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Combined Effect of High Temperature and Different Supplementary Cementitious Materials on the pH and Some Mechanical Properties of Concrete.

A Thesis

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in Partial Fulfillment of the Requirements for the Degree of
Master in Engineering/Civil Engineering/Construction Materials**

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

وَأَنْزَلْنَا إِلَيْكَ الْكِتَابَ فِيهِ تَحْفَظُوا فِيهِ فَاكْرُمُوا

وَأَجْعَلُوا لَهُ سَبِيلًا مَسْرُورًا

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

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Abstract

Recently, and as a result of the great development that has taken place, especially with regard to the production of sustainable concrete by reducing the amount of cement that generates large quantities of carbon dioxide gas during its manufacture, various supplementary cementitious materials (silica fume, metakaolin, lime stone powder and ground granulated blast furnace slag and etc.) have been used as a replacement for cement to produce concrete with distinctive specifications and environmentally friendly. Knowing that, these various supplementary cementitious materials in concrete react slowly with the products of hydration reactions (Calcium Hydroxide) to produce cement compounds that contribute to improving some mechanical properties of concrete.

This research studied the dual action of high temperature and different supplementary cementitious materials (silica fume, metakaolin, lime stone powder and ground granulated blast furnace slag) as a substitution material of cement in concrete with different concrete age (7, 28 and 90) days. Substitution proportion ratios were 10%, 20%, 30% and 40%.

Concrete hardened characteristics compressive strength, flexural strength, and splitting tensile strength were studied. All samples were studied at 23°C and three high temperatures (150°C, 350°C, and 550°C) at 1.5 hours.

The combined effect of high temperature (150°C, 350°C and 550°C) with the use of different percentages (10%, 20%, 30% and 40%) various Supplementary cementitious materials (silica fume, metakaolin, lime stone powder and ground granulated blast furnace slag) as a replacement for cement and its effect on the alkalinity level of concrete was also studied. The apparent or surface PH was tested for several ages of concrete (1,7,28 and 90) days.

Results showed that drop in mechanical properties of concrete decreased with increasing temperature as supplementary cementitious materials (silica fume, metakaolin, lime stone powder and GGBS) replacing ratio increased.

Among the best supplementary cementitious materials used, the use of silica fume as a replacement for cement by 30% leads to the production of concrete that resists exposure to high temperatures up to 550 degrees Celsius (the lowest decrease in

compressive strength reaches (10.48%) better than ordinary concrete without replacement and especially at older ages (90 days).

using metakaolin and GGBS as replacement from cement by 20% and 40% respectively lead that less drop in compressive strength (23.29%) and (23.81%) respectively after using material silica fume in 90 days ages at 550C° temperature, while using limestone powder is large descend in compressive strength (27.80%) with replacement 20% from cement compared to author SCMs (silica fume, metakaolin, GGBS) at high temperature 550C° in 90 days ages.

The effect of these materials (SMCs) on splitting tensile strength and flexural is less compared to the compressive strength when concrete is exposed to high temperatures, the less drop in splitting tensile strength of concrete is (29.70%) in use 10% silica fume as replacement with cement compared to concrete without replacement and others supplementary cementitious materials (metakaolin, lime stone powder), while the minimum descend in flexural strength of concrete is (36.06%) in 10% metakaolin as replacement with cement compared to the concrete without replacement and others supplementary cementitious materials (silica fume, lime stone powder, GGBS).

The effect of these materials (supplementary cementitious materials) as a replacement (10%,20%,30%, and 40%) for cement in concrete leads to a decrease in the apparent pH value when concrete is exposed to high temperatures up to 550 C° especially for later ages (more than 28 days).

When limestone powder is used as a 40% replacement for cement, the apparent pH value decreases by (7.41%) when concrete is exposed to high temperatures up to 550 C°, while the best drop in pH of concrete is (1.9%) in 30% silica fume as replacement with cement compared to others supplementary cementitious materials (metakaolin, lime stone powder, GGBS).

Resulting in the best-hardened characteristics of concrete, as age progressed for concrete from 7 days to 90 days, drop-in hardening characteristics reduced gradually.

Finally, results showed that pH was slightly decreasing in age (1, 7, 28 and 90) days for all temperatures.

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List of Abbreviations & Notations

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British Standard
CH	Calcium Hydroxide
C–S–H	Calcium Silicate Hydrates
fc	compressive strength Mpa
EN	European standard
fr	Flexural Strength
HSC	High-strength concrete
L.O.I	Loss on Ignition
NSC	Normal strength concrete
RC	Reinforced concrete
SCM	Supplementary cementitious materials
SF	Silica fume
MK	Metakaolin
GGBS	Ground Granulated Blast Furnace Slag
ft	Splitting Tensile Strength
SAI	Strength Activity Index
Temp.	Temperature
Pu	Ultimate applied load kN
UHSC	Ultra-high strength concrete
w/b	Water to Binder ratio
w/cm	Water to Cementitious Materials ratio
w/c	Water to cement ratio

Chapter One
INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 General

Many studies about the fire impact on concrete have been done in recent years. Concrete is usually an slow material, and short-time eminent temperatures faintly affect the acts of it when firstly exposed to fire. However, fairly long-time revelation would inescapably change the chemical composition, mechanical and physical properties strictly. thermal-induced crashes usually induce material collapse and further impend the serviceability and safety of total structures. therefore, wide experiments have been lead on the fire responses of concrete afterward high temperatures.(**Xie et al., 2019**)

pH Measurement is a rapid, cost-effective and simple technique that is important to analytical chemistry and used widely in science of cement. Fresh cement typically has a pH more than (13). Retaining such a great pH is vital to ensure steel passivation in steel-clad concrete, thus preventing deterioration of structural.

activator solution pH in a material of alkali-activated productions a critical part in sign dissolution, and solutions with high pH more than (13) that are typically active for this determination. In both alkali-activated material and Portland cement systems, the reaction products formation has been shown depending on pH also. (**Traynor et al., 2020**)

SCMs “Supplementary Cementitious Materials” were added to cement to replace clinker in cement. Some natural materials can use as SCMs with processing or without. Hydration products hydrate SCMs by a reaction Known as a pozzolanic reaction. These materials react in a pozzolanic reaction known as pozzolans. (**Kaur, 2016**)

1.2 Objective of Study

The objective of research:

1. Studying the combined effect of high temperature and supplementary cementitious materials (Silica fume, GGBS, Metakaolin, Lime stone powder) with replacement from cement by ratio (10%,20%,30%,40%) on PH concrete and mechanical properties of concrete (Compressive strength, Splitting tensile strength, Flexural strength)
2. The specimen subjecting to temperature (150C^o,350C^o,550C^o) to (1.5 hours) to testing (compressive strength, splitting tensile strength and flexural strength) test in temperature (23C^o) in age (7, 28,90 days for compressive strength), age (28,90 days for splitting strength), age (90 days for flexural strength) and age (1,7,28,90 days for pH)

1.3 Research significance

The current research aim is to study the combined effects of high temperature with different types and proportions of SMCs “supplementary cementitious materials” as an alternative to cement (that’s using many more of concrete mixes) on the compressive strength, flexural strength and splitting strength and Apparent pH concrete. Knowing that, the key parameters influencing the corrosion rate of the concrete is pH value which as it deteriorates the concrete itself, the corrosion of reinforcement is the biggest durability problem for reinforced concrete structures. Fractional replacement of cement with SMCs decreasing of hydroxide calcium concentration, lead to the decreasing pH vale of the solution prompted the forming impermeable steel films. Reductions the apparent pH value often twice quality the negative film in concrete.

1.4 Thesis Layout

The chapters in this study are planned as follows:

- Chapter one: gives an introduction to the general topic of the research and objectives of the current work.
- Chapter two: In this chapter, a number of scientific studies and researches by accredited scientists and researchers that are related to the research were reviewed.
- Chapter Three: It includes the details of the raw materials used and the mixture, and tests performed throughout the trial period work.
- Chapter Four: Explains the results of the experiment Work, graphical representation of the results and their discussions.
- Chapter Five: deals with the study's findings and recommendations for future research.

Chapter Two
LITERATURE
REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

High Temperature is the greatest severe environment condition effects on the concrete, therefore inspecting for safety of fire in concrete constructions is important for construction of building. The sluggish heat transmission and strength damage allows the concrete to be operative for resistance to fire.

Concrete constructions resist when exposed for fire permitting to: their rate of heating, thermal properties, concrete mixes characteristic properties and composition of these mixes and on the fire duration, and troubled with thermal property with the further factors like mass loss that affected by moisture content, aggregate type, and concrete mix composition.

The main parameters affecting the erosion rate of concrete are the pH value that degrades the concrete itself, and reinforcement erosion is the biggest durability problem for reinforced concrete structures. When replacing Portland cement by SMCs, calcium hydroxide concentration decreased, that reducing pH of solution. Reduction in calcium hydroxide influencing on formation of passive film on steel. **(Kaur, 2016)**

2.2 SCM “SUPPLEMENTARY CEMENTITIOUS MATERIALS”

SCMs “Supplementary cementitious materials” used as a partial substitute for Portland cement in concrete mixes or instead clinker’s in cement. SCMs are soluble siliceous or calcium aluminosiliceous powders. Many of SCMs produced from other industries such as fly ash which produced from coal-fired power plants. On the other hand, many types of SCMs produced from natural resources. This type whose energy is less than that used from industrial production. **(Juenger et al., 2019)**

SCMs "supplemental cementitious materials," using replace clinker Portland cement in composite producing cement or using cement in concrete. Due to the performance

and cost afforded by supplemental cementitious materials (SCMs), they have also been widely used in the concrete industry.

In recent, supplementary cementitious materials (SCMs) It has been getting increase care for the characteries they playing in decrease of the carbanion footmark for concrete, where using vigor and CO₂ productions from clinker cement industrial significantly offset of those extra components of concrete, and supplementary cementitious materials (SCMs) have less environmental impact compared with clinker of Portland cement.

The high-quality demand for supplementary cementitious materials SCMs is great, typified from the fact that average worlds for the clinker factor reduced (0.85) at year (2003) to (0.77) with year (2010), and long-term calculations are these number spirit continuing reduction as far (0.71).

Mixed cements denoted (75%) from the production of cement Holcim in year (2009), comparing (39%) with year 1995.

in the United States., where SCMs supplementary cementitious materials are added to mixes of concrete rather than to added to the cement, over percentage of (60%) from mixing of concrete added supplementary cementitious materials (SCMs) as an additional material for the Portland cement portion.

In some areas, demand for supplementary cementitious materials SCMs is outstrip of supply, mainly in development nations any using concrete and traditional are expected to rise SCMs supplementary cementitious materials, such as GGBFS and fly ash, not locally produced.

Looking ahead, demand for concrete and cement is expected to increase, and Supplementary Cement Materials (SCMs) are rising in recent years in assuring those sufficient quantities of cementitious materials are available to meet the predicted concrete production volume. For example, in 2011, the world produced (3.59) billion tons of cement. By 2050, the global demand for cement is predicted to reach 5.75 billion tons, with much of that demand being satisfied by a mix of supplemental cements (SCMs) and clinker to meet environmental constraints such as Carbon Taxes (Kirkpatrick & Scrivener 2008). Since the manufacture of slag and fly ash is not expected to rise, and recent simulated annual quantities of global production

have been estimated at nearly one billion tons and 350 million tons of these materials, on their own, there is a fundamental exploration of alternative supplemental cements (SCMs) for the opportunity to increase demand.

Promising grounds for alternative supplemental cements SCMs including plain mineral payments also wasteland from variety of industries. This materials specifically discussed & identified on this paper. There is a lot experiences opposite documentation, production, description and approval from the alternative supplemental cement materials SCMs. Due to variety & number filter material, it would not be effective taking an appropriate empirical test method to qualify of these materials. Furthermore, test methods standardized characterizing reactivity SCM aren't suitable to all materials. **(Juenger et al., 2012)**.

2.2.1 Ground Granulated Blast Furnace Slag (GGBS)

GGBS can be defined as a byproduct of the iron industries. Coke, iron ore, and limestone are fed into the furnace, and floats are produced from molten slag over molten iron at a temperature ranging from (1500°C) to (1600°C).

a composition of molten slag silicon dioxide (SiO₂) of (30%) – (40%) and (CaO) approximately to (40%), that is close to Portland cement chemical composition. Next molten iron nominated off, molten slag remaining, that on the principle involves the silicic and aluminous residues are then quenched with water, resulting in the formation of shiny granules. These shiny granules are dry and ground to basic size known as GGBS “ground granulated blast furnace slag”. **(Arivalagan, 2014)**

ground granulated blast furnace slag Superior workability, compaction easier and making placing, Lesser temperature rise of the early age, decreasing in large pours the risk of thermal cracking, Removal the risk of detrimental internal reactions, chloride ingress resistance, Attack with resistance to sulfates and other chemicals, significant sustainability benefits. **(Juenger et al., 2019)**

2.2.2 Silica Fume (SF)

SF “Silica fume” is a by-product of the manufacture of ferrosilicon and silicon minerals, and is largely a pozzolanic reactor. It's a gas flue developed for use with an electric arc furnace. Silica fume (SF) is a fine powder contains particles in it less than medium cement granules. It is available as a flake powder or in a water-based

slurry. Generally, cementitious material is utilized to get great-strength concrete with low permeability to water. Silica fume increase concrete strength from making a more dense cement paste matrix because its great amount of silicon dioxide that is amorphous (92 to 94 percent of SiO₂). From creating a denser matrix to cement paste, it enhances the durability and strength of concrete. **(Kaur, 2016)**

A by-product of alloying is SF "silica fume", ferrosilicon & silicon industries, also the expressions (microsilica) and (condensed silica fume) too. It's excellent complement to highly effective pozzolanic cement because its (SiO₂) in amorphous form and a high content of (SiO₂) accurate size distribution of fine particles (0.1) to (0.2) mm average diameter. **(Snellings et al., 2012)**

It can be viewed as a extremely active pozzolan and is a by-product of high-purity quartz industrial when wood and coal are burnt in an electrical furnace in the practice of producing alloys of ferro silicon. removing Silica from use gases as it cools and abbreviates into ultra-fine silica glass droplets. It possesses about (92- to 94%). spherical in shape and is very small, having a diameter with an average about one/tenth of the micron. It is available in a form as a water-slurry or a densified powder. Because of the large purity (SiO₂), special measures are warranted when processing, pouring and curing concrete containing silica fumes. **(Series & Science, 2019)**

Silica Fume increased concrete strength and durability, very effective at mitigating Alkali-silica reaction and sulfate attack, corrosion resistance by reducing the rate of penetration of chloride ions, reduce quantity of heat generated in concrete, High-strength concrete, high early-strength concrete, Lightweight concrete. **(Snellings et al., 2012), (Juenger et al., 2019)**

Silica Fume Material Physical Properties

- silica fume diameter unit ranges from (0.1) - (0.2)micron.
- The surface area is around 30000 m²-kg.
- Density if silica fume differs from (150) – (700) kg-m³, on the other hand when it is about (550) kg-m³, silica fume best suitable as an additive for concrete.

Properties of Fresh Concrete contain silica fume

- it requires water content higher, as of conventional concrete for the similar workability.
- Little workability
- Little value of slump.
- Possibility of segregation and bleeding and is low.
- cohesive mixture.
- High in the plastic shrinkage.

Advantages

- it enhances the properties of fresh and hardened concrete.
- it reduces and bleeding and segregation.
- it given the amount of higher durability.
- due to low bleeding, it gives efficient in finishing process.
- compressive strength with high early.
- and modulus of elasticity and flexural strength higher.
- High quantity for bond strength.
- it considered Suitable for mass of concrete due that it prevents induced cracking thermally.

Applications

- High growth buildings.
- structure of Parking.
- structure of Dam.
- Nuclear for the facility of waste storage.
- rehabilitation of Shotcrete.

When varying volumes of silica-fume are added to cement composites reinforced with CaCO₃ whisker, compressive and flexural strength increases just little. Furthermore, whisker reinforced composites containing 10% silica fume showed higher compressive and flexural strengths than plain mortar, ranging from 6 to 16 percent and 8 to 33 percent, respectively. In cementitious composites reinforced with basalt fiber, adding silica-fume enhanced compressive and flexural strength. Nevertheless, compared to plain mortar, this enhancement has a silica-fume amount of up to 10% and has a 17% and 34% silica-fume amount, respectively. **(Khan et al., 2021)**

2.2.3 Metakaolin

MK “metakaolin” is one from newly developing supplementary cementitious materials aimed at high-performance concrete. It is produced by calcining purified kaolin clay in precise temp. to destroy the crystal structure and bring out the chemically bound water in the vacuoles of kaolin, which effectively changes the material to (MK phase), an amorphous aluminosilicate. In contrast to those industrial by products, such as fly ash, silica fume (SF), and blast furnace slag, MK removes inert impurities, carefully tops off lightening, and controls particle size. This well-controlled procedure results in a white powder that is stable in performance and appearance with high reactivity. MK grain size is less than (2 mm), it is naturally incorporated into the concrete displacing (5) - (20) wt% of the cement.

