flexural tensile strength of SCLWC(0.25S+0.15PP) and SCLWC(0.5S+0.15PP) mixes were less than the residual flexural strength of SCLWC mix by [3.5% , 2%] and [2% , 1.4%] at 28 and 56 days respectively. Whereas at 450°C the residual flexural tensile strength of these mixes were less than those on SCLWC mix by [4.9%, 3.9][5.1%, 2.5%]at 28 and 56 days respectively. On the other hand at 600°C the residual flexural strength of these mixes were higher than of those mix by_[4%, 6%] and [3.3%, 5%] at 28 and 56 days respectively.

At 300°C 0f fire flame exposure, The residual flexural tensile strength [10SFSCLWC, 10FASCLWC and 10MKSCLWC] mixes was higher than residual flexural strength of (SCLWC) reference mix by [2.5%, 0.5% and1.5 %] and [2.3%, 1.7%and2.1%] at 28 and 56 days respectively. At 450°C the residual flexural strength of [10MKSCLWC and 10FASCLWC] mix was higher than residual flexural strength of (SCLWC) mix by [3%, 4%]_and [4.8%, 3.6%] respectively at 28 and 56 days .While the residual flexural strength for [10SFSCLWC] mix was lower than that of residual flexural strength of SCLWC mix by [2.9% and 3.2%] respectively at 28 and 56 days. Whereas at 600°C of fire exposure the residual flexural strength of [10MKSCLWC and 10FASCLWC]mixes was higher than those of SCLWC mix by [5%, 2%] and [4.8%, 3.6%] respectively at 28 and 56 days, while for 10SFSCLWC was lower than those of SCLWC mix by [3% and 2.8%] at 28 and 56 day respectively. . Concrete incorporating MK as a weight-based replacement for cement exhibits superior heat resistance compared to the optimal replacements of SF and FA. This discrepancy could be attributed to the distinctive morphological characteristics and chemical compositions of MK, which encompass angular particle shapes along with elevated levels of Al2O3 and SiO2. **(Abdelmelek, N, Lubloy, E, 2021)**

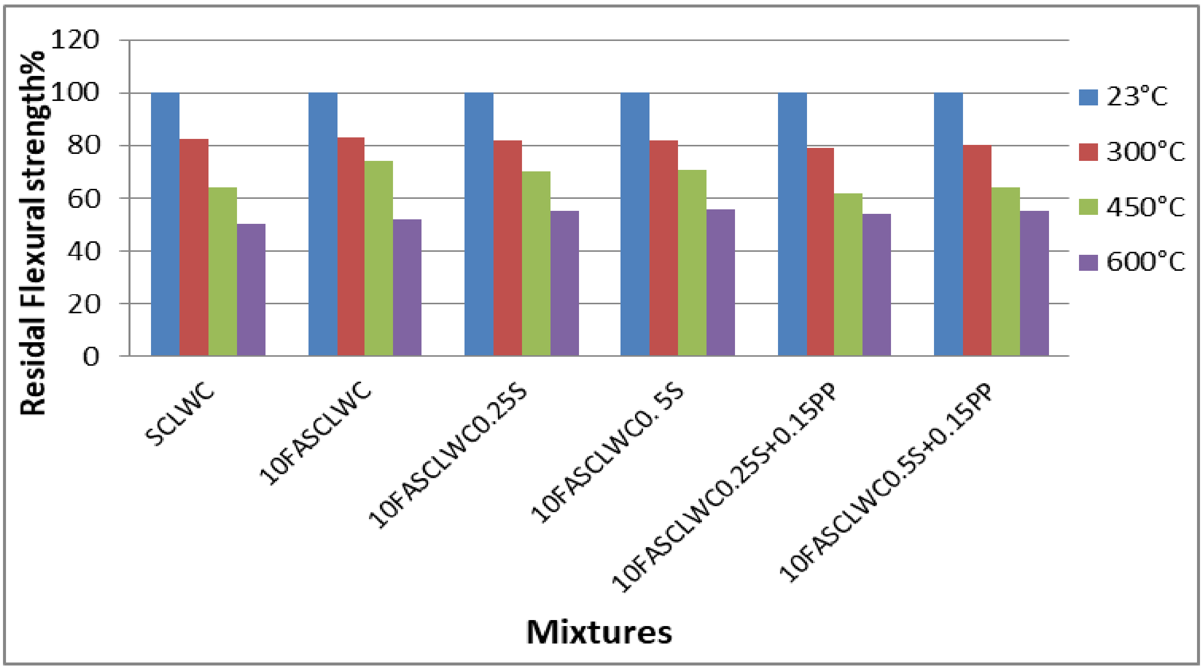


(a)