MK “metakaolin” improves the performance of concrete by reacting with calcium hydroxide for secondary action C-S-H. For the reason that of MK white color, high-reactive of it doesn't blacken concrete such as Silica Fume It usually does (SF is white too partially in payload), which makes it suitable for color matching and other architectural applications. **(Ding & Li, 2002)**

MK “Metakaolin” is an a alumino silicate product mineral. Metakaolin is produced from thermal transformation of kaolinite in several million tons in worldwide, which are mined in many parts of the world. Kaolinite calcinations occurs between 550-750C° dries. After that, kaolinite Amorphized to produce material lacks long-range order. Produced by heat treatment an alumino silicate material, it is reactive with pozzolanic reactivity. The calcining temperature must be is carefully controlled to

prevent produce idle stages (mullite). once you increase the use SCMs produced from clay, to develop concrete performance and environmental credentials, and commercialization of alkali activated binders, it is important to develop a detailed understanding of the activities and chemical structures of SCMs. During calcination, it's very important to noticed that the dehydroxylation and amorphization directly affected on its pozzolanic behavior. The evaluation of pozzolanic reactivity can be tested by thermal analysis, x-ray diffraction, and infrared spectroscopy. However, the specific surface and particle size also effect on this reactivity. On the other hand, kaolin purity affects on pozzolanic reactivity, though there is no sufficient and relevant information about fraction impurities and metakaolin reactivity. There are very little reliable data in the literatures on the atomic structure of metakaolin effect on metakaolin reactivity. **(Juenger et al., 2012)**

Metakaolin, also mentioned to as highly calcined clay reactive, is manufactured by high calcining grade kaolinite at temperatures between (600) – (900 C°). The kaolinite structure involves of a (1:1) layer of combined of silicate tetrahedral sheets bonded to aluminium of octahedral oxide sheets continuously and alternatively by a layer of an interstitial of molecules bound water.

expelled the bound water, and collapses the material structure, followed by the an amorphous phase (metakaolin) formation during calcination. Metakaolin being either a byproduct nor a naturally happening material is used as a Supplementary Cementitious Material (SCM) compatible to natural pozzolan to ASTM C 618 and calcined natural pozzolana (Q) to (EN 197-1).

Kaolinite clay is copious in various sites worldwide. This clay is used in various applications of industrial like manufacturing of paper, adhesives, plastics, paint rubber, cement, bricks, refractories and ceramics.

However, all these applications, excluding those related to construction resolves, require kaolinite clay of the high grade. Therefore, considering its comparative abundance, principally in those areas of the world that are developing rapidly, and in terms of modifying the effect of universal warming accredited to production Portland cement, the construction industry is advised to focus on the using this clay benefits. **(Barbhuiya, 2017)**

MK reduced expansion due to alkali-silica reaction, increased concrete strength, increased concrete durability, reduces permeability to gases in concrete, resistance to chemical attack, increase in the rate of heat evolution. **(Ding & Li, 2002), (Barbhuiya, 2017), (Juenger et al., 2012)**

2.2.4 lime stone powder

Limestone, also known as calcium carbonate (CaCO_3), has long been a major component of concrete. Provides an additional surface for settling the water product while reducing the amount of water required to maintain the workability of the concrete by replacing part of the cement with limestone powder. Mixing ordinary cement with limestone has been reported to speed up the initial hydration process of the Interaction, during the processing of hydrate accumulation of cement pastes. This improves clinker hydration through the effect of grouting, rather than its according chemistry, limestone powder has little effect on the temperature properties of fresh concrete. Limestone powder, on either hand, is not really a completely inert filler. Although there is a little reaction between calcium carbonate and calcium silicate (C3S), no pozzolanic reaction, and no gel (CSH) is produced.

The particle packing efficiency of the limestone powder particles in the binder phase of the mixture improves, resulting in better capillary pore blockage and stripped penetration. As a result of the reduced water outflow, there is less water demand, this improves durability and operability.

It was also mentioned that low W/C ratio main factor in cement with high content of limestone, leading to higher volume of solids & low of porosity in concrete. It creates that the formation of ettringite derived the reaction of sulfoaluminates with water, calcium hydroxide and water increase volume molar of putty solids and can amplify the space filling properties of the putty. This may reduce the porosity of the paste and the permeability. **(Yoo-Jae Kim 2018)**

When mixing water with lime, it slowly turns into (dense) the mineral portlandite in $\text{CaO} + \text{H}_2\text{O} = \text{Ca}(\text{OH})_2$. Lime is mixed with an extra water so lime stays fluid, this is named slaking and the lime resultant is called slaked lime which continues to harden above a weeks period. Lime must be mixed with sand and other constituents to take slaked lime cement form, which can be used as mortar between bricks or stones in a wall or spread above the surface of a wall, next several weeks or longer,

it re-joins with CO₂ in the air to custom calcite again (artificial limestone). (Thakur, 2019)

Lime stone is produced from natural resources and from industrial as a by – products from aggregate and lime stone industries. Lime stone used in self – compacted concrete (SCC) and supplementary material in cement.

There are two types of cement produced in Europe, however they allow 20% to 30% limestone content, which is a high content. In United States and Canada, limestone allowable percent is up to 5%, but now ASTM C595 specification allows up to 15% filler of limestone and other Supplementary cementitious materials. In Australia lime stone allow up to 20% from cement. In general, using lime stone with about 5weight% in Portland cement improves early hydration and has no effect on performance of cement.

However, replacing cement by lime stone has an impact on strength development. “Filler effect” effects on essential properties of limestone fines and the behavior of fresh and hardened concrete. Limestone chemical characteristics are related to dolomite, quartz, imperities, including clay, and other minerals. Therefore, purified limestone is preferred in cement production, some standard limits the composition of limestone such as EN 197-1. Also, Clay content decreases the workability of fresh concrete caused by increasing water requirements to the limestone filler. **(Juenger et al., 2012)**

Lime stone powder using substitute for cement in concrete has little or results on the new properties, the relationship between the rupture modulus and split tensile strength with the compressive strength of concrete concludes that lime stone powder disturbs mechanical strength properties in a similar way, dry shrinkage decreases with rising lime stone powder in concrete. However, the shrinkage depends slightly on limestone particle size at all levels of substitution, for substitutions (20%) or less, emission reduction aids improve, but not to the same degree with (30%) or higher levels of substitution. **(Thakur, 2019)**

2.3 THE PH OF CONCRETE

2.3.1 INTRODUCTION

The logarithm of the hydrogen ion concentration in g/l atoms is the pH. For a solution of neutral concentration, the hydrogen ion is equivalent to (7) to (10), so the pH value is (7). Acid solutions have a pH lower than (7) while basic solutions have an upper pH of 7. (Poe & Adamczak, 1980)

Generally, the pH is one of the most important limitations because measuring many researches analytical chemistry of works. Therefore, many researchers have worked on the development of Various electrochemical and non-electrochemical quantum techniques. Vonau and Guth summarized pH experimental methods measurement values as shown in Figure (2-1). Non electrochemical approaches it was introduced earlier e.g., Arrhenius in 1889 he developed his method based on motivational measurements. Moreover, the chromatic methods that were previously widely used based on changing the color of the organic acid system now using opcodes to measuring pH value. (Behnood et al., 2016)

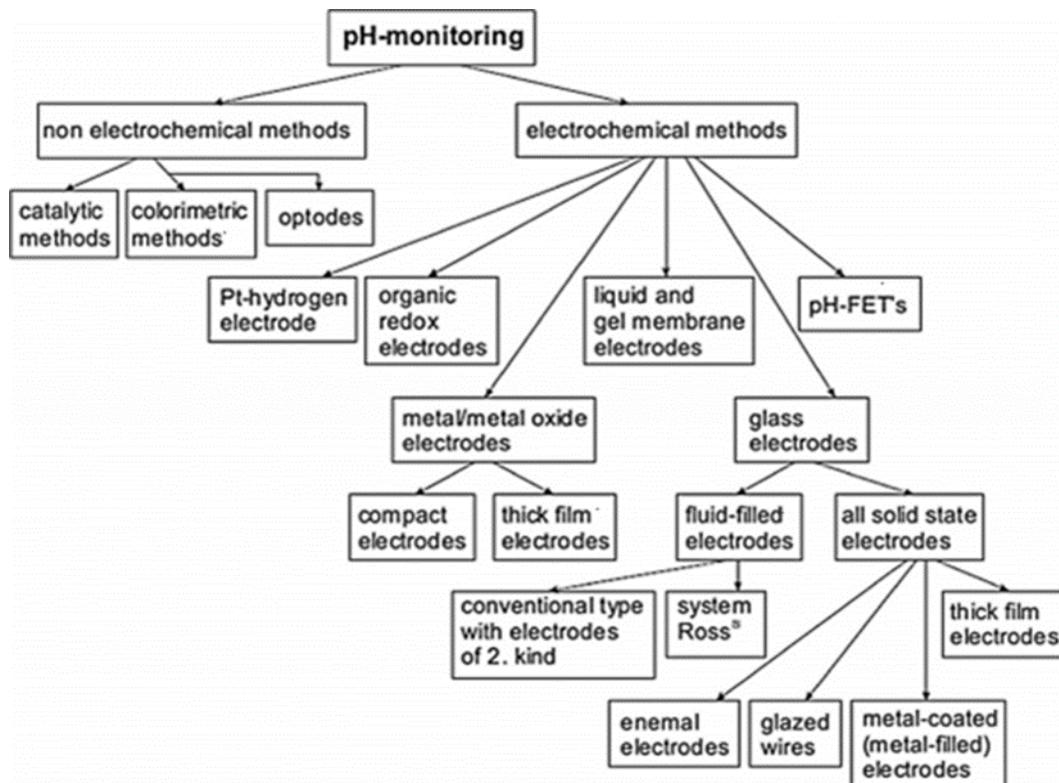


Figure (2 - 1): Summary of methods to measuring pH value (Behnood et al., 2016)

Instead, most importantly lineage mechanisms for concrete reinforcement structures including carbonization, corrosion and acid attack are related to concrete's alkalinity levels. The concentration of active hydrogen ions is defined as the negative logarithm of pH. and displays alkalinity levels of concrete about various conditions. The pH of ordinary Portland cement usually ranges from 12.5 - 13, but the pH can drop due to weakening mechanisms such as carbonation, chloride ingress, or acid attack. The access of chloride to concrete can lead to a decrease in the pH because the formation acid hydrochloric. Moreover, the carbonation method, in which hydroxide calcium is changed to carbonate calcium, can drop the pH to value less 9. Corrosion initiative of reinforced steel incorporated into concrete can occur at low chloride concentrations once the pH is low. shown in Figure 2-2, this action can acceleration the protective destabilization of the passivation layer for corrosion initiation in reinforced concrete elements and on reinforcing bars. Figure (2-2) shown that decreasing the pH of concrete to value less than 11 in the vicinity from steel reinforcement can influence the initiation of active corrosion in the occurrence from close to zero (ppm) chloride ions. **(Behnood et al., 2016)**

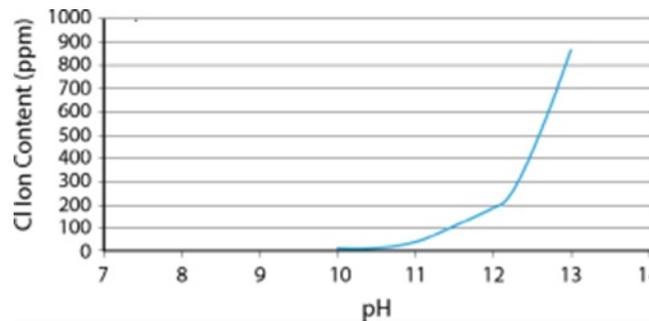


Figure (2 - 2): Relationship between threshold concentration and pH.(Behnood et al., 2016)

Therefore, it is of great importance to measure pH and various researchers have developed various methods for this determination in concrete. This paper analytically reviews the methods that can be obtained for studying the pH value of concrete at different stages. **(Behnood et al., 2016)**

2.3.2 INFLUENCE PH VALUE ON CONCRETE CORROSION

The most common causes in concrete for initiation of corrosion of steel is Chloride ions. The environment of high alkaline forms a passive oxide layer round the reinforcement and thus, avoids corrosion response to occur. Such passive layer might be destroyed if level of the pH falls down due to access of chloride ions. The corrosion decreases the area of cross-sectional of rooted reinforcement within concrete that significantly reduces the strength of the reinforcement. In addition, creation of rust causes volumetric development that leads to spalling and cracking of the nearby concrete and consequently, decreasing the compound act of concrete and steel due to bond decline. **(Hossain et al., 2020)**

In sound concrete, this response is prevented by the great alkalinity of the pore solution of concrete and an iron-oxide passivating layer is formed on the reinforcement bar the surface. However, this passivation may be cracked. dioxide of atmospheric carbon may react with the cement in the matrix and lesser the pH of the pore solutions inside the concrete, resulting in reinforcement bars depassivation. Extra initiation mechanism common corrosion is the ingress of chloride ions concluded the concrete cover.

The kinds of corrosion classically distinguished for reinforcement bars are constant (or general) and restricted (or pitting) corrosion. As the names suggest, a uniformly reinforcement bar corroded shows regular damage of material, while localized corrosion happens at discrete chairs along the bar of the reinforcement. Schematically, a high concentration of chloride (or concrete carbonation) is related with general corrosion, while lower concentrations chloride are related to localized corrosion. **(Blomfors, 2020)**

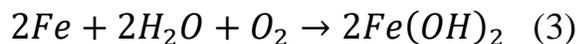
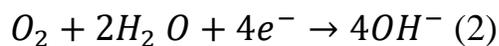
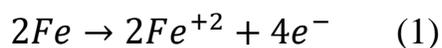
The surface of the steel in reinforced concrete is covered with a negative oxide layer, which protects the reinforced bars from corrosion. When the pH is greater than 11, the passive layer remains stable. The alkaline environment around the reinforcement be damaged as the pH of concrete starts to drop. This extremely alkaline environment can be damaged (vented) for the following reasons: sea water, chlorine from salts, low pH via carbonation. Carbon dioxide penetrates the concrete during the carbonization process and reacts with hydroxides. The pH of concrete is reduced with carbonation, and the passivation layer on steel is disturbed.

The oxygen in water (or around steel) takes electrons and forms OH ions. Iron hydroxide is made up of OH⁻ ions. This compound is relatively soluble in aqueous media and, depending on the pH of the environment, can form various oxides or hydroxides. Concrete has a high pH, which causes a negative Fe₂O₃ layer to create around the steel.

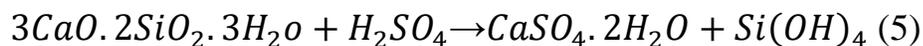
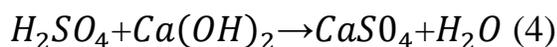
One of the most important events that results in a reduced pH in concrete is carbonation. Carbonation occurs as carbon dioxide (or other acidic gases like nitrogen oxides and nitrogen oxides) from the atmosphere react with the free lime in the concrete. Corrosion of the steel begins when carbonization reaches the reinforcement. Alkanolamine inhibitors (just for chloride reinforcement corrosion) were proven to reduce the occurrence of carbonization-induced corrosion protection. **(Topçu & Uzunomeroğlu, 2020)**

Major sorts of chemical concrete degradation like acid attacks and carbonation, associated with reducing external, internal and surface pH. During these processes of destructive, changes in pH are measured by concrete interactions environment, like penetration of chemically destructive solutions or harmful gases diffusion, and of chemical and mineralogical concrete properties consequent alteration. **(Grenng et al., 2019).**

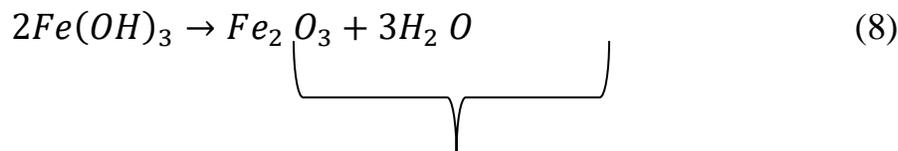
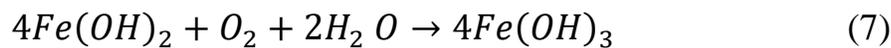
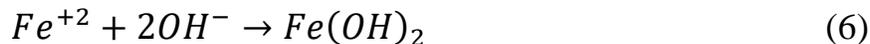
(Bohni, 2005) The corrosion of metals is an electrochemical process. For steel in concrete the following reactions occur:



(Catchings & Guidry, 2018) The deterioration of sulfuric acid for concrete occurs due to two different reactions. Initially, sulfuric acid reacts with concrete in two stages, as shown in equation 4 and 5



(Topçu & Uzunomeroğlu, 2020) steel reinforcement corrosion is a chemical reaction that involves electrochemically. Corrosion is always the result of two electrochemical reactions that are mutually exclusive. This is the process of oxidation and reduction. The dropping of electrons converts an atomic metal into an ion, which is known as oxidation. The ejection of electrons into a distinct environment from the atom is known as reduction. The anode is the process of oxidation. The cathode reaction is the name for the reduction. The erosion process is halted if any of these responses are predicted. Waiting for the anodic response, $Fe + 2$ ions enter the electrolyte solution. Electrons modify and learn from the cathodic area as they travel along the steel band. (OH) ions are drawn from the electrolyte to the anode (rising from the process at the cathode). The electrical pathway of the whole cell ceases when the entrance of ions (OH) stops. The reaction with each new item is then marked by $(OH) -$ and $Fe + 2$ ions in the electrolyte solution, resulting in ferric hydroxide. $Fe(OH)_2$ (ferrous hydroxide) is an unstable and soluble hydroxide that reacts with water and oxygen in solution to form $Fe(OH)_3$ (ferrous hydroxide). This corrosion is Fe_2O_3 hydroxide (ferric oxide) and causes yellow corrosion to occur in the cavities around the anode. Here are the resulting responses:



Hydrated Ferric Oxide (Rust)

(Alisa& Petter& Klaartje 2018) Study towards acceptance of the pH dependency of mandatory chloride Portland cement pastes. A method has been developed to lower with closed scheme, pH pore solution in wet cement paste. The chloride obligatory in aqueous paste cement was experimentally to become closely related the pH value of the pore solution. decreasing the pH from 13.2 to 12.2 the binding of chloride increases. If the pH value dropping 11, the chloride binding to the cement paste is significantly reduced. Practical model thermodynamic determine the pH dependence binding chloride is related the pH dependent fluctuations in the C-S-H Ca/Si ratio I had been unable to experimentally confirm Friedel's salt's role in pH-dependent

chloride to its low crystallinity in the examined samples. These results may explain why penetrative leaching on the surface lessens chloride binding in concrete structures, due to the fact that extra mild leaching in concrete corresponds in enhanced chloride binding and hence a maximum increase in the chloride scheme. Service life prediction models for chloride-exposed concrete structures should consider the influence of pH reduction owing to chloride binding leaks to achieve more accurate forecasts of chloride entrance. (Machner, 2018)

studied impact of chloride on cement mortal at ages (28 and 180 days). The samples were exposed to NaSO₄ solution with different pH values (pH = 14,8 and 5). The mechanism of the process of hydration and corrosion for cement mortar in case of sulfate presence is the same as low aluminum composition in cement compositions. As a result, it is important to increase pH to increase sulphate attack resistance. (G. Zhang et al., 2021)

2.4 INFLUENCE OF HIGH TEMPERATURE ON CONCRETE PROPERTIES

2.4.1 INTRODUCTION

Concrete is a non-homogenous multiphase material consist of inert aggregates that is held together by the hydrated paste of Portland cement. When concretes are exposed to high degree of temperatures, mechanical changes occurred, that resulted in decrease durability of concrete. Concrete material properties became nonlinear, after that, variation of physical and mechanical properties occurs and tensile cracks appeared caused by thermal forces, in addition, load-carrying capacity and concrete ductility are decreased. The variation of these properties occurred largely because of the bond deterioration between cement paste and aggregates, also changes in moisture content of the concrete. The difference in expansion between cement paste and aggregates is very important and critical in concrete behavior. Bonding between aggregate and cement paste affect mainly by surface roughness of aggregate, physical and chemical interactions. Physical interaction depends on dimensional compatibility between cement paste and aggregate. On the other hand, chemical interaction resulted from reactions between both aggregate and cement. At high temperature, concrete Behavior depend on degree of temperature, load, moisture concrete and exposure time. Concrete curing influences on the hydration, when

concrete exposed to temperature, that could have a good effect on Portland cement and thereby the concrete mixes. Concrete at high temperature is sensitive to temperature degree, thermal cycles, heating rates and duration, all that caused physical and chemical deterioration occurred. (Naus, 2006)

2.4.2 INFLUENCE OF HIGH TEMPERATURE ON CONCRETE PROPERTIES (Compressive Strength, Tensile Strength, Flexural strength)

The compressive strength for concrete considered a very important properties that affected on the load capacity of concrete. Thermal stresses affect on the concrete durability as well as concrete strength and stiffness. Figure (2 - 3) and Figure (2 - 4) below showed compressive strength results for non-loaded specimens tested in cold (residual) case and at temperature (hot) case, respectively, these figures obtained from many tests and results from many investigators. Figure (2 - 5) is presented other information about the impact of high temperatures on the environment compressive strength to nuclear power plant, type concrete was PCPV – type concrete which consist of limestone, bazalt or gravel aggregate. That figure showed both hot (symbol H) and cold (symbol C) condition tests. Finally, these figures showed thermal exposure on concrete compressive strength with different test condition.

The behavior of concrete strength loss with high temperatures effected on cement paste and increased role of aggregate materials. Factors affect on general behavior of loss compressive strength with high temperatures are: weakness in bond between aggregates and cement paste, aggregate damage, cracking appears in concrete, chemical reaction caused by thermal conditions, cement paste weakening and partial breakdown of the C-S-H. Almost types of aggregate are thermally stable up to 350 C°, at that temperature most applications considered. At high temperatures the compressive strength mainly depends on the bond between aggregates and cement paste. (Naus, 2006)

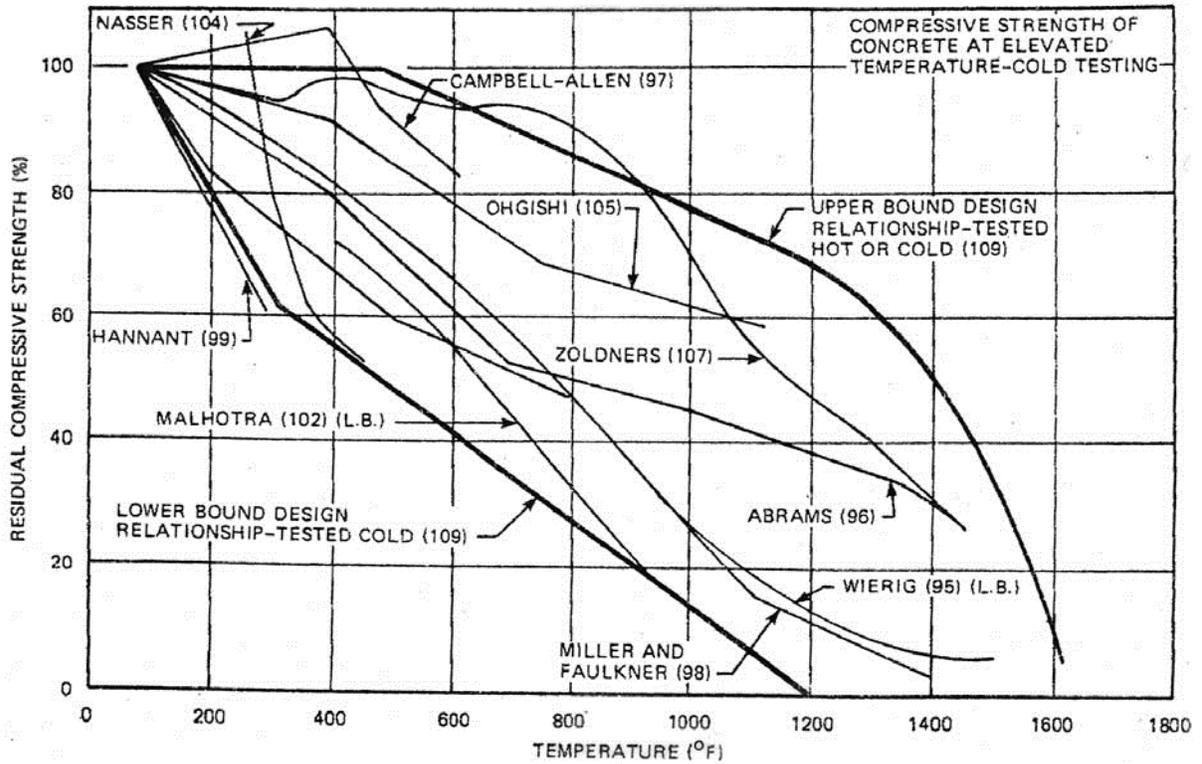


Figure (2 - 3): temperature exposure Effect on compressive strength for concrete (Naus, 2006) COLD TESTING

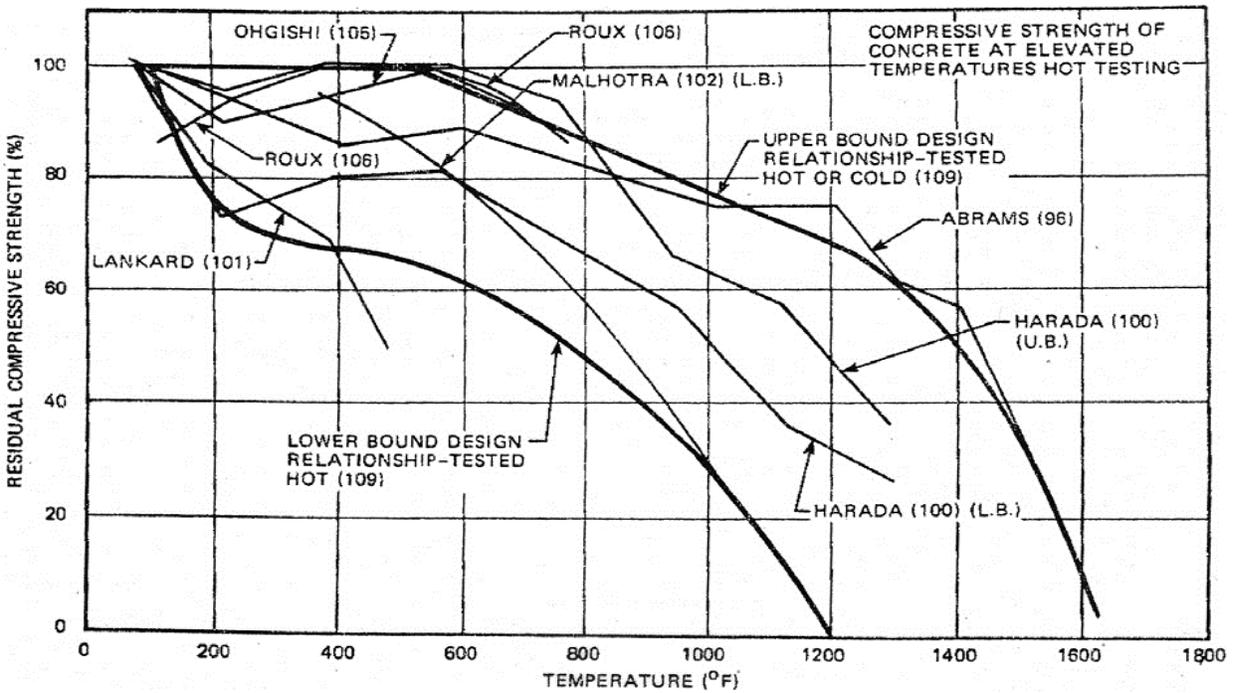


Figure (2 - 4): Temperature exposure Effect on compressive strength for concrete (Naus, 2006) HOT TESTING

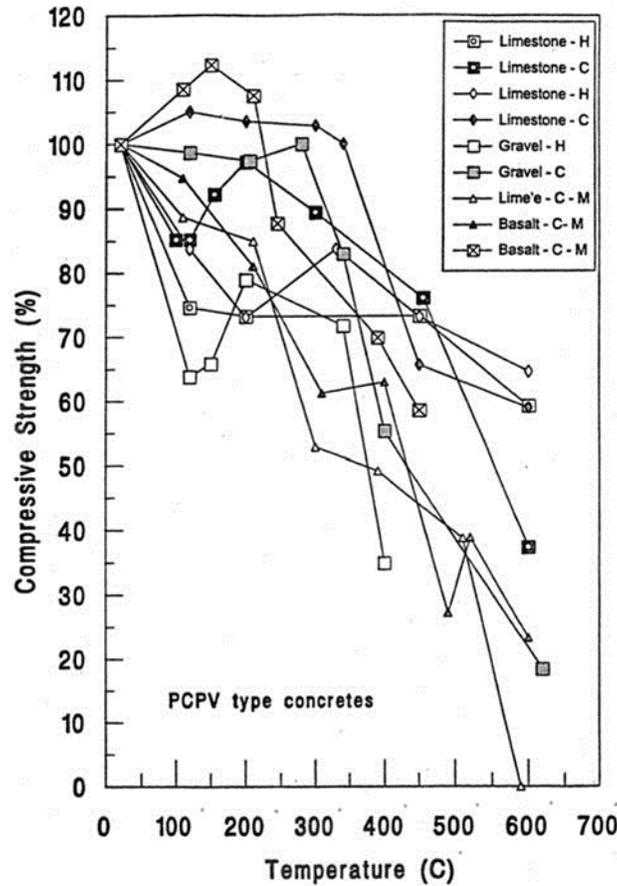


Figure (2 - 5): Effect of temperature on uniaxial compressive strength (H = hot, C = cold). (Naus, 2006)

Number of journals showing results of tensile strength changes (ft) resulting from heating control. This is a consequence of the technical difficulties encountered when testing concrete in straight tension at the hot step. Most of the tensile strengths (ft) found in real-world works were then obtained after cooling the material. However, the permanent values of tensile strength (ft)-both for compressive strength - were found to be inferior to those of the hot phase. Comparative values of tensile strength were obtained using different techniques for example by splitting, hot direct tension test, and direct tension after cooling the samples, decreasing slowly with heating fever. Analysis of fluctuations in the tensile strength of concrete as a temperature target is very important from the point of view of understanding splintering, since this type of destruction occurs when the internal stresses due to vapor pressure and thermal strains exceed the tensile strength value of concrete. (Hager, 2013)

Changes in flexural strength of cement mortar containing gravel or limestone aggregate the effect of being exposed to temperatures as high as 260°C were investigated. When concrete is subjected to temperatures of up to 80°C the increase in flexural strength is low, but if temperatures increased to 120°C and up to 260°C flexural strength decreased noticeably. At high temperature, concrete mixes with gravel were showed less decrease in flexural strength than that with limestone. As a result, concrete flexural strength decreased as much as temperature increase. **(Naus, 2006)**

Compressive strength of samples decreased significantly for ordinary concrete mixed concrete samples when exposed to a temperature of more than 400°C. decline compressive strengths of about 60% and 69% are observed at 800 °C for 7 and 28 days cured. Samples, respectively. **(Mwilongo et al., 2020)**

Regular strength concrete behaves differently when exposed to high temperatures. The decrease in mechanical properties occurs gradually with increasing temperature for normal strength concrete, while the lower the tensile strength is higher than the compressive strength since the tensile strength more likely to develop cracks with increasing temperature. **(Hsiau et al., 2004)**

Uniaxial compressive strength of concrete It decreases linearly with increasing exposure temperature. Exposure to high temperatures for two hours leads to infection Concrete is easily deformed during loading. Below 400 ° C, the detected phases of the exhibition the slurry sample is the same as that received mortar, the cement as received is dense and obviously free holes. cement and aggregates are tightly bound, no cracks were observed. After exposure to 200°C For two hours, water loss of calcium silicate hydrate (C–S–H) causes the formation of small holes in the cement and microcracks at the bonding interface of aggregate / cement. After exposure above 400°C, the Ca(OH)₂ decomposition leads to formation Small holes grow in the cement, and the small cracks in the aggregate/cement bonding interface gradually expand into a cohesive network of fissures; Above 600°C, Ca(OH)₂ . decomposes CaCO₃ results in the local cracking of cement Microcracks further expand in bonding aggregate/cement interface. **(B. Zhang et al., 2019)**

The flexural strength of OPC drops to 26% for 100C°, 42% for 200C° and 39% for 300C° for the first bending strength, respectively. Compressive strength decreases by 3% for 100C°, 6% for 200C° and 20% for 300C° for OPC. After being heated and cooled for a week, concrete continued to lose strength, indicating that air cooling did not help the samples restore strength. (Tchekwagep et al., 2020)

Discount on concrete's compressive strength when exposed to high temperatures. Despite the concrete mixture ranges, test methods, such as sample size, stressed/non-stressed conditions, and hot/residual states, also affect the mechanical goods of concrete at high temperature. Therefore, in order to eliminate the conceivable influence initiated by these factors, data aggregation was performed only on the permanent resulting the uncompressed cubes samples. It can be seen that after heating concrete to a high temperature, the permanent compressive strength of the concrete goes through stages:

1. Room temperature - 300C°, the concrete's compressive strength maintains its stability or even increases somewhat
2. 300-800C°, the concrete's compressive strength blocks is greatly.