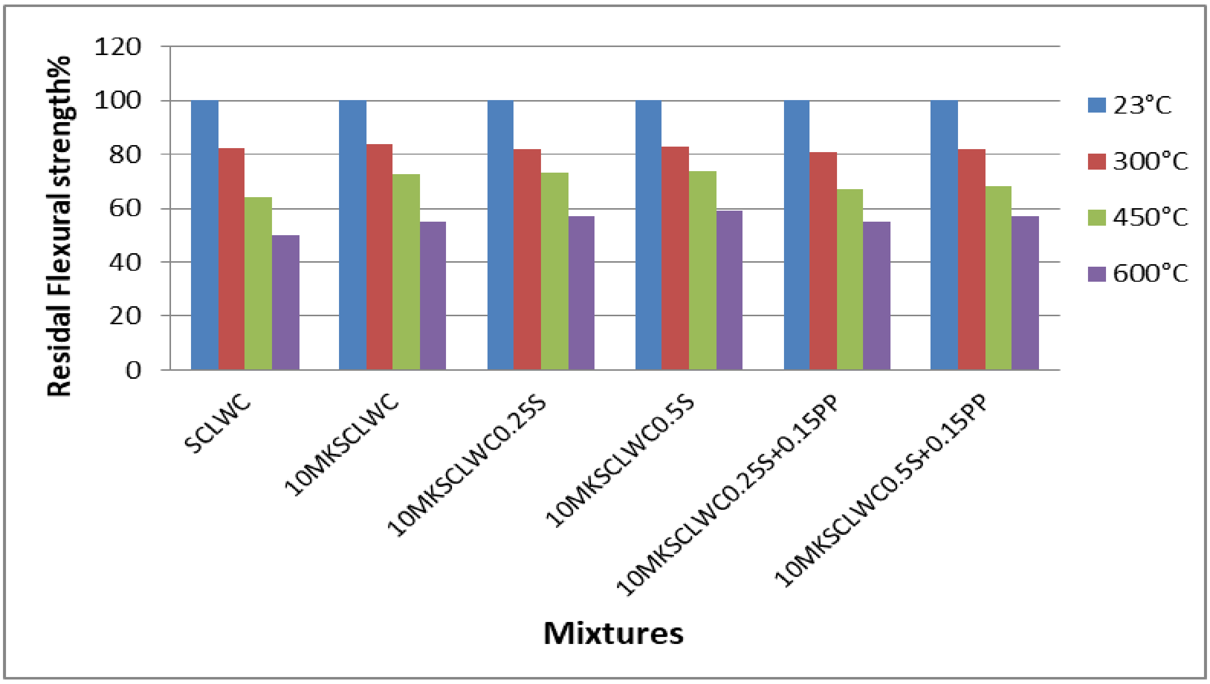
Residual Flexural strength%
120
100
80
60
40
20
0
SCLWC
10SFSCLWC
10SFSCLWC0.25S
10SFSCLWC0.5S
10SFSCLWC0.25S+0.15PP
10SFSCLWC0.5S+0.15PP
Mixtures
23°C
300°C
450°C
600°C

(b)



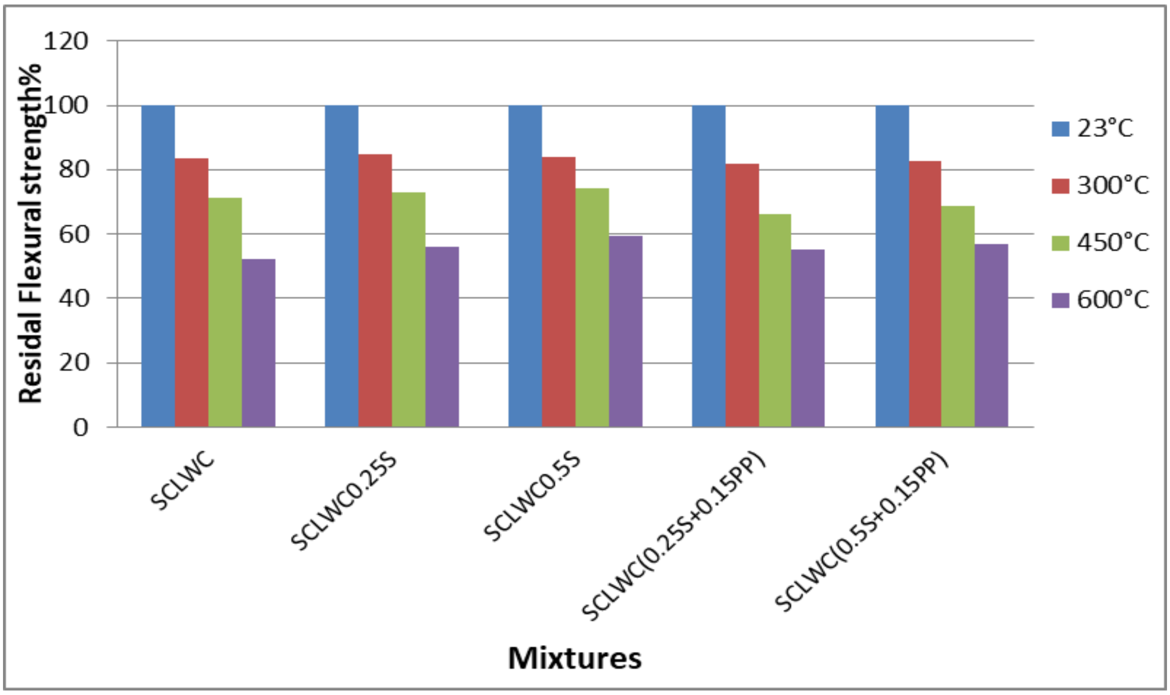
Residual Flexural strength%
120
100
80
60
40
20
0
SCLWC
10FASCLWC
10FASCLWC0.25S
10FASCLWC0. 5S
10FASCLWC0.25S+0.15PP
10FASCLWC0.5S+0.15PP
Mixtures
23°C
300°C
450°C
600°C

(c)