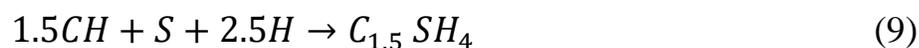
Residual flexural strength, the residual tensile strength of concrete after exposure to elevated temperatures. The same data collection system is used with compressive strength. Similar to the compressive strength, the flexural strength, and the splitting tensile strength of concrete decreases with increasing temperature, but at an approximately linear rate. (Ma et al., 2015)

Mirza K. U. studied in 2002 effect of flame on density, modulus of elasticity, load deflection relationship and hardened concrete properties for concrete. Temperatures were investigated at (25, 400, 500 and 700 co) at two ages 30 and 90 days. The reduction in density ranged between (1.9-7.7%), (4-8%) and (8-11.2%) for temperatures (400, 500 and 700) C° respectively. A residual compressive strength was (70-85%), (59-78%) and (43-62%) for temperatures (400, 500 and 700) C° respectively. On the other hand, splitting tensile strength was (67-78%), (40- 67%) and (20-45%) for temperatures (400, 500 and 700) C° respectively. Deflection was increased noticeably while concrete exposed to flame in addition to reduction in ultimate load

2.5 INFLUENCE OF SUPPLEMENTARY CEMENTITIOUS MATERIALS ON CONCRETE PROPERTIES

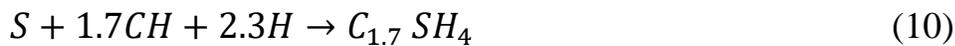
The fine-grained covering of the active forms of silica or alumina when introduced into a cement mixture can volatilize with $\text{Ca}(\text{OH})_2$ which is formed by hydration of the cement. As a result, an additional total was modeled for C–S–H and C–A–S–H phases while the $\text{Ca}(\text{OH})_2$ content was summed. As mentioned earlier, such slender SCMs, i.e., which have low calcium mechanisms and do not exhibit self-cohesion properties but are gifted to interact with $\text{Ca}(\text{OH})_2$ in the presence of water, are commonly recognized by pozzolana (pozzolana materials)/additives. The increased use of aluminum silicate in cement mixtures means that the binding mixture can cover a greater amount of aluminum alloys, and therefore has less calcium than typical Portland cement. It causes the formation of C – S - H in such a mixture having a lower C / S ratio compared to the product formed during hydration of SCM-deprived Portland cement. In composite cement-SCM, the basic properties, such as compressive strength, hardness, hardness, etc., are mainly formed not only by the C – S – H phase, as in the case of complex Portland cement, but also by C – A – S – H. Its effect is dependent on the amount of C -A -S -H and the conformation. In general, the methods used to estimate the SCM interaction gradient can be isolated into two groups: direct and indirect. The first revenue techniques that allow the degree of SCM responsiveness to be assessed directly, based on dimensions of the amount of unreacted SCM. Indirect methods are based on measuring some properties of the sample (for example) the amount of $\text{Ca}(\text{OH})_2$ spent in the Pozzolanic reaction or the compressive strength of solids) dependent on the SCM reaction. The degree of SCM response is then calculated, often as a ratio of the amount slow to the result of the fully reacted SCM (Pacewska & Wilińska, 2020)

Although SCM does not have cementitious property on its own, it hydrates with cement hydration crops or in the presence of cement to produce additional C-S-H and other hydration crops. This reaction is generally known as the pozzolan answer and these substances are also known as pozzolans. Equation 9 shows the stoichiometry of a typical Pozzolanian hydration.

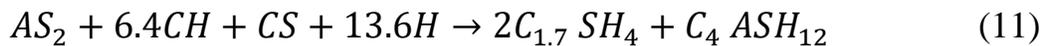


The reaction of SCM depends on the pH and temperature of the pores response and its reaction is generally advanced at alkalis and higher temperatures. (Kaur, 2016)

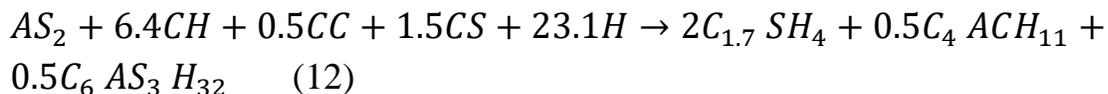
In general, SCM consists of the same chemical basics as the phases of Portland clinker, only their proportion and mixing of the constituent solid phases are different. Of great importance is the interaction of SCM in the consequences of cement blended into similar hydration products as long as $\text{Ca}(\text{OH})_2$ can be obtained. The proportions and composition of hydration crops change dramatically upon the liberal interaction of SCM. The reaction of the predominantly pozzolanic SCM as silica fume (S) guides to the formation of C-S-H:



For aluminum silicate aluminates, such as metakaolin (AS_2), calcium aluminate hydrate also appears in the reaction equation, the type dependent on the counter anion, eg monosulfoaluminate if stoichiometric calcium sulfate (CS) is available.:



For systems where calcium carbonate (CC) is present in the mixed cement, make the calcium carbonate hydrate in place of the monosulfoaluminate and the equilibrium sulfate will precipitate as ettringite.:



Compare equations. (11) and (12), it appears that the combined use of Al-rich SCMs and limestone can impede more water in the bodies, a reaction scheme that is exploited in a new group of triple-mixed cements such as limestone-fly ash-cement, stone Limestone - slag - cement, or limestone - calcined clay - cement. When the SCM covers magnesium and aluminum as in the case of blast furnace slag, hydrotalsite is formed as an additive reaction creation. As the latent hydraulic SCM, blast furnace slag impregnates less $\text{Ca}(\text{OH})_2$ and therefore can accommodate a higher degree of reaction before $\text{Ca}(\text{OH})_2$ is exhausted, see comparison between metakaolin and slag. (Skibsted & Snellings, 2019)

The use of supplementary cementitious materials (SCMs) in mixed concrete can reduce the amount of carbon dioxide in the atmosphere (Imbaby et al. 2012)

Recently, SCMs and their use in blended concrete have received great attention worldwide to reduce carbon emissions to the atmosphere since energy use and CO₂ emissions from the manufacture of Portland cement clinker greatly exceed those of other concrete components. Mixed concrete using SCMs has economic and performance benefits compared to conventional concrete. Benefiting from these materials or combinations of these industrial materials through products such as fly ash, granular mill-furnace slag, lime sludge and other waste materials occupies more percentage of local landfill space and leading to pollution problems in those regions. In order to minimize the disposal and pollution problems originating from these industrial by-products, it is the need of the hour to develop profitable building materials out of these wastes. Replacing Portland cement with these industrial by-products in concrete can significantly reduce the release of greenhouse gases into the atmosphere also to avoid disposal and pollution problems to some extent. This point led to the search for complementary cementing materials, which give us the same strength as Portland cement without compromising aspects of durability. Complementary cements are sometimes referred to as mineral additives. They can be used singly or in combination in concrete. It can be added to the concrete mixture as a blended cement to improve the properties of concrete in a new, hard state. **(Kumar & Prasad, 2019)**

From the results it is concluded that the silica fume is a better replacement of cement. The rate of strength gain in silica fume concrete is high. The optimum value of compressive strength can be achieved in 10% replacement of silica fume. Compressive strength decreases when the cement replacement is above 15% of silica fume. Workability of concrete decreases as increase with of silica fume. **(Adil et al., 2020), (ACI 234R-06, 2006)**

By using the same cementitious blending material (total weight of Portland cement plus GGBS), the same strength will be achieved for 28 days of Portland cement when up to 50% GGBS is used. In advanced GGBS ratios, you may need to augment the fun cement to achieve a strength equivalent to 28 days. The strength of the advantages of GGBS concrete is little by little more than that of equivalent Portland cement concrete. For the same strength 28 days, GGBS concrete will have lower strength in the early ages but its long-term strength will be greater, and the decrease in early strength will be more pronounced at higher GGBS levels and lower temperatures. Typically, Portland cement concrete will achieve about 75 percent of

its 28-day strength in seven days, with a slight increase of five to ten percent between 28 and 90 days. The degree of workability of concrete was normal with the addition of GGBS up to 40% replacement level for M35 grade concrete. **(Juenger et al., 2019), (Arivalagan, 2014)**

This study signifies the behavior of concrete, having incomplete replacement of cement with barites and lime powder. M30 grade of concrete was rummage-sale for which the barites and lime powder is substituted and an experimental study was carried out and the outcome on compressive strength faces (0%,10%,20%,30%) was studied. It was found that there is an growth in strength in early 7th day and it remain almost alike in 14th day but did not show any positive product for 28th day. The concrete mix with 30% of cement substituted by lime powder gives the best mix with tall compressive strength with high workability. **(Li et al., 2020), (D. Wang et al., 2018), (Tu et al., 2016) (P Meenakshi 2017)**

Partial replacement with metakaolin (MK) can improve concrete strength. However, it is not lively whether MK or silica fume produces better increases in strength. If it is firm that metakaolin (MK) increases strength as abundant or more than silica fume, metakaolin (MK) might find greater request in high strength concrete (HSC) and high-performance concrete (HPC) in the future. These authors concluded that three primary factors influence the contribution of metakaolin (MK) to strength when it partially replaces cement in concrete. These are the filler effect, acceleration of PC hydration, and the pozzolanic interaction of metakaolin (MK) with CH. metakaolin is expensive and gives poor workability. **(Kumar & Prasad, 2019), (Barbhuiya, 2017), (Ding & Li, 2002), (Gedam et al., 2016)**

Compressive strength, and flexural strength split tensile strength there was a significant improvement in the strength properties of concrete with the presence of mineral additives. The increase in compressive strength was about 42.5% in 30 MPa, 32.48% in 50 MPa and 22.79% in 70 MPa, respectively, while the increase in split tensile strength was about 19.54%, 12.46% and 13.35% at 30 MPa, 50 MPa, and 70 MPa, respectively. The increase in flexural strength was about 20.48%, 14.56% and 11.22% in concrete of 30 MPa, 50 MPa and 70 MPa. From these results it is clear that the mineral additives lead to a significant increase in the resistance properties of concrete mixed with SCM. **(Kumar & Prasad, 2019)**

2.6 INFLUENCE OF HIGH TEMPERATURE ON PH OF CONCRETE

The temperature rise reduced the pore solution pH by about 2 units and caused the sulfate concentration to increase through dissolution of ettringite. Conversely, the soluble alkali fractions did not change significantly. (Bach et al., 2012)

2.7 INFLUENCE OF SCMs ON PH OF CONCRETE

Both Portland cement and lime-based adhesives have in common that the initial rapid closure of clinker minerals or Ca(OH)_2 in water leads to an alkaline solution saturated in Ca(OH)_2 . In systems based on Portland cement, the solution may reach values of 13.8 when the abundant dissolved alkali is released from the clinker minerals, on the other hand In Ca(OH)_2 -based systems, The pH of the solution is usually about 12.5. At an alkaline pH greater than 10.8, the solubility of silica and silicates (i.e. the amount of silica in solution) increases greater and greater with pH and pozzolan will undergo solubility.

Silicate closure rate at high pH undergoes deprotonation, the processes of hydration, hydrolysis, and ion adsorption at the mineral water boundary. Greenberg (1961) concluded that the Pozzolanic reaction was controlled by the hydrolysis of the apparent silica groups. It is necessary to know the molecular details and energetics of the actual pathway connecting the reactants and yields through the activated compound, that make us understand and predict dissolution kinetics. Activation energy is the energy change between the polyhedral or transition state and the reactants. From the outset, important mechanistic calculations of limited molecular groups have elucidated the pathway to solubilization of silicates and alumino silicates at high pH in recent years. (cf. Xiao and Lasaga 1994; Lasaga 1998). Reactions with rehydration products with elucidation of carbonate tolerance lead to the formation of calcium carbonate, silica and/or alumina gel. In porous bonds, the penetration of carbonation can lower the pH of the pore solution, which may cause the steel to pass into the reinforced concrete. However, in relatively resistant adhesives, carburizing is usually limited to the upper top surface and does not progress into the bond matrix.

In general, the summary permeability effectively compensates for the temporary Ca(OH)_2 loss, Although the depleted Ca(OH)_2 reserve may reduce the mixture cements more susceptible to carbonation. Low pH and calcium $(\text{OH})_2$ depletion. Although, supplementary materials can contain relatively large amounts of alkali, but the true soluble amount of alkali -in most cases- is rather low. Moreover, the increased alkali binding capacity of hydroponic crops (that is, C-A-S-H) enabled a lowering of the alkalinity of the solution. However, it should be known that at reserve ratios as low as 20%, the addition of supplementary materials can increase the reactions of alkaline silica taking into account the parent Portland cement. This weak behavior could be related to the release of alkaline supplementation of SCMs along with the semi-consumption of Ca(OH)_2 . (Hobbs 2002)

Typically, more than 20% reserve is sufficient to avoid expansion, indicating that expansion is greatly reduced when 20% or more zeolite filler is added to highly alkaline cement (Feng and Peng 2005).

In general, low-alkali SCMs covering both alumina and silica are considered experimental to be most effective in reducing growth. supplementary cementitious materials which poor in alumina have less potential to reduce silica alkali reaction. (Snellings et al., 2012)

In cement pastes, Page and Vennesland (1983) found that increasing the silica fume substitutes for Portland cement resulted in reducing pH of pore solutions. The decrease in pH could be led to an amplified reaction of alkali and calcium hydroxide with silica fumes. Concern about low pH of pore water is usually raised by methane intoxication by silica fume and the effect of any such antagonist on the passivation of armature. Usually, at the heights of silica fume use originating in concrete, the pH reduction is not significant enough to be a concern. For corrosion defense purposes, the increased electrical resistance reduces permeability and presumably chloride ions are more important than any pH antagonist of the pore solution. pH level of pore water, electrical resistance. He concluded that silica fume works with mixed cement in almost the same way as it does with concrete covering only Portland cement. (ACI 234R-06, 2006)

Metakaolin (MK) is chemically altered from many other SCMs in that it has a top to bottom alumina content. The reaction crops that make up metakaolin (MK) and

methane are not only (C-S-H), but also include C₃AH₆, C₄AH₁₃ and C₂ASH₈. A clear correlation has been drawn between the tri-calcium aluminate (C₃A) content of Portland cement and its sensitivity to sulfate attack.

If sulfate is present, ettringite is formed from the reaction of ingress of sulfate (C₃A), and monosulfoaluminate. The formation of ettringite during a sulfate attack can, but not always, lead to a significant expansion in size and can be detrimental to concrete life.

In addition, sulfate ions reacts with CH to form gypsum, which can then resulted in decreasing in the pH of the pore solution, destabilization of hydration products, and a decalcification of C-S-H. The net result of this form of chemical seizure is a loss of adhesion and strength. (Justice, 2005)

The effect of replacing limestone in the pH value of the solution reduces the efficiency of chloride binding to concrete, which leads to a higher percentage of permissible chloride ions. Increased limestone content, due to the presence of a grain at the pH of a concrete pore solution. Nutrients for cement hydration, such as Ca(OH)₂, revert to the high alkalinity of concrete pore results. Limestone powder is a non-catalyst and its dilute effect reduces the molar parts of cement hydration products, thus lowering the pH value. The measured pH value rang by the replacement of limestone in order. (Li et al., 2020)

The results showed that, the GGBS generated by cement and lime could be effective in reducing the susceptibility of pollutant infiltration into the polluted soil. Martin and others in (2012), studied the effect of pH and acid in concrete mixes. The conclusions were that the concrete tested specimens could not be adequate to address the continuity risk of all parts of the waste water infrastructure over a significant lifetime due to the extremely harsh nature of this form of attack.

Wang Ling et al. (2004), analyzed GGBS presentation and GGBS results on fresh concrete specimens and hard concrete specimens . GGBS concrete is rated for high strength, low water temperature and fight chemical corrosion. (Arivalagan, 2014)

Song and Saraswathi investigated the wear resistance of reinforced steel in GGBS concrete. They stated that there was no adverse effect, due to the low pH value of

Using GGBS in concrete. Even an increase in GGBS replacement levels reduces the wear rate of reinforced steel bars in GGBS concrete. (Turu'allo, 2013)

Partial replacement of Portland cement with a supplemental cementitious material reduces interest in calcium hydroxide, which lowers the pH of the pore solution and induces the formation of negative films on the steel. A decrease in pH is often associated with low-quality negative films, but as has been shown recently, this is not always the case.

This study investigated the effect of partial replacing of Portland cement with silica fumes, on both the corrosion resistance of reinforced concrete and the pH of the pore solution. Three concrete mixes were produced with variations of replacing cement with silica fumes (0, 5 and 10% by volume). The chemical arrangement of the pore solution, polarization resistance and erosion current density were constant up to 90 days. The results showed that, especially at early ages, when the concrete resistivity residue is low and unchanged among the different mixtures tested, the partial reserve of cement by silica fume action improved the passivation procedures and increased wear resistance, even with the decrease associated with calcium hydroxide, attenuation and pH. (Ortolan et al., 2016)

2.8 CONCLUDING REMARKS

The following conclusions can be summarized from the review of the literature:

1. The effect of high temperature on concrete properties decreasing compressive strength, splitting tensile strength and flexural strength with increasing temperature.
2. Effect of supplementary cementitious Materials on Concrete Properties by Substituting SCM of Cement to Improve Mechanical Properties of Concrete.
3. The high effective pH temperature of concrete reduces the pH of concrete about two units.
4. The effect of supplementary cementing materials on concrete with pH is the pH decrease in partial replacement of Portland cement with supplemental cementitious materials which leads to a decreasing concentration calcium hydroxide.
5. Effect pH value on concrete erosion, pH lowering due to leaching on chloride binding.

Chapter Three
Experimental
Program

Chapter Three

Experimental Program

3-1 Introduction

In this chapter, the aspects of the experimental work are presented. Details of the materials that used mix proportions, procedure of mixing, preparation and curing of specimens and testing program are described, burning process of specimens (cubes, cylinders, prisms) and testing program, test apparent pH for specimens (1,7,28,90) days.

In order to ensure adequate production of concrete, stringent procedures adopted in materials selection, controlling and proportion of the whole ingredient. Under this experimental investigation, the sources of materials, chemical compositions and physical properties of the material that were used are described in details; the necessary tests were conducted at University of Babylon, College of Engineering, Civil Engineering Department laboratories.

3.2 PROGRAM OF THE WORK

The experimental program of this research comprises of two stages. In the first stage, the selection, preparation and evaluation the physical and chemical properties of raw materials used in this study. Subsequently, this stage also performs trail mixes to select the optimum mix proportions and, in this stage, various Supplementary cementitious materials (silica fume, metakaolin, lime stone powder and ground granulated blast furnace slag) as a substitution material of cement in concrete were used to studies the impact of high temperature. Substitution proportion ratios were (10%, 20%, 30% and 40%) to select the proper type and dosage of mineral. Then, the selected materials are mixed with the selected optimum mix proportions and with a suitable mixing procedure. Finally, the casted auxiliary samples and cured for the required ages (7, 28 and 90 days).

While the second stage consists of the burning of the specimens with high temperatures (1.5 hr.) after reaching the required age, preparing and testing of the exposed. The overall experimental details planned in this study are shown in the flowchart given in **Figure (3-1)**. This chapter describes the testing procedure only,

3.3 MATERIALS

It is very important to check the materials that were used in the experimental investigation on the one hand the sources of materials, chemical compositions and physical properties according to the standard specifications. The materials properties were studied and compared with the standard specifications of (IQS) and/or of (ASTM). The necessary tests of the raw material used in the experimental work were conducted at Babylon University, College of Engineering, Civil Department, Construction Materials laboratory. The materials and main properties are as follows:

3.3.1 Portland Cement

Type of cement used in this study was Portland cement known by **KARASTA**, produced in Iraq by the Lafarge Company in Al-Sulaymaniyah city, and occupied from local markets. This cement meets complied with the (EN 197-1:2011) and the international standards It was saved in a dry spot, in order to prevent exposure to different atmospheric conditions. The chemical analysis and physical test results of the cement used are indicated in **Tables (3-1)** and **(3-2)** respectively.

Table (3-1): Chemical Composition and Main Compounds of the Cement

Compound composition	Chemical composition	Percentage by weight	Limit of (EN 197-1:2011)
Lime	CaO	62.79	/
Silica	SiO ₂	20.58	/
Alumina	Al ₂ O ₃	5.6	/
Iron oxide	Fe ₂ O ₃	3.28	/
Sulfate	SO ₃	2.35	2.5 if C ₃ A ≤ 5 2.8 if C ₃ A > 5
Magnesia	MgO	2.79	5% max
Free lime	Free CaO	0.9	/
Loss on ignition	L.O.I.	1.94	/
Insoluble residue	I.R	1.00	/
Lime saturation factor	L.S.F	0.9	/

Main compounds (Bogues Eqs.)	Percent by weight of cement
Tricalcium silicate (C ₃ S)	50.12
Dicalcium silicate (C ₂ S)	21.26
Tricalcium aluminate (C ₃ A)	9.29
Tetracalcium aluminoferrite (C ₄ AF)	9.98

Table (3-2): Physical Properties of Cement

Properties	Test result	Limit of (IQS NO.5/1984)
Setting time (vicat's method)		
Initial, (min)	122	≥ 45 min
Final, (hrs.)	3:13	≤ 10 hrs.
Fineness (Blaine method), m ² /kg	314	≥ 230 m ² /kg
Compressive strength, MPa		
3 days	19	≥ 15 MPa
7 days	28.0	≥ 23 MPa

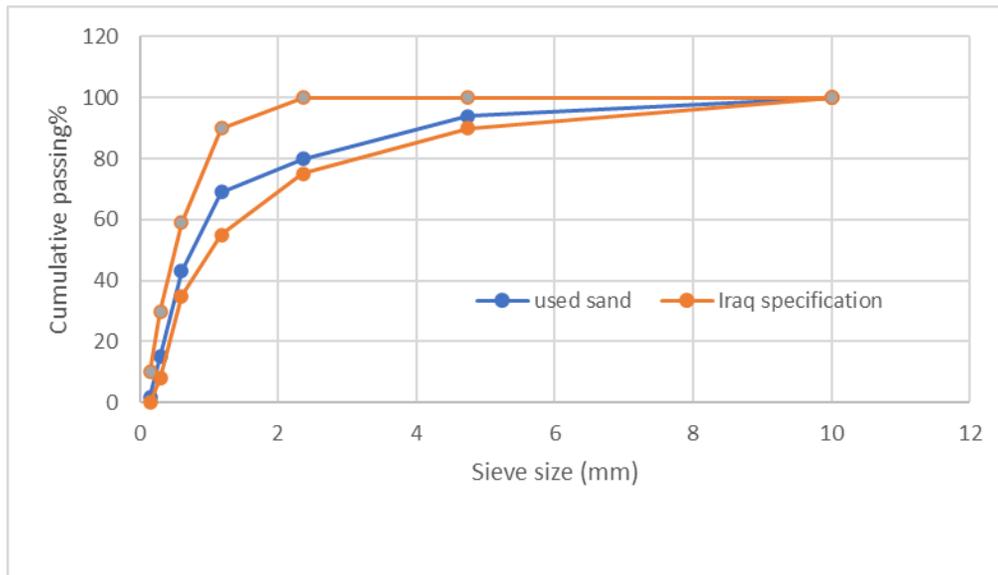
3.3.2 Fine Aggregate (Sand)

Natural sand from (Al-Ekhaider region) was used as fine aggregate. The grading of fine aggregate is shown in Table (3-3) and Figure (3-2). Results of sieve analysis show that fine aggregate grading is agreed with the Iraqi Specification (IQS No.45, /1984 (Zone 2)). Physical and chemical properties of the fine aggregate are shown in Table (3-4). The sulphate content, specific gravity, fineness modulus and absorption of the fine aggregate were carried out in accordance with (IQS No.45/1984). Water was used to wash and clean the sand, and then it was spread out and left in air to ensure that the aggregates are free as possible from silt or clay because it will reduce the cement aggregate bond strength and increasing the water demand, also to get saturated and dry surface state before use it.

Table (3-3): Grading of Fine Sand

Sieve size (mm)	Cumulative passing%	Limits of Iraqi specification No.45/1984 (Zone 2)
10	100	100
4.75	94	90-100
2.36	80	75-100
1.18	69	55-90
0.6	43	35-59
0.3	15	8-30
0.15	2	0-10

*Test was carried out at the University of Babylon College of Engineering, Civil Department laboratories.

**Figure (3-2):** Grading of fine aggregate**Table (3-4):** The physical and chemical properties of fine aggregate.

Properties	Test result	Limits of Iraqi specification No.45/1984
Specific gravity	2.65	/
Fineness modulus	2.9	/
Absorption	1.6%	/
Sulfate content	0.244%	$\leq 0.5 \%$

3.3.3 Coarse Aggregate (Gravel)

The coarse aggregate used was natural rounded gravel with a maximum size of (20mm) as shown in **Table (3-5)** and **Figure (3-3)** which represent the sieve that met requirements of IQS 45-84 limits Size (20-5), obtained from (AL-Nawfith Company) Najaf-Iraq. Gravel was washed to remove clay and salts and then stored in containers to achieve a Saturated Surface Dry (SSD) condition before use it. Mechanical and chemical properties meet the requirements of (**Iraq specification No.45/1984**) as shown in **Table (3-6)**.

Table (3-5): The sieve analysis of the Coarse Aggregate.

Sieve Size (mm)	Passing By Weight %	IQS 45-84 limits Size (20-5)
37.5	100	100
25	100	-
20	100	95-100
10	42	30-60
5	5	0-10
2.36	0	-

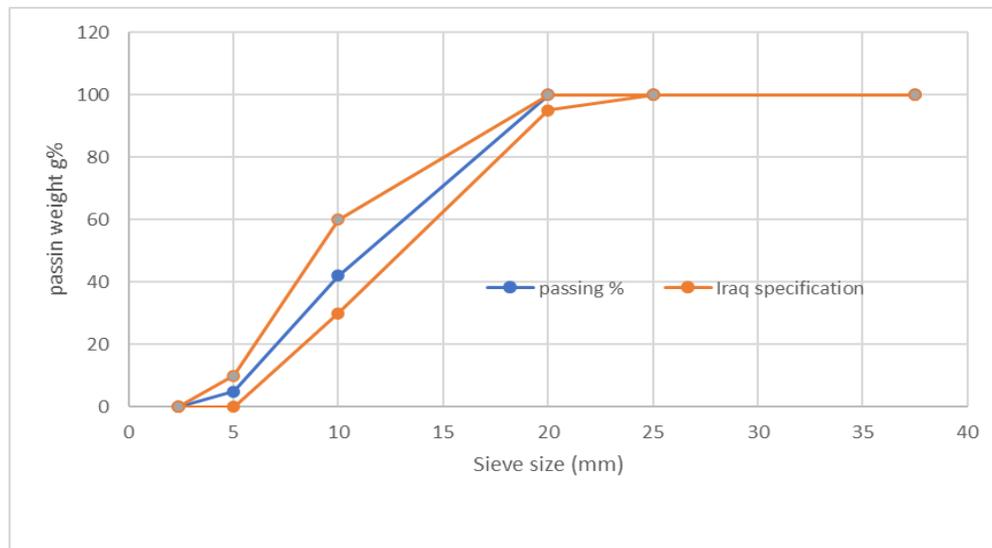


Figure (3-3): Grading curve for the used coarse aggregate

Table (3-6): The physical and chemical properties of Coarse Aggregate*.

properties	Test result	Limits of Iraq specification No.45/1984
Specific gravity	2.66	-
Sulfate content SO ₃ %	0.03%	≤ 0.1%
Absorption	0.05%	-
Clay content	0.3%	≤ 2%

*Test was carried out at the University of Babylon, College of Engineering, Civil Department laboratories.

3.3.4 Water

Drinking water from the college campus was used for all mixing and curing of specimens, water was free of organic material, turbidity and salts; mixing water temperature was maintained at (25±2 ° C).

3.3.5 Silica Fume (SF)

Silica fume (SF) is a by-product of the silicone and ferrosilicon melting process. Reducing high-purity quartz to silicon at temperatures up to 2000 ° C produces SiO₂ vapors that oxidize and condense to tiny particles consisting of noncrystalline silica in the low-temperature zone. The silica condensed fume was then treated to extract impurities and monitor the particle size. **Plate (3-1)** shows the silica fume used in this study.



Plate (3-1): silica fume used in this study.

The particle size ranges from (0.1 to 1 μm) about (100 times) smaller than the typical particle in cement, silica fume strengthens the microstructure of the cement paste and makes it more resistant to some kind of outside effects

The chemical analysis and physical requirement of the silica fume used are listed in **Table (3-7)**. Results show that the (SF) used in this study meets the requirement of (ASTM C 1240/2015). Obtained from CONMIX IRAQ Baghdad/Iraq

Table (3-7): Chemical analysis of silica fume*.

Oxide composition	Oxide content %	ASTM C1240- 05 Limitation
SiO ₂	89.41	Min. 85%
Al ₂ O ₃	0.63	/
Fe ₂ O ₃	0.45	/
CaO	0.82	< 1
SO ₃	0.87	< 2
K ₂ O+Na ₂ O	1.35	/
L.O.I	4.10	Max. 6%
Cl	0.18	/
CaO (free)	2.15	/
Physical Properties	Results	
Percent retained on 45µm (No.325) sieve, max, %	1.7	≤ 10
Specific Surface, Min, (m ² /g)	23	≥ 15
Strength activity index	130%	≥ 105

* Data provided by the manufacture.

3.3.6 Lime stone powder

Limestone powder was used as filler, locally known as AL-Ghubra. The particles size for AL-Ghubra are less than 0.125 mm and that like to the fineness of Portland cement. Limestone powder used in self-compacting concrete to increase density, workability, soundness and initial strength, in addition to reduce the required compaction power. In self-compacting concrete, the cement was partially replaced by limestone powder to develop a certain property such as:

- 1.Improving segregation resistance.
- 2.Avoiding excessive heat generation.
- 3.Enhancing cohesiveness and fluidity.

This filler conforms to BS 7979 BS 7979, Specification for limestone fines for use with Portland cement. The chemical analysis requirement of the lime stone powder used are tabled in **Table (3-8)**. **Plate (3-2)** shows the Lime stone powder used in this study, Data provided by the manufacture from Al Nora factory.

Table (3-8): Chemical analysis of lime stone powder.

Chemical Composition		% by weight
Lime	CaO	45.73
Silica	SiO ₂	6.84
Iron Oxide	Fe ₂ O ₃	0.24
Alumina	Al ₂ O ₃	1.12
Magnesite	MgO	4.37
Sulfate	SO ₃	3.2
Loss of ignition	L.O.I	37.12

*Chemical Analysis was Conducted by the Local Laboratory in AL Nora Factory



Plate (3-2) Lime stone powder used in this study

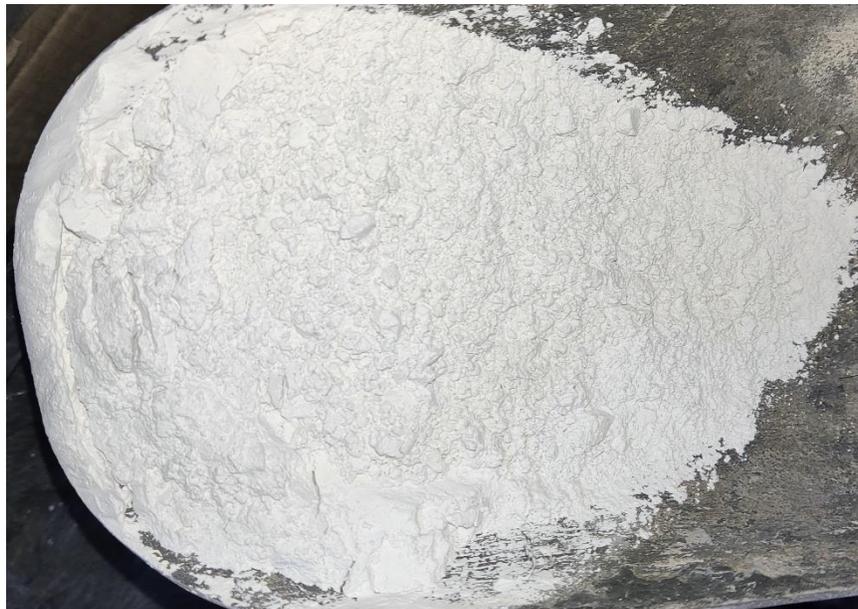
3.3.7 Ground Granulated Blast-Furnace Slag (GGBS)

Ground granulated blast-furnace slag is the granular material formed when molten iron blast furnace slag is rapidly chilled (quenched) by immersion in water. It is a granular product with very limited crystal formation and is highly cementitious in nature. It is ground to cement fineness and hydrates like Portland cement. Properties of GGBS are shown in **Table 3.9**. **Plate (3-3)** shows the GGBS used in this study.