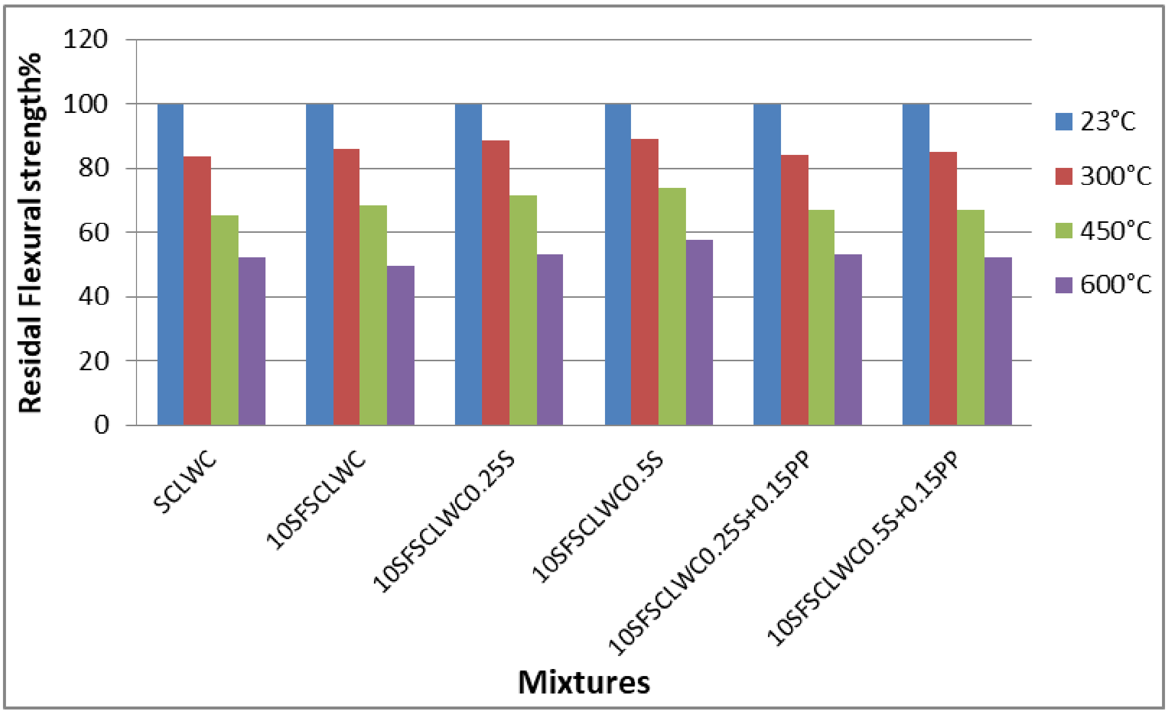


(d)

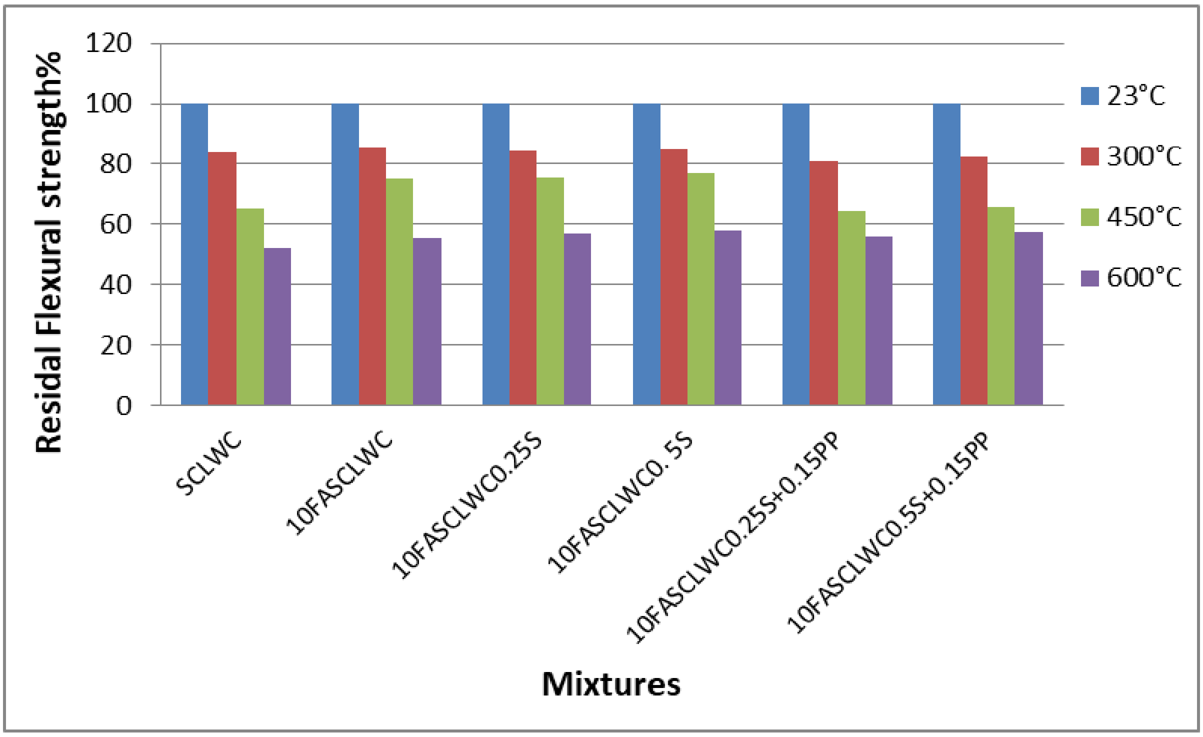
Figure (4-15) (a, b, c, d) residual flexural tensile strength at 28 day after fire flame exposure as a percentage of that at room temperature (at 25 °C). a) Without mineral admixture, b) SF=10%, c) FA=10%, d) MK=10%.



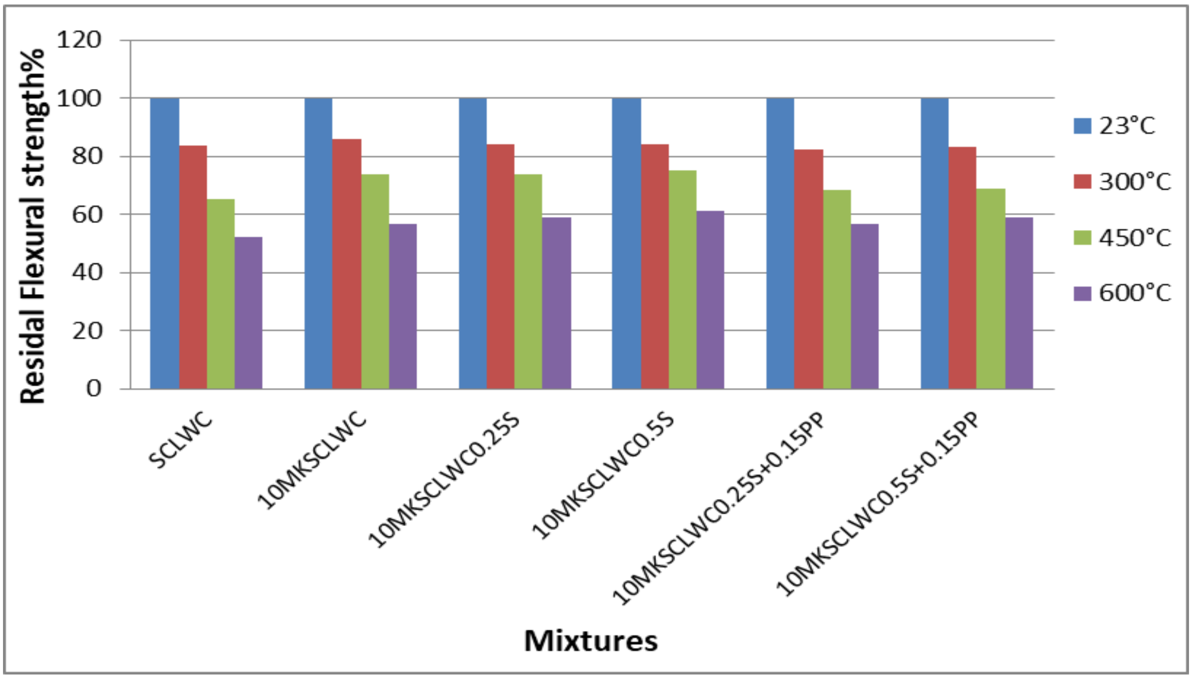
(a)