Obtained from Hanson Cement -Purfleet Regen GGBS to BS EN 15167.

Table 3.9 properties of GGBS

Chemical Composition	% by weight
SiO ₂	34.40
Al ₂ O ₃	13.26
Fe ₂ O ₃	0.43
MgO	8.86
MnO	0.29
CaO	38.94
Na ₂ O	0.38
K ₂ O	0.59
SO ₃	0.29
LOI	1.17
TiO ₂	0.94
S ₂ ⁻	0.99
C	0.09
Cl ⁻	0.011
Activity	
7d activity index	65%
28d activity index	90%

**Plate (3-3)** GGBS used in this study.

3.3.8 Metakaolin

Metakaolin differs from other supplementary cementitious materials (SCMs), like fly ash, silica fume, and slag, in that it is not a by-product of an industrial process; it is manufactured for a specific purpose under carefully controlled conditions. Metakaolin is produced by heating kaolin, one of the most abundant natural clay minerals, to temperatures of 650-900 °C. This heat treatment, or calcination, serves to break down the structure of kaolin. Bound hydroxyl ions are removed and resulting disorder among alumina and silica layers yields a highly reactive, amorphous material with pozzolanic and latent hydraulic reactivity, suitable for use in cementing applications. Obtained from Al-Mohandis Technical scientific Bureau Baghdad/Iraq

The chemical analysis of the Metakaolin used are tabled in **Table (3-10)**

Plate (3-4) shows the Metakaolin used in this study.

Table (3.10) Chemical analysis of Metakaolin

Chemical Composition	% by weight
SiO ₂	51.2%
Al ₂ O ₃	45.3%
Fe ₂ O ₃	0.60%
MgO	—
CaO	0.05%
Na ₂ O	0.21%
K ₂ O	0.16%
SO ₃	—
LOI	0.51%
Activity	
7d activity index	84
28d activity index	94



Plate (3-4) Metakaolin used in this study

3.3.9 STRENGTH ACTIVITY INDEX FOR MINERAL ADMIXTURE

Various Supplementary cementitious materials (silica fume, metakaolin and ground granulated blast furnace slag) are a very small particle; it is used to reduce the cement content in the concrete mixture by replacing a part of cement content with these materials. When adding these materials, the changes in microstructure of concrete will occur. These changes result from two main processes. Firstly, chemical process by react with calcium hydroxide liberated from cement hydration that will produce additional binder by increased amount of calcium silicate hydrate gel (C-S-H). Secondly, physical process, if these materials are not react chemically, it will fill the space between cement particle and cause improvement in the structure of concrete (Holland, 2005).

There are two test methods used to detect of pozzolanic activity: direct method measuring consumption of $\text{Ca}(\text{OH})_2$, and indirect methods by measuring the relative compressive strength of test specimens, Strength Activity Index (SAI). Strength Activity Index (SAI) is used in this study. Test specimens was prepare according to (ASTM C1240, 2015) by forming two sets of test specimens that have size (50*50*50) mm, three cubes for each set. First set (control mixture), use 100 % Portland cement, another set (test mixture) where part of the Portland cement is replaced by a equivalent mass of the pozzolan to be tested .The mix proportions of the control and the test specimens was described in Table (3-11) according to (ASTM C1240, 2015).

Table (3-11): Mix proportions of the control and test specimens.

Control Mixture	Test Mixture
500g of Portland cement.	450g of Portland cement.
1375g of standard graded sand.	1375g of standard graded sand.
242ml of water.	242ml of water
---	50g SCM
---	10g of high range water reducer required to produce a flow of (100-115) %.

Casting the cubes (control and test specimens) and leave it 24 hrs in the wet room had temperature ($23 \pm 2^\circ\text{C}$) and relative humidity greater than 95%, then the cubes placed in sealed glass containers and stored for six days at ($65 \pm 2^\circ\text{C}$). The specimens tested as specified in testing method ASTM C109/C 109M to determine the compressive strength at 7 days after molding.

The result of the tested specimens was applying in the equation according to (ASTM C 311, 2017) to calculate the strength Activity Index (SAI).

$$\text{SAI} = \text{A/B} * 100 \quad (3-1)$$

where

A: Average compressive strength of test mixture cubes, (MPa).

B: Average compressive strength of control mixture at the same age of age A, (MPa).

3.4 Concrete Mix Proportion

Many forms of mixed concrete were used, the first mix include concrete without replacement whit 25MPa. And other mix includes replacement cement with supplementary cementitious materials (Silica fume, Metakaolin, GGBS, Lime stone powder) by ratio (10%, 20% ,30%, 40%)

3.4.1 Concrete without replacement

The quantity of materials mix shown in **Table (3-11)**

Table (3-11) mix proportion of concrete without replacement for (25 MPa) according to (ACI 211.1-91,1991)

Materials	Proportion of mix (kg/m ³)
Cement	380
Coarse aggregate	988
Fine aggregate	700
Water	210
W/c ratio	0.55

3.4.2 The mix with replacement cement by supplementary cementitious materials

This mix includes replacement cement by supplementary cementitious materials (Silica fume, Metakaolin, GGBS, Lime stone powder) by ratio (10%,20%,30%, and 40%) for every one of them shown in **Table (3-12)**

Table (3-12) mix proportion of concrete with replacement cement by supplementary cementitious materials

Mix symbol	The Description	Proportions of mix (kg/m ³)								
		cement	Fine aggregate	Coarse aggregate	water	w/c	Silica fume	GGBS	metakaolin	Lime stone powder
S1	10% silica fume	342	700	988	210	0.55	38	-	-	-
S2	20% silica fume	304	700	988	210	0.55	76	-	-	-
S3	30% silica fume	266	700	988	210	0.55	114	-	-	-
S4	40% silica fume	228	700	988	210	0.55	152	-	-	-
L1	10% metakaolin	342	700	988	210	0.55	-	-	38	-
L2	20% metakaolin	304	700	988	210	0.55	-	-	76	-
L3	30% metakaolin	266	700	988	210	0.55	-	-	114	-
L4	40% metakaolin	228	700	988	210	0.55	-	-	152	-
W1	10% lime stone powder	342	700	988	210	0.55	-	-	-	38
W2	20% lime stone powder	304	700	988	210	0.55	-	-	-	76
W3	30% lime stone powder	266	700	988	210	0.55	-	-	-	114
W4	40% lime stone powder	228	700	988	210	0.55	-	-	-	152
G1	10% GGBS	342	700	988	210	0.55	-	38	-	-
G2	10% GGBS	304	700	988	210	0.55	-	76	-	-
G3	10% GGBS	266	700	988	210	0.55	-	114	-	-
G4	10% GGBS	228	700	988	210	0.55	-	152	-	-

3.5 Mixing procedure of concrete

The mixing procedures of strength concrete according to (ASTM C192) to obtain compressive strength greater than 25 MPa, begin by weighing and packing all quantities of the raw materials (gravel, sand and cement) in a clean plastic container before mixing. The electrical horizontal rotary drum mixer of (0.09 m³) volume capacity is applied to saturated surfaces, dry rounded gravel and sand, and mixed for several minutes. Then, cement is gradually added to the mix. Total time for mixing (8-10 minutes). Mixer shown in **Plate (3-5)**.



Plate (3- 5): Mixer that used.

3.6 Casting and curing specimens

For specimen's strength concrete, fiber class cube molds were used to study the compressive strength and fiber class cylinder molds were used to study the splitting strength test and fiber class prism molds were used to study the flexural strength test. The molds were cleaned and oiled before casting each mixture, to prevent adhesion between the concrete and the molds. The fresh concrete should be placed in layers.

After finishing the casting process, each layer compacted by hand using a compacted stick to reduce air voids, leveled the surface using a steel trowel and left in the laboratory for one day. Then the specimens were removed from the mold after that, and cured in natural water tank until the time of the test. **plate (3-6)** show specimen's (cube, cylinder, prism)



plate (3-6) show specimen's (cube, cylinder, prism)

3.7 Experimental Test

All the tests were carried out in the Construction Material Laboratory at the Civil Engineering Department / University of Babylon

3.7.1 Test for Fresh Properties of Concrete (Slump test)

Slump test was used to determine the suitable (W/C) (0.55) ratio to get good workability and consistency for normal strength concrete. Slump test was carried according to (ASTM C143-15) as shown in **plate (3-7)**.



Plate (3-7) Slump test for concrete.

3.7.2 Test of Hardened Strength Concrete (Compressive Test)

The compressive strength of normal strength concrete was carried out in accordance to (BS1881-116), through using (100mm) cubes loaded uniaxial by the universal compressive machine. The loading rate was applied at (0.3 N/mm² per second)

Cubes were tested at different ages (7, 28,90 days) with two methods of curing: the first method by immersion the specimens in water tank inside the laboratory and the second method was outside the laboratory (conventional curing method) for the cubes; to simulate the practical site conditions.

Thereafter, cubes were cured with saturated wet coverings by using burlap and covering with polyethylene sheet to prevent evaporation of curing water, then used the equation ($f'c = f_{cu} \times 0.8$) to find the value of $f'c$ according to (ACI 318). **Plate (3-8)** compressive strength test machine.



Plate (3-8) compressive strength test machine.

3.7.3 Flexural Strength Test

This test was performed in accordance with (ASTM C78,2002), using prismatic specimens of (100×100× 400 mm). The specimens were tested as simply supported beam with third point load at a constant rate of loading about (0.015Mpa/sec), by using a hydraulic machine CONTROLS digital of (150 KN) capacity as shown in **Plate (3-9)**. The specimens were tested at ages of (90 days) and the average of two specimens was recorded. The following equation is used to estimate the flexural strength:

$$f_r = PL / bd^2 \text{ ----- Eq.(3-1)}$$

Where:

f_r : modulus of rupture (MPa),

P: maximum applied load (N),

L: span length (mm) [in this work, L=300mm],

b: average width of specimen (mm),

d: average depth of specimen (mm).



Plate (3-9): Flexural testing machine.

3.7.4 Splitting Tensile Strength Test

The indirect tensile strength (splitting tensile strength) test is carried out on concrete specimens in accordance with (ASTM C496 / C496M,2017). Split cylinder strength tests are made on specimens with dimensions (100 × 200 mm), after curing the specimens by immersion in water tank inside the laboratory for (28 and 90 days). **Plate (3-10)** shows the machine used for test.

The splitting tensile strength is calculated, as follows:

$$F_t = 2P/\pi dl \text{ ----- Eq. (3-2)}$$

Where:

F_t = Splitting tensile strength (Mpa),

P = Maximum applied load, (N),

L = Length, (mm),

d = Diameter, (mm).



Plate (3- 10): Splitting tensile strength test machine.

3.8 Burning Procedure

The main aim of the fire flame furnace is to elevate the temperature degree of specimen models for testing under certain thermal conditions, the full details and equipment of the furnace are illustrated below:

1. Brick furnace.
2. Infrared thermometer.
3. Gas source.
4. Gas connections and pipelines.
5. Furnace steel cover.
6. Ignition tool.

The samples were burning in the furnace, the durations of the fire loading were 1.5 hours at (150 c⁰, 350 c⁰, and 550 c⁰), After the processing was completed, the burning procedure was applied. The samples were burned with a direct fire flame by a network of methane burners inside brick oven for target temperature. Burning has been done by the steps blow:

1. After preparing the furnace with all connections, samples are taken they are carefully hand held and placed horizontally inside the oven.
2. Opened the gas valve and the burners caught the ignition instrument, the measured temperature was increasing gradually every (5 minutes) .

3. After burning time (1.5 hours after exposure) Gas valve closed and samples cooled immediately.

3.8.1 Brick Furnace

The furnace is manufactured with outer dimensions of (1000 mm×1000mm×1000 mm) (length× width× height) respectively. And the wall thickness in all sides is fixed at 250 mm, the main structure is made of fire brick and mortar with small opening to provide the necessary fresh oxygen for the burners, the furnace cover is made of insulator plate with thickness of 8 mm to keep the temperature constant as described in **Plate (3-11)**. The burners network consists of sixteen arranged in four horizontal lines each line consist of four burners and all burners are connected together to the control gas charge which connected to the main gas, two networks are equipped for purpose of burning three scenarios to simulate the heating condition in a realistic fire.



Plate (3-11): Details of the brick furnace and furnace steel cover.

3.8.2 INFRARED THERMOMETER

Infrared thermometer GM550. A device that measures temperature with a laser from (50 to 550) degrees Celsius, show in **Plate (3-12)**



Plate (3-12) Infrared thermometer GM550

3.9 TSET PH OF CONCRETE

Test PH of concrete from PH meter (pHep HI98107 HANNA) show in **Plate (3-13)**



Plate (3-13) pH meter

TEST PROCEDURE USING PH METER

1. Calibrate the pH meter with three pH calibration standards either supplied by the pH meter manufacturer or an independent chemical supplier. The three calibration solutions shall be of pH 7, 10, and 12. The measuring tip of the pH meter shall be cleaned by dipping in a clean container of fresh distilled water and wiped dry with a clean, fresh paper towel before taking the pH readings. Repeat the same cleaning procedure immediately after completing each pH reading. Record each of the three pH readings.
2. Use infrared thermometer to measure surface temperature of concrete to the nearest degree Fahrenheit or Celsius.
3. Clean the concrete surface to remove dirt, concrete sealer, and existing adhesive residue.
4. Lightly abrade an approximate 12 in. (300 mm) diameter area of the clean concrete surface for 60 ± 10 seconds with 50-grit sandpaper. Collect and measure 0.5 g (0.0011 lb) of concrete powder using a gram scale.
5. Add concrete powder in a bottle containing 0.34 fluid ounces (10 mL) of fresh distilled water. Close the bottle lid and shake the bottle for 30 ± 5 seconds. Allow the bottle to rest for 2 minutes.
6. Insert the pH meter into the concrete mixture solution and record the stable pH of the mixture solution to the nearest tenth.
7. Report calibration pH readings, pH of concrete surface, and concrete surface temperature. **(Ashok, 2014)**

Show test pH concrete in **Plate (3-14)**



Plate (3-14) test pH concrete from pH meter

CHAPTER FOUR
RESULTS AND
DISCUSSION

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. INTRODUCTION

The main objective of the research is to study the combined effect of high temperature and supplementary cementitious materials as replacement (silica fume, lime stone powder, metakaolin and GGBS) on pH concrete and mechanical properties (compressive strength, splitting tensile strength and flexural strength).

4.2. PROPERTIES of CONCRETE

The Fresh concrete properties were recorded by the slump test. The test results were ranged from (90 mm) to (105 mm) with average (100 mm) for all samples in thesis. The test was done according to (ASTM C143-12). On the other hand, Mechanical properties were listed as shown below:

4.2.1. Compressive strength

Compressive test is a very common test that used to determine a compressive force or crush resistance for concrete. Compressive test is used to determine the behavior of the concrete under applied load. The average of three cube specimens with dimension (100mm) were used to determine compressive strength at ages (7, 28 and 90) days. These cubes were cast using supplementary cementitious materials (silica fume, lime stone powder, metakaolin and GGBS) with (10%,20%,30%, and 40%) as replacement with cement. The cubes were exposed to high temperature at duration of (1.5 hr.) to determine the compressive strength. The specimens were tested at temperature (23c°,150c°,350c° and 550c°) at ages (7,28 and 90) days.

4.2.1.1 Compressive strength for Concrete without Replacement.

The test results of the compressive strength of concrete were listed in

Table (4 - 1) for concrete without replacement supplementary cementitious materials.