Residal Flexural strength%
120
100
80
60
40
20
0
SCLWC
10SFSCLWC
10SFSCLWC0.25S
10SFSCLWC0.5S
10SFSCLWC0.25S+0.15PP
10SFSCLWC0.5S+0.15PP
Mixtures
23°C
300°C
450°C
600°C

(b)


Residal Flexural strength%
120
100
80
60
40
20
0
SCLWC
10FASCLWC
10FASCLWC0.25S
10FASCLWC0. 5S
10FASCLWC0.25S+0.15PP
10FASCLWC0.5S+0.15PP
Mixtures
23°C
300°C
450°C
600°C

(c)



(d)

Figure (4-16) (a, b, c, d) residual flexural tensile strength at 56 day after fire flame exposure as a percentage of that at room temperature (at 25 °C). a) Without mineral admixture, b) SF=10%, c) FA=10%, d) MK=10%.

4.6 Ultrasonic Pulse Velocity

Ultrasonic pulse velocity (UPV) testing is a widely used technique for assessing the quality of concrete in various structures. However, it is essential to consider several factors that can influence the measured pulse velocity of concrete. These factors include the smoothness of the concrete surface, temperature of the specimen, moisture conditions, and age of the specimen. Proper consideration and control of these factors are crucial for obtaining accurate and reliable UPV values. The UPV values obtained from testing are valuable for detecting the presence of cracks, voids, and other imperfections inside the concrete. It serves as a non-destructive method to evaluate the internal condition of concrete structures without causing any damage. Tables (4-8) and (4-9) present the results of UPV testing with and without the presence of fibers in the concrete. The results show similar behavior for both compressive strength .It is clear from the results that using (SF,FA and MK) with SCLWC helps to improve the structure of the aggregate / mortar interface, get high density as that of the bulk mortar and thus the least the number of interfaces that lie in the path of the ultrasonic wave.

Table (4-8) Ultrasonic Pulse Velocity Values for All Mixes at 28 Day

Mixes	Period of exposure (hour)	Ultrasonic pulse velocity m/sec			
		Temperatures °C			
		25 A	300 B	450 C	600 D
SCLWC	**1.0**	Good	Medium	Poor	Poor
SCLWC0.25S		Good	Medium	Medium	Poor
SCLWC0.5S		Good	Good	Medium	Poor
SCLWC(0.25S+0.15PP)		Good	Medium	Poor	Poor
SCLWC(0.5S+0.15PP)		Good	Medium	Poor	Poor
10SFSCLWC	1.0	Good	Good	Poor	Poor
10SFSCLWC0.25S		Good	Good	Poor	Poor
10SFSCLWC0.5S		Good	Good	Medium	Poor
10SFSCLWC0.25S+0.15PP		Good	Good	Poor	Poor
10SFSCLWC0. 5S+0.15PP		Good	Good	Poor	Poor
10FASCLWC	1.0	Good	Medium	Medium	Poor
10FASCLWC0.25S		Good	Medium	Medium	Medium
10FASCLWC0. 5S		Good	Good	Medium	Medium
10FASCLWC0.25S+0.15PP		Good	Medium	Poor	Poor
10FASCLWC0. 5S+0.15PP		Good	Good	Poor	Poor
10MKSCLWC	**1.0**	Good	Medium	Medium	Poor
10MKSCLWC0.25S		Good	Good	Medium	Poor
10MKSCLWC0. 5S		Good	Good	Medium	Poor
10MKSCLWC0.25S+0.15PP		Good	Medium	Poor	Poor
10MKCLWC0. 5S+0.15PP		Good	Medium	Poor	Poor

Table (4-9) Ultrasonic Pulse Velocity Values for All Mixes at 56 Day

Mixes	Period of exposure (hour)	Ultrasonic pulse velocity m/sec			
		Temperatures °C			
		25 A	300 B	450 C	600 D
SCLWC	**1.0**	Good	Medium	Medium	Poor
SCLWC0.25S		Good	Good	Medium	Poor
SCLWC0.5S		Good	Good	Medium	Medium
SCLWC(0.25S+0.15PP)		Good	Medium	Poor	Poor
SCLWC(0.5S+0.15PP)		Good	Medium	Poor	Poor
10SFSCLWC	1.0	Good	Good	Medium	Poor
10SFSCLWC0.25S		Good	Good	Medium	Poor
10SFSCLWC0.5S		Good	Good	Medium	Poor
10SFSCLWC0.25S+0.15PP		Good	Good	Poor	Poor
10SFSCLWC0. 5S+0.15PP		Good	Good	Poor	Poor
10FASCLWC	1.0	Good	Good	Medium	Poor
10FASCLWC0.25S		Good	Good	Medium	Medium
10FASCLWC0. 5S		Good	Good	Medium	Poor
10FASCLWC0.25S+0.15PP		Good	Medium	Poor	Poor
10FASCLWC0. 5S+0.15PP		Good	Good	Poor	Poor
10MKSCLWC	1.0	Good	Good	Medium	Poor
10MKSCLWC0.25S		Good	Good	Medium	Medium
10MKSCLWC0. 5S		Good	Good	Medium	Medium
10MKSCLWC0.25S+0.15PP		Good	Good	Poor	Poor
10MKCLWC0. 5S+0.15PP		Good	Good	Poor	Poor

It can be noticed from Figures (4-17) and (4-18) the SCLWC incorporating steel fibers showed a lesser degree of UPV loss than the plain SCLWC mixes However, with further increase in exposure temperature the residual UPV of steel fiber-reinforced SCLWC increased in comparison with residual values of plain SCLWC. As shown at 600 °C, the residual UPV of (SCLWC0.25S) and

(SCLWC0.5S) mixes were higher than the value corresponding to the reference mix by [10%,13%] [11.4%,14.1] respectively at 28 and 56 days . This can be attributed to the fact that the presence of steel fibers in concrete repress crack formation and consequently they can reduce deterioration of concrete.

Also, Figures (4-17) and (4-18) reveal that the residual UPV of (SCLWC0.25S+0.15PP) and (SCLWC0.5S+0.15PP) mixes were lower than that the residual UPV of reference mix at 300 °C and 450 °C. In fact, at 160 °C, the reduction in the volume of polypropylene fibers due to the melting starts to happen. As the temperature increases, the fibers will degrade, beginning to ignite at temperatures close to 360 °C. This is leading to increased porosity and microcracking **(Nahla Naji, 2012).**

In contrast, at 600 °C the results for these mixes were higher than those of the reference mix (the SCLWC mix) by [3%, 4%][4.3,4.2] at 28 and 56 days respectively . The decreasing trend in the ultrasonic pulse velocity of (SCLWC) concrete exposed to fire can be attributed to several factors. As the temperature rises, the water content inside the SCLWC evaporates, causing chemical components to decompose, and leading to the gradual growth of micro-cracks and pores within the concrete.

Due to the propagation property of sound waves, when the ultrasonic pulse travels through the fire-affected concrete, a portion of the sound wave gets reflected upon encountering air pockets or voids formed by evaporation and decomposition. Another portion of the sound wave directly traverses through the air gaps, while the remaining part of the sound wave detours through the concrete and continues to propagate. The behavior of (10SFSCLWC, 10FASCLWC and 10MKSCLWC) mixes in terms of residual UPV was somewhat similar to that of residual compressive strength for these mixes at 300°C, 450°C and 600°C.

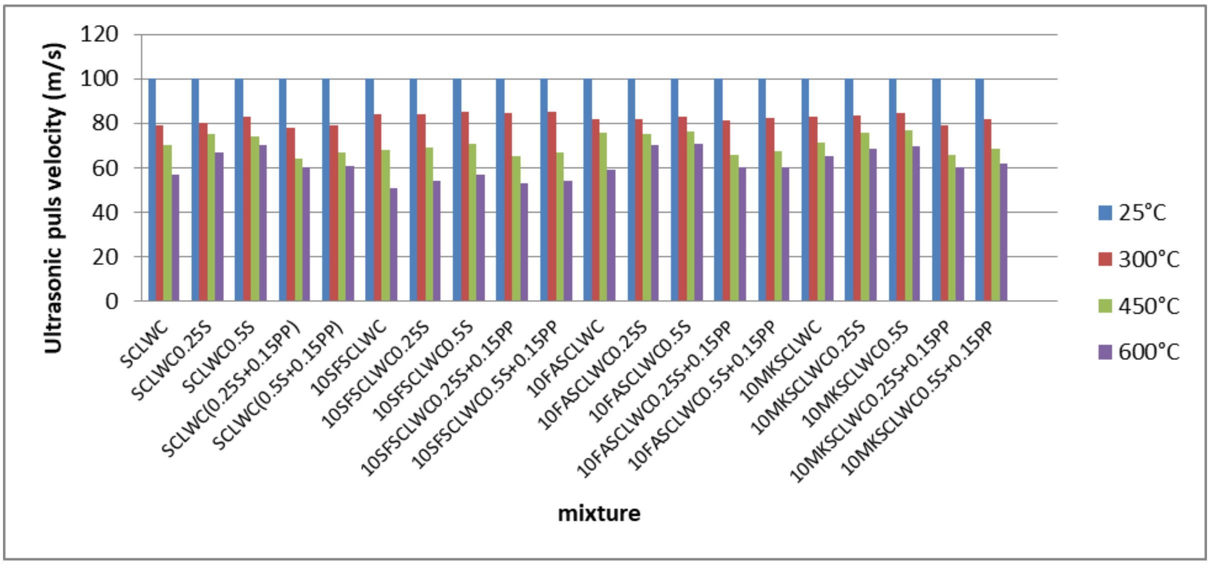


Figure (4-17) Residual Ultrasonic Pulse Velocity at 28 Day After Fire Flame Exposure as a Percentage of That at Room Temperature (at 25°C)

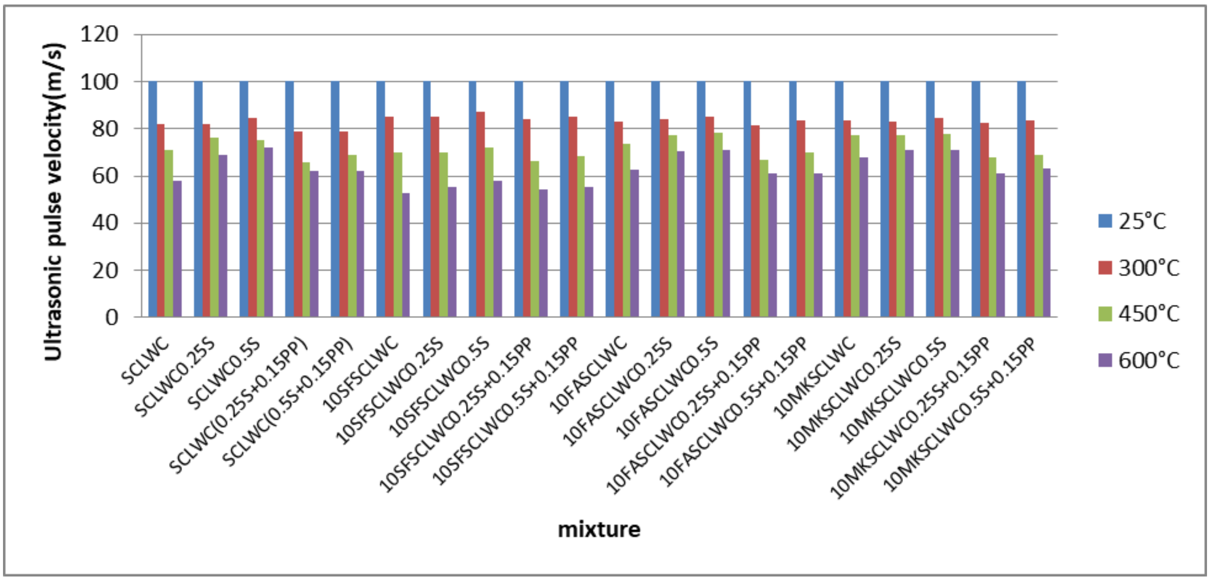


Figure (4-18) Residual Ultrasonic Pulse Velocity at 56 Day after Fire Flame Exposure as a Percentage of that at Room Temperature (at 25°C)