Table (4 - 1): Summary of compressive strength for concrete without replacement

Symbol of		Compressive strength (MPa)					
specimens	Temp.(C°)	7days	% Drop in compressive strength	28 days	% Drop in compressive strength	90 days	% Drop in compressive strength
R	23	13.46	-	22.9	-	26.9	-
	150	12.05	10.5	16.3	28.8	21.9	18.3
	350	10.23	24.0	14.6	36.5	19.0	29.2
	550	7	48.0	10.0	56.3	17.0	36.7

The results are plotted in

Figure (4 - 1), which shows the compressive strength at different ages and temperature.

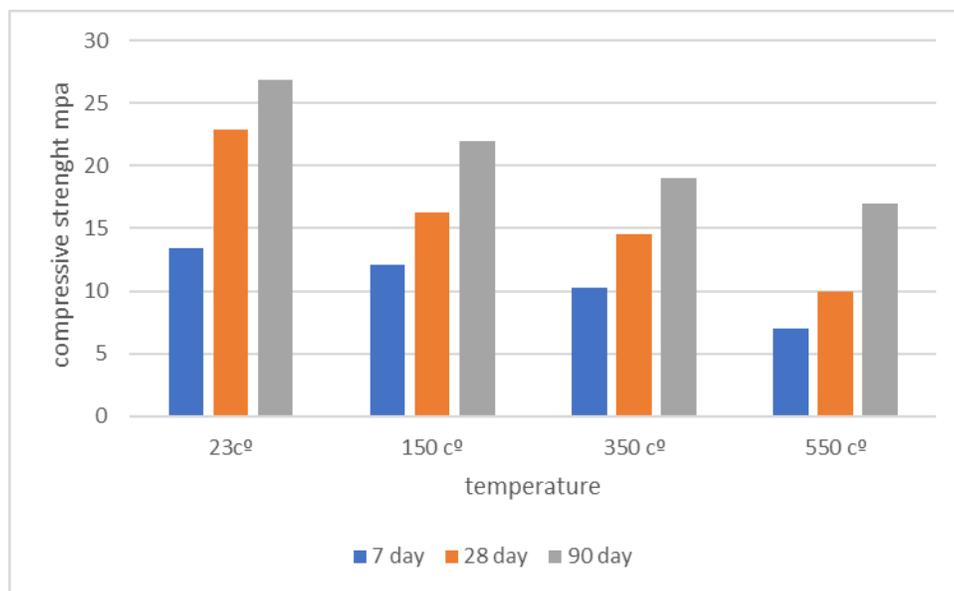


Figure (4 - 1): Results of compressive strength test for concrete without replacement

4.2.1.2 Compressive strength for concrete with replacement (silica fume).

The test results of the compressive strength for concrete with replacement (silica fume) were listed in Table (4 - 2)

Table (4 - 2): Summary of compressive strength for concrete with silica fume as replacement (10%,20%,30% and 40%)

Symbol of specimens	Ratio content replacement silica fume from cement %	Temp. (C°)	Compressive strength (MPa)					
			7days	% Drop in compressive strength	28 days	% Drop in compressive strength	90 days	% Drop in compressive strength
S1	10%	23	13.46	-	17.48	-	24.6	-
		150	12.50	7.13	15.51	11.27	22.73	7.60
		350	11.40	15.30	14.85	15.05	18.73	23.86
		550	9.50	29.42	12.45	28.78	15.8	35.77
S2	20%	23	17.43	-	26.39	-	28.87	-
		150	14.80	15.09	25.43	3.64	26.3	8.90
		350	13.10	24.84	24.82	5.95	25	13.40
		550	12.42	28.74	20.8	21.18	21.2	26.57
S3	30%	23	20.68	-	27.9	-	30.16	-
		150	19.85	4.01	26.7	4.30	29.23	3.08
		350	16.5	20.21	26	6.81	28.1	6.83
		550	11.84	42.75	24.5	12.19	27	10.48
S4	40%	23	17.75	-	19	-	25.92	-
		150	14.34	19.21	14.84	21.89	24.36	6.02
		350	11	38.03	13.53	28.79	23	11.27
		550	9	49.30	11.85	37.63	15.51	40.16

The results are plotted in Figure (4 - 2), which shows the compressive strength at different ages and temperature with silica fume (10%,20%,30% and 40%) replacements. Figure (4 - 3), Figure (4 - 4) and Figure (4 - 5) showed drop percent in compressive strength with different temperatures after using silica fume at age(7, 28 and 90) respectively.

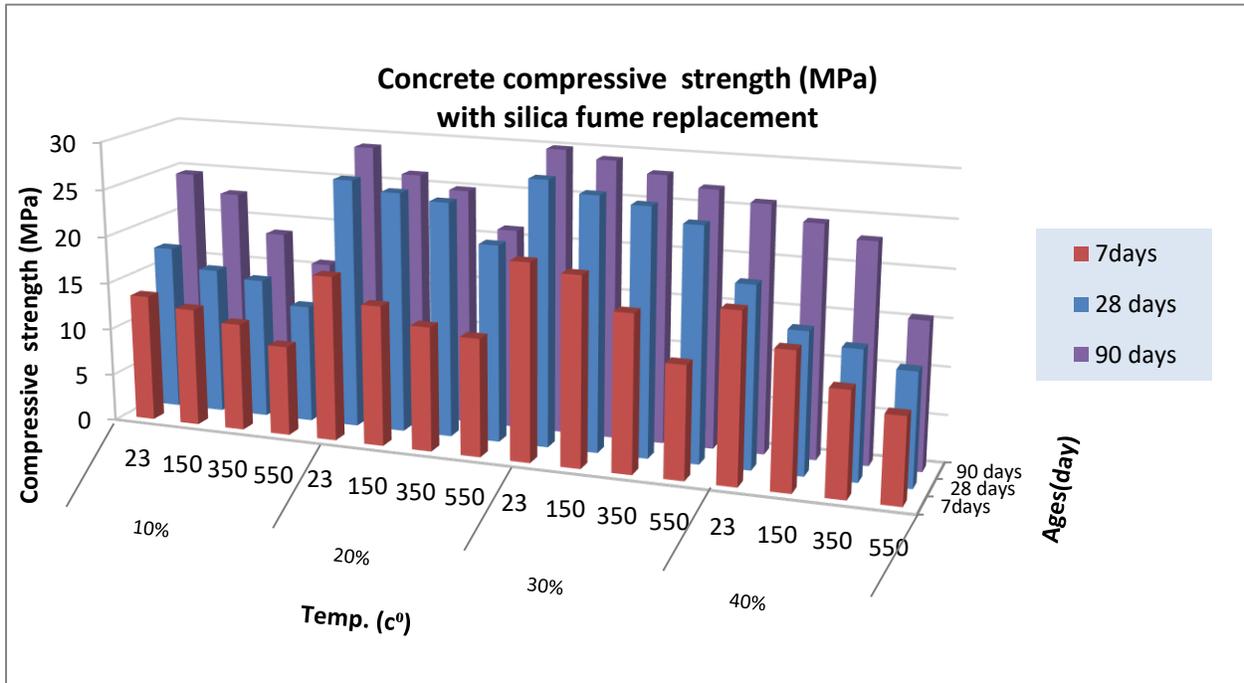


Figure (4 - 2): Results of compressive strength test for concrete with silica fume replacements.

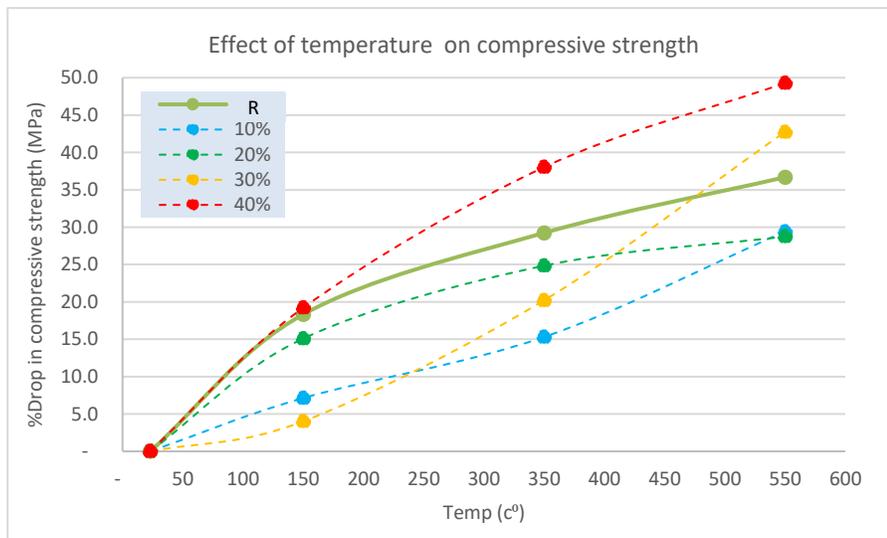


Figure (4 - 3): Drop in compressive strength for concrete with replacement (silica fume) at age 7 days.

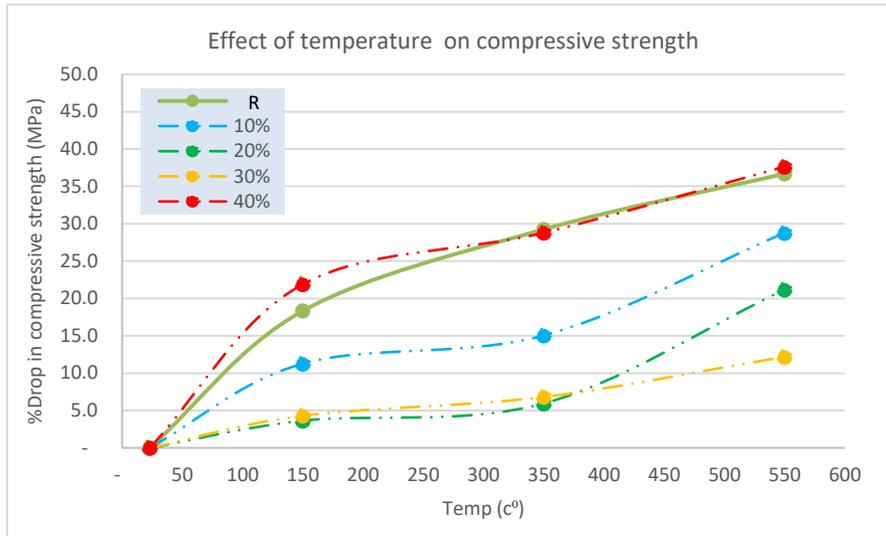


Figure (4 - 4): Drop in compressive strength for concrete with replacement (silica fume) at age 28 days.

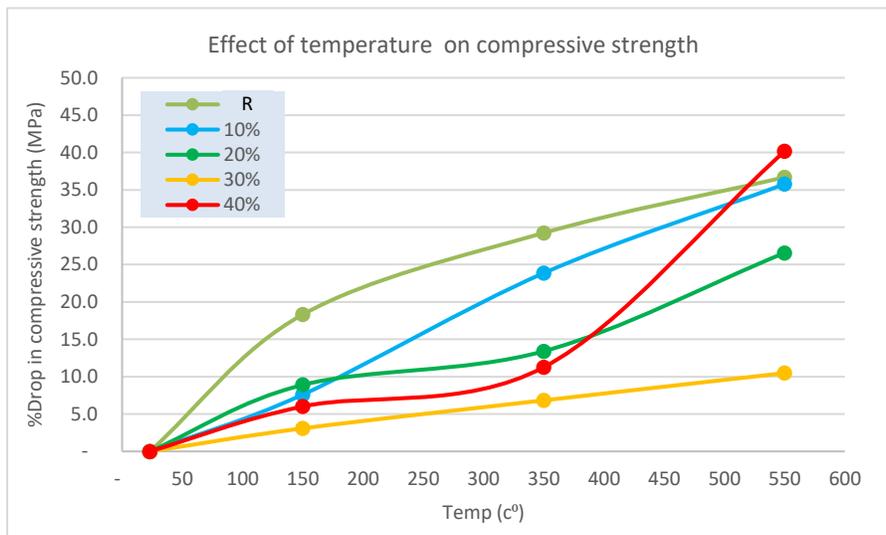


Figure (4 - 5): Drop in compressive strength for concrete with replacement (silica fume) at age 90 days.

4.2.1.3 Compressive strength for concrete with replacement (metakaolin)

The test results of the compressive strength of concrete in Table (4 – 3)

Table (4 – 3): Summary of compressive strength for concrete replacement metakaolin (10%,20%,30% and 40%)

Symbol of specimens	Ratio content replacement metakaolin from cement %	Temp . (C°)	Compressive strength (MPa)					
			7days	% Drop in compressive strength	28 days	% Drop in compressive strength	90 days	% Drop in compressive strength
M1	10%	23	6.05	-	11.33	-	18.44	-
		150	5.25	13.22	9	20.56	15.54	15.73
		350	4.95	18.18	8.7	23.21	14.61	20.77
		550	4.8	20.66	7.92	30.10	12.76	30.80
M2	20%	23	8.22	-	15.72	-	22.16	-
		150	6.36	22.63	15.12	3.82	20.42	7.85
		350	5.78	29.68	14.95	4.90	18	18.77
		550	4.94	39.90	11.63	26.02	17	23.29
M3	30%	23	12.2	-	24.16	-	28.33	-
		150	11.12	8.85	17.46	27.73	23	18.81
		350	10.18	16.56	17.2	28.81	21.29	24.85
		550	9.31	23.69	15.19	37.13	19.9	29.76
M4	40%	23	12.07	-	17.2	-	22	-
		150	10.45	13.42	13.45	21.80	18.56	15.64
		350	9.48	21.46	10.12	41.16	17.71	19.50
		550	7.18	40.51	9	47.67	14.93	32.14

The results are plotted Figure (4 - 6), which shows the compressive strength at different ages and temperature with metakaolin (10%,20%,30% and 40%) replacements. Figure (4 - 7), Figure (4 - 8) and Figure (4 - 9) showed drop percent in compressive strength after adding metakaolin at ages (7, 28 and 90) respectively.

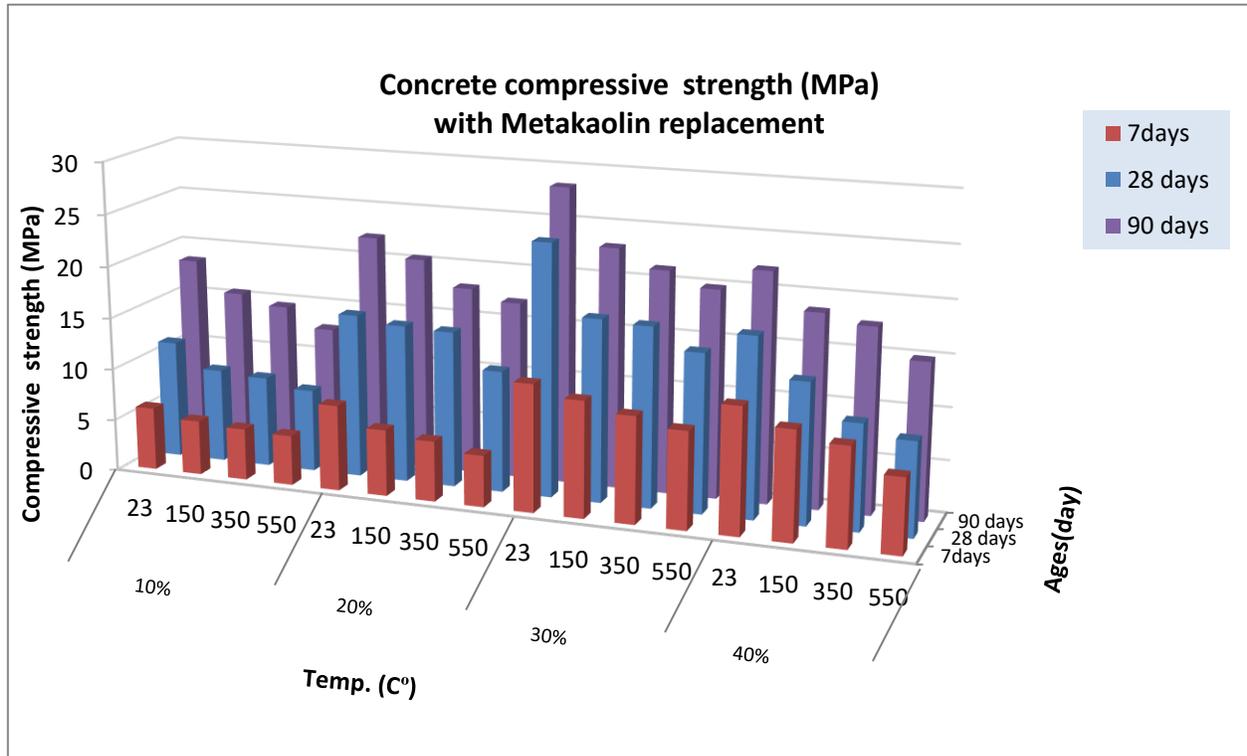


Figure (4 - 6): Results of compressive strength test for concrete with metakaolin replacements

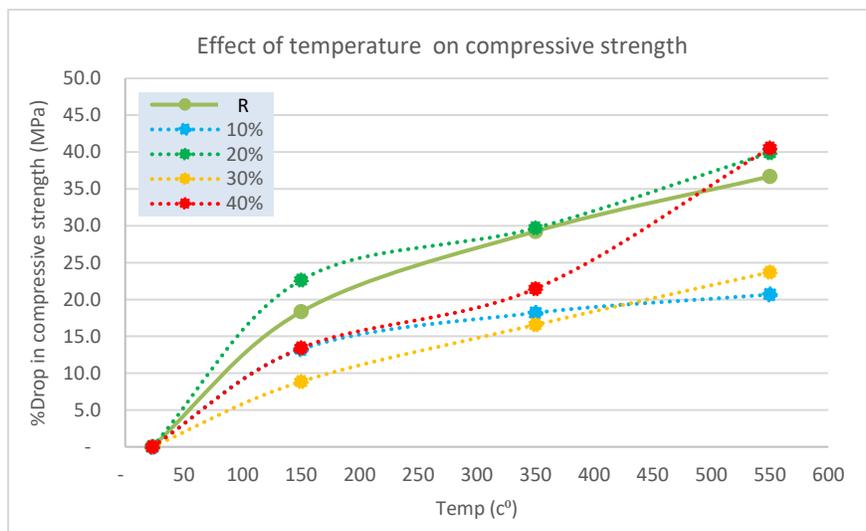


Figure (4 - 7): Drop in compressive strength for concrete with replacement (metakaolin) at age 7 days.