4.7 Oven Dry Density

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. Table (4-10) and Figure (4-19) present the test outcomes for the oven-dry density of all SCLWC mixes at 28 and 56 days. The relatively high variation of this property among mixes was due to the amount of micro steel fiber, The reduction in oven dry density when compared to fresh density which was given in Figure (4-6) primarily due to the improved binding ratio. In fact, a significant portion of the decrease may have been due to LECA's greater water absorption (12%) which contributed to the increased in loss of moisture throughout oven drying **(Nahhab, A. H., and Ketab, A. K. 2020).**

The effects of the binders of mineral admixture blends on the oven dry density of blended cement concrete are shown in Table (4-10). the oven dry density of (10SFSCLWC, 10FASCLWC and 10MKSCLWC) mixes was (1776, 1787 and 1792)kg/m3 and (1781, 1793 and 1799) kg/m3 at 28 and 56 days respectively ,while the oven dry density of SCLWC mix was (1810 and 1818) kg/m3 at 28 and 56 days, respectively. This result can be attributed to the fact that the specific gravity of the pozzolanic materials is considerably lower than that of cement. The specific gravity of (SF, FA and MK) was measured to be 2.2, 2.35 and2.5 respectively. The oven dry density of all the types of SCLWC mixes increases with curing age. Consequently, a greater amount of Ca(OH)2 is utilized, resulting in an increased formation of cement gel. This, in turn, serves to diminish the gaps present between individual cement particles and microcracks within the (ITZ), leading to a favorable impact on density, as illustrated in Figure (4-19).

Table (4-10) Oven Dry Density Values

Mixes	Oven dry density (Kg/m^3)	
	28 day	56 day
SCLWC	1810	1818
SCLWC0.25S	1826	1833
SCLWC0.5S	1835	1840
SCLWC(0.25S+0.15PP)	1826	1834
SCLWC(0.5S+0.15PP)	1834	1840
10SFSCLWC	1776	1781
10SFSCLWC0.25S	1787	1788
10SFSCLWC0.5S	1804	1792
10SFSCLWC0.25S+0.15PP	1788	1788
10SFSCLWC0. 5S+0.15PP	1804	1791
10FASCLWC	1787	1793
10FASCLWC0.25S	1802	1809
10FASCLWC0. 5S	1817	1822
10FAFSCLWC0.25S+0.15PP	1801	1810
10FASCLWC0. 5S+0.15PP	1818	1821
10MKSCLWC	1792	1799
10MKSCLWC0.25S	1806	1812
10MKSCLWC0. 5S	1820	1828
10MKSCLWC0.25S+0.15PP	1805	1813
10MKSCLWC0. 5S+0.15PP	1821	1829

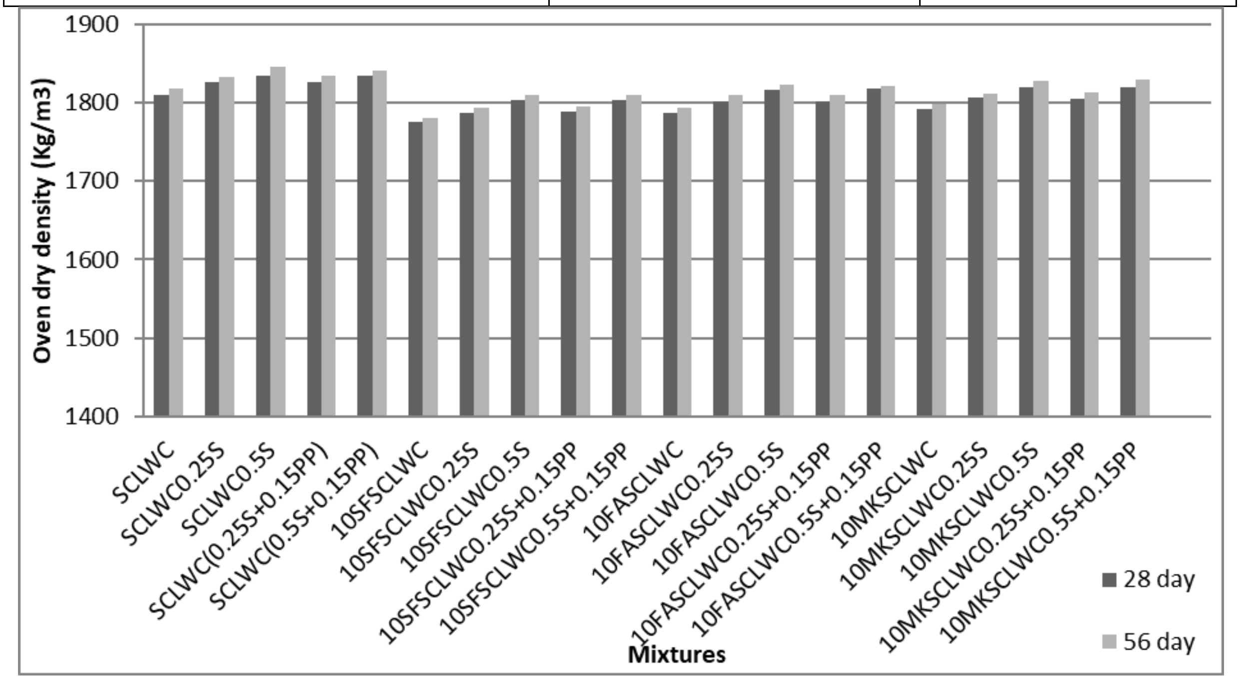
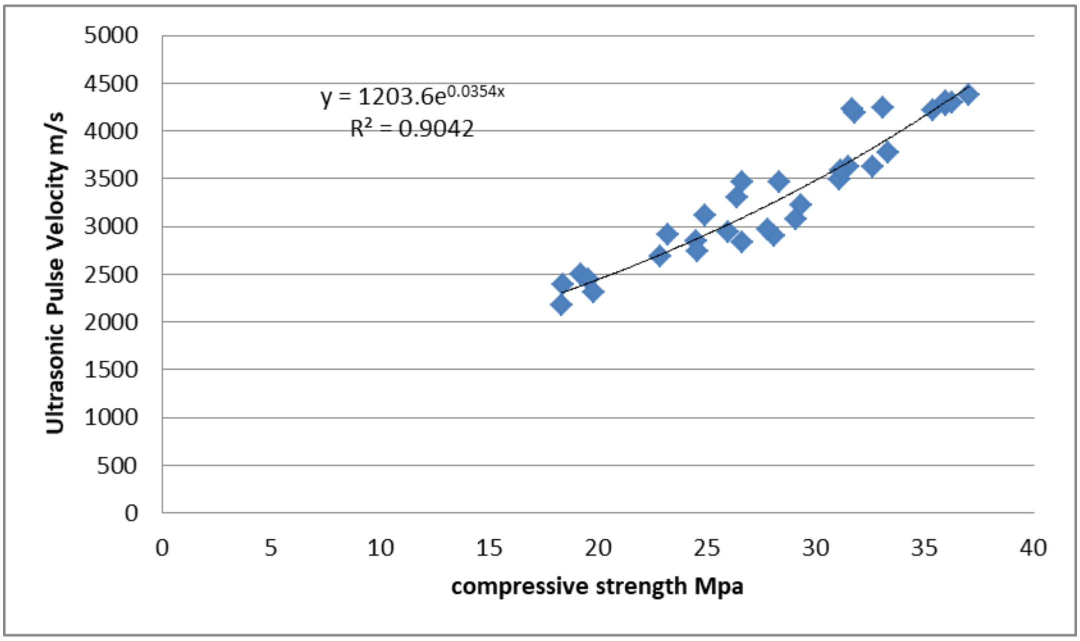


Figure (4-19) Oven Dry Density

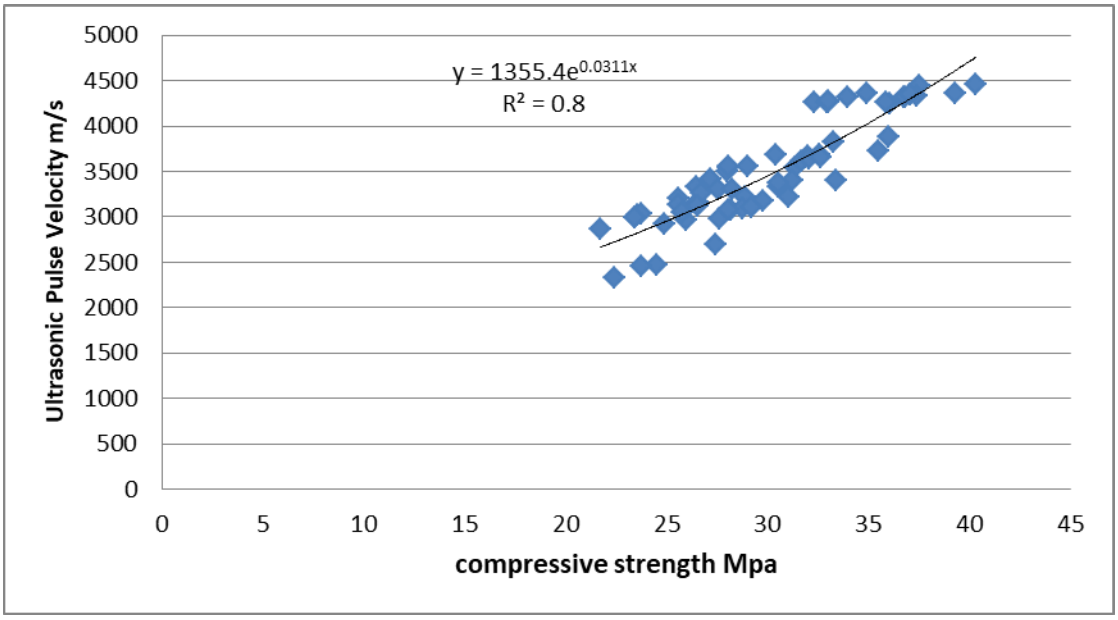
4.8 Relationships of Ultrasonic Pulse Velocity with Compressive strength

The general trend in compressive strength behavior is also shown in the results of this investigation regarding the effect of fire flame on SCLWC mixes with fibers and mineral admixtures. This connection results from the fact that the high temperature has an impact on both compressive strength and UPV, though not to the same extent. Thus, it would be convenient to find out reliable relationships between the compressive strength and UPV of plain and reinforced SCLWC mixes. The relationships that were found between compressive strength and UPV are plotted in Fig. (4-20) (a, b, c).

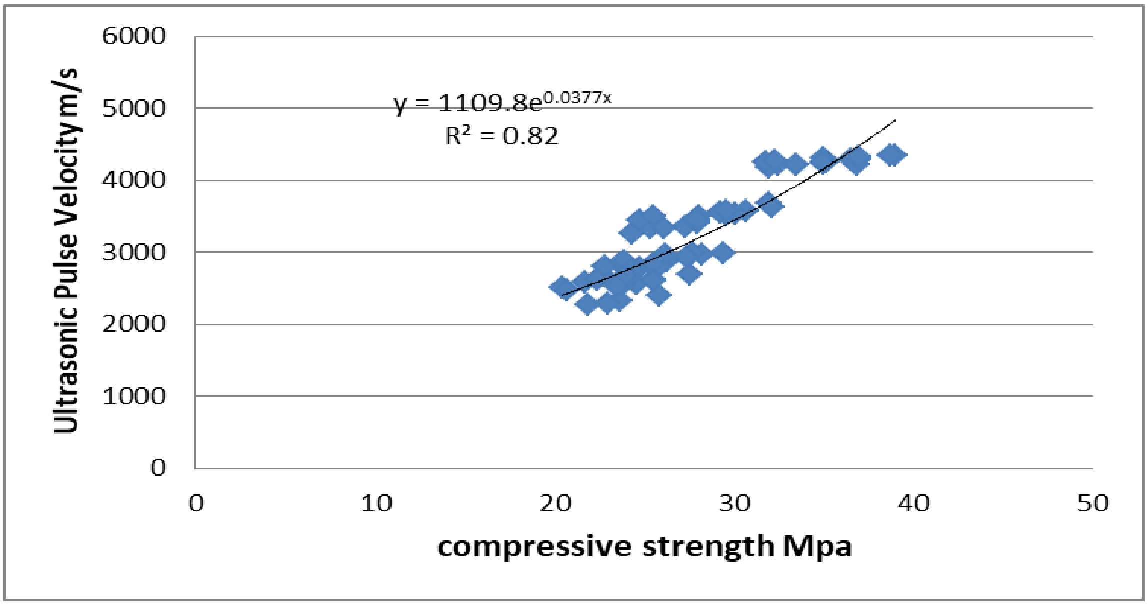
The proposed equations and their coefficients of determination (R^2) are also clarified. The values of (R^2) reveal that there is a good correlation between ultrasonic pulse velocity and compressive strength.



(a) The relationship between compressive strength and UPV for concrete without fibers



(b)The relationship between compressive strength and UPV for concrete with steel fibers



(c)The relationship between compressive strength and UPV for concrete with Hybrid fibers

Figure (4-20) (a, b, c) the relationship between compressive strength and UPV for concrete

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Depending on the experimental investigation of this study and the interpretation of the consequences, the following conclusions are drawn:

1- The addition of steel fibers resulted in an increase in the fresh density of self-compacting lightweight concrete (SCLWC). On the other hand, the inclusion of polypropylene fibers in hybrid fibrous concrete did not result in any significant reduction in fresh density when compared with plain SCLWC.

2- Fresh density was reduced when mineral admixtures were used in SCLWC, and the reduction value depends on the type and density (specific gravity) of the mineral admixtures. The percentages of reduction were (2.1%, 1.3%, 0.95%) for mixes containing 10% of (SF, FA and MK) respectively.

3- As the volume fraction of fibers increased, the required dosage of superplasticizer (SP) to achieve the target slump flow also increased. Additionally, both T50cm and V-funnel flow time became longer, indicating an increase in viscosity.

4- Using mineral admixtures (SF, MK, and FA) in SCLWC led to an increase in the SP dosage, T500 and v- funnel but reduced the H2/H1 ratio of L box.

5- The presence of steel fibers did not influence the variation of the compressive strength, splitting tensile strength, and flexural strength of SCLWC below 450 °C.

6- At 600 °C, the residual (compressive, splitting tensile and flexural) strengths of steel fiber-reinforced SCLWC mixes were higher than the value corresponding to the plain SCLWC mixes.

7- Incorporating mixed steel and polypropylene fibers into SCLWC resulted in enhanced residual (mechanical properties) of the SCLWC when exposed to a fire temperature of 600°C, in comparison with plain SCLWC mix. The percentages of increment in residual of (compressive strength, splitting tensile strength and flexural strength) for SCLWC(0.25S+0.15PP) were (6%, 7% and 4%) and (7.6%, 7.6% and 3.3%) at 28 and 56 day respectively , while the percentages of increment in residual (compressive , splitting tensile and flexural) strengths for (SCLWC(0.5S+0.15PP) mix were (9%, 9%, and 6%) and (9.35%, 9.5% and 5%) at 28 and 56 day respectively.

8- The steel fibers were not effective enough to totally prevent spalling during the fire test, even with large quantities, while the use of polypropylene (even with only 0.15% by volume) and steel fibers in hybrid SCLWC improved the resistance to spalling.

9- At 300 °C, the residual (compressive, splitting tensile, and flexural tensile) strengths for mixes containing mineral admixtures (SF, FA, and MK) were higher than the value corresponding to the SCLWC mixes without mineral admixtures.

10- After exposure to 600°C, the 10MKSCLWC mix gave more residual compressive strength than the (SCLWC, 10SFSCLWC and 10FASCLWC mixes) by about (3%, 10% and 0.3%) (4.6%, 10.4%, 0.5%) at 28 and 56 day respectively.

11- At 600°C of fire flame, the (10MK SCLWC) mix gave more residual splitting tensile strength than the (SCLWC, 10SFSCLWC and 10FASCLWC mixes), by (9%, 15% and 2%) (9.7%, 15.6%, 2%) at 28 and 56 day respectively.

12- The (10MKSCLWC) mix gave more residual flexural tensile strength than the (SCLWC, 10SFSCLWC and 10FASCLWC mixes) by about (5%, 8% and 3%) (4.8%, 7.6%, 1.2%) at 28 and 56 day respectively, at 600 °C

13- After exposure to 600°C, the 10MKSCLWC mix gave more residual ultrasonic pulse velocity than the (SCLWC, 10SFSCLWC and 10FASCLWC mixes) by about (8%, 14% and 6%) (10.1%, 15.1%, 5.4%) at 28 and 56 day respectively.

14- After exposure to 600°C, partial spalling has occurred on a mixes containing SF (10% replacement by weight of cement), because the porosity decreases in the presence of 10% SF. Therefore, using 10% SF replacements for cement is not recommended.

5.2 Recommendations

From this study, the following can be recommendations for future works:

1- Studying the impact of fire flame on the behavior of self-compacting light weight concrete beams.
2- Studying the impact of elevated temperatures on the properties of SCLWC using different types of light weight aggregates such as natural pumice and perlite
3- Studying the effect of different types of admixtures, such as fly ash, silica fume, and metakaolin on the resistance of LWSCC to internal sulfate attack.
4- An investigation is required to study the durability properties of SCLWC reinforced with diversified types of fibers, such as glass fibers and basalt fibers.

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