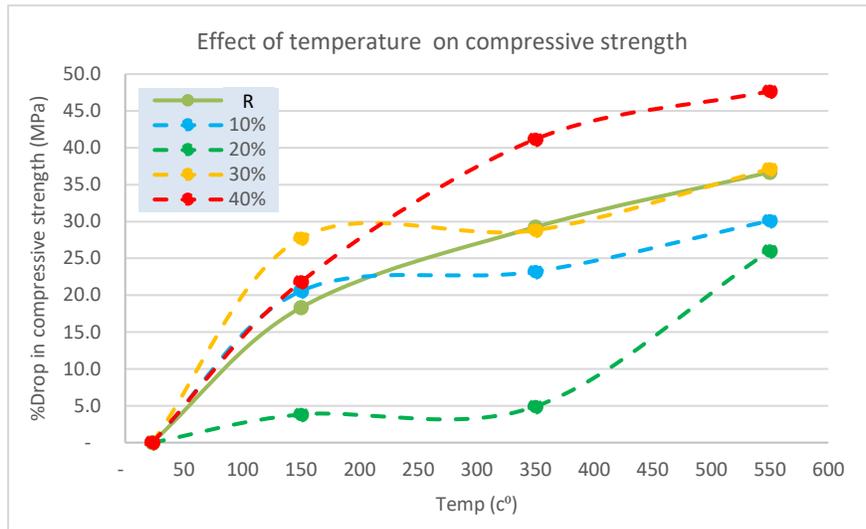


Figure (4 - 8): Drop in compressive strength for concrete with replacement (metakaolin) at age 28 days.

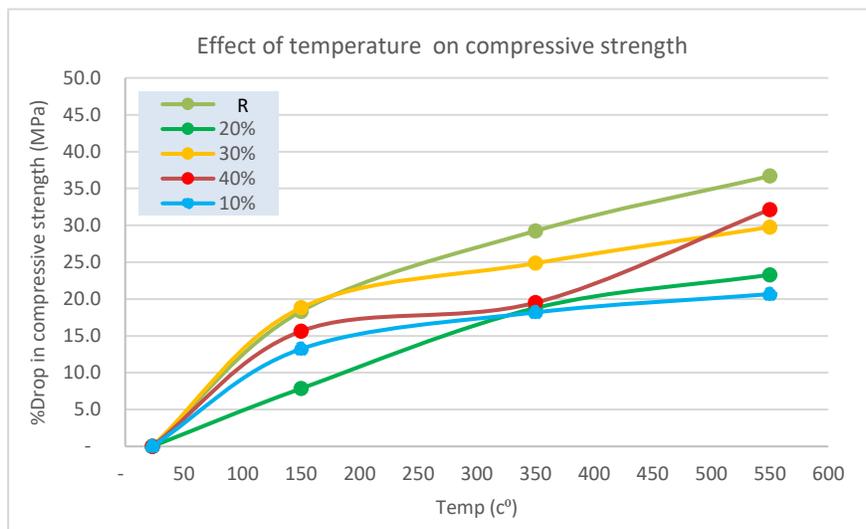


Figure (4 - 9): Drop in compressive strength for concrete with replacement (metakaolin) at age 90 days.

4.2.1.4 Compressive strength for concrete with replacement (lime stone powder)

The test results of the compressive strength of concrete with replacement (lime stone powder) in Table (4 - 4)

Table (4 - 4): Summary of compressive strength for concrete replacement lime stone powder (10%,20%,30% and 40%)

Symbol of specimens	Ratio content replacement lime stone powder from cement %	Compressive strength (MPa)						
		Temp. (C°)	7days	% Drop in compressive strength	28 days	% Drop in compressive strength	90 days	% Drop in compressive strength
L1	%10	23	11.04	-	12.52	-	19.73	-
		150	10.82	1.99	7.77	37.94	17	13.84
		350	9.85	10.78	7	44.09	15	23.97
		550	8.26	25.18	5.44	56.55	10.45	47.03
L2	%20	23	9.21	-	11.44	-	15	-
		150	8	13.14	8.96	21.68	14.62	2.53
		350	5.66	38.55	6.48	43.36	13	13.33
		550	4.47	51.47	5.95	47.99	10.83	27.80
L3	%30	23	7.4	-	7.54	-	11.25	-
		150	6	18.92	6.95	7.82	10.96	2.58
		350	5	32.43	6.63	12.07	10.77	4.27
		550	3.48	52.97	5.65	25.07	6.94	38.31
L4	%40	23	6.46	-	6.27	-	16.45	-
		150	4.4	31.89	5	20.26	8.1	50.76
		350	3.6	44.27	3.73	40.51	6.5	60.49
		550	3	53.56	3.5	44.18	6	63.53

The results are plotted in Figure (4 - 10), which shows the compressive strength at different ages and temperature with lime stone powder (10%,20%,30% and 40%) replacements. Figure (4 - 11), Figure (4 - 12) and Figure (4 - 13) showed drop percent in compressive strength after adding lime stone at ages (7, 28 and 90) respectively.

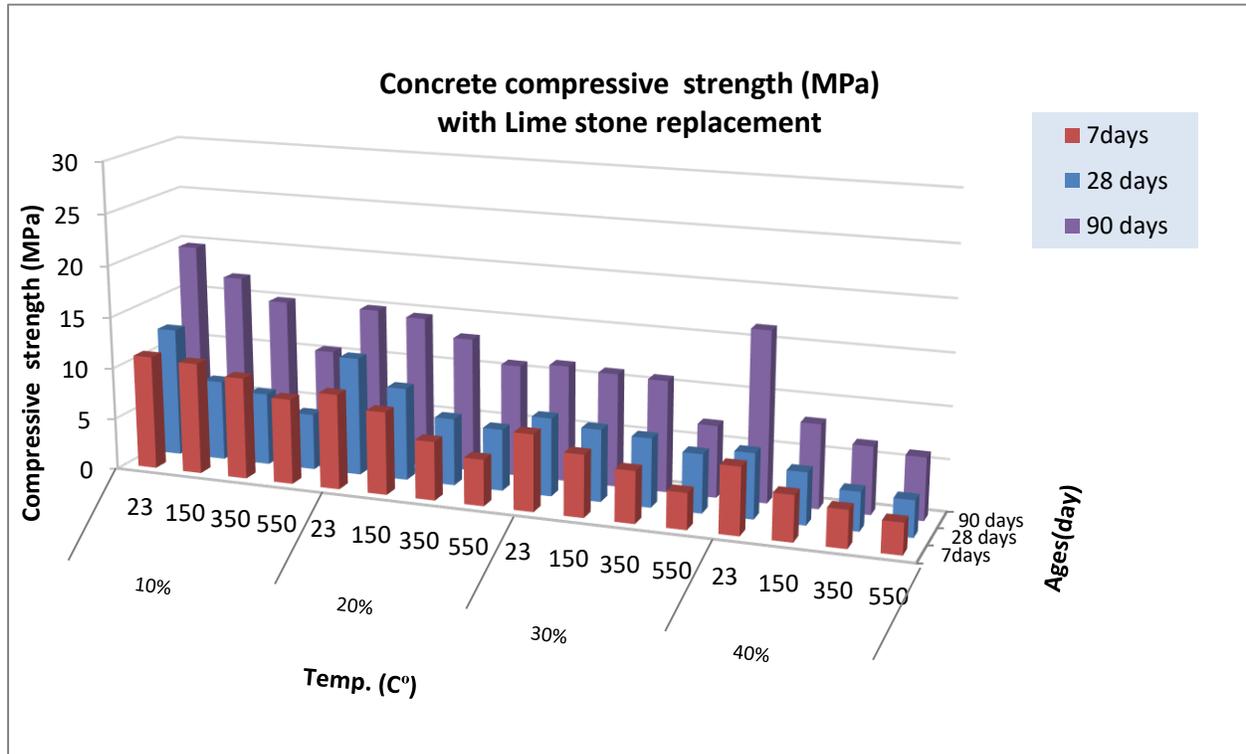


Figure (4 - 10): Results of compressive strength test for concrete with lime stone powder replacements.

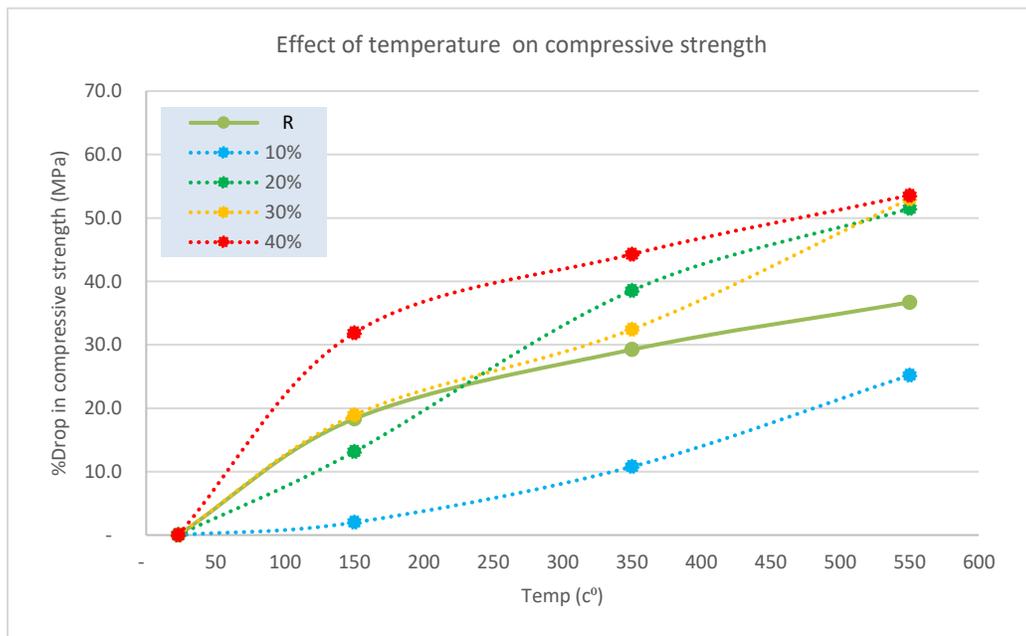


Figure (4 - 11): drop in compressive strength for concrete with replacement (lime stone powder) at age 7days.

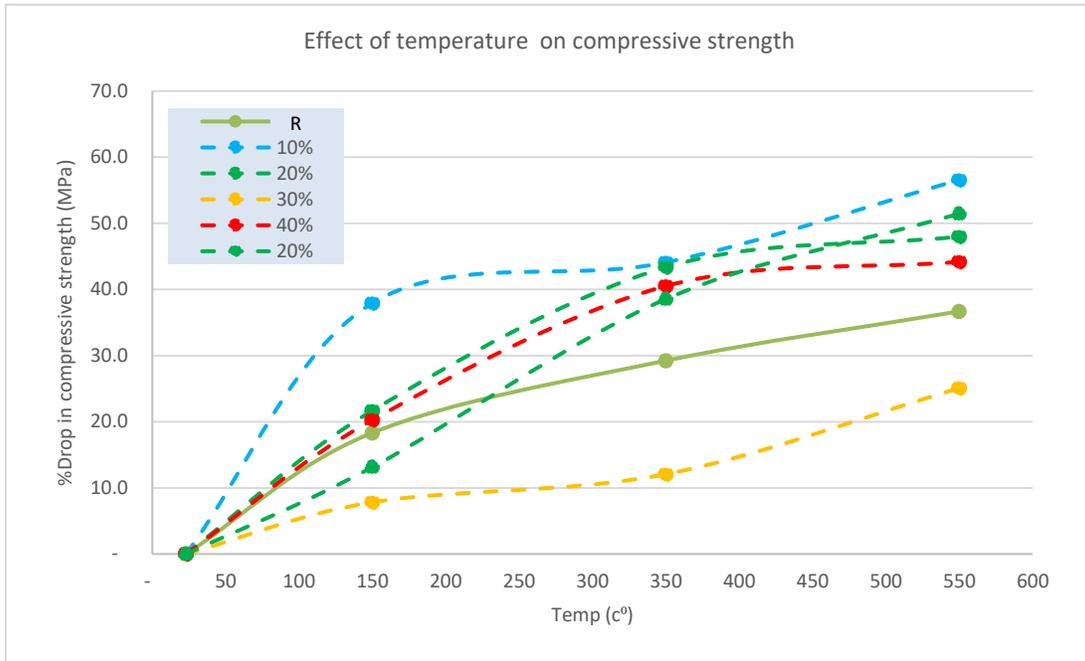


Figure (4 - 12): drop in compressive strength for concrete with replacement (lime stone powder) at age 28 days.

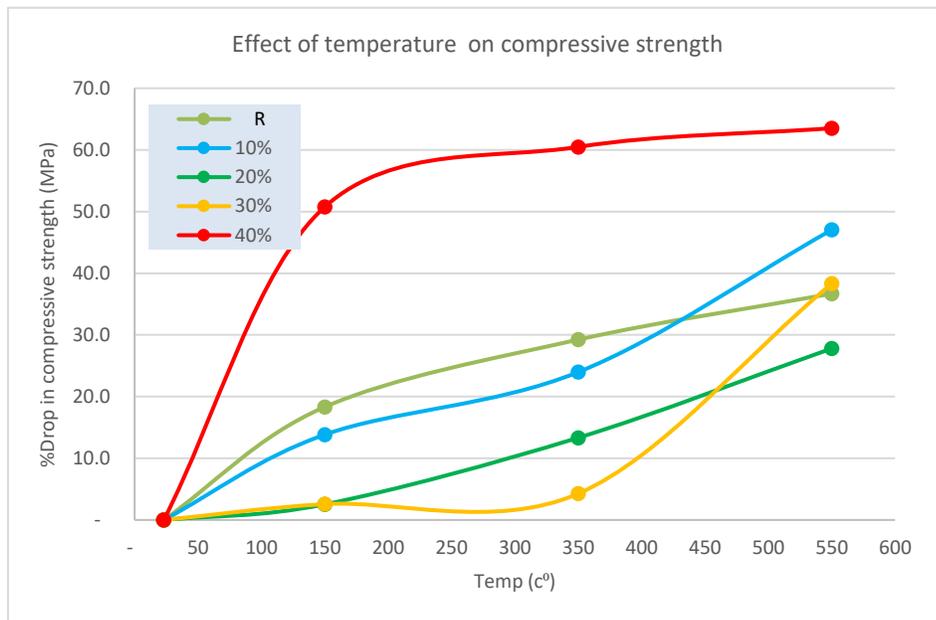


Figure (4 - 13): drop in compressive strength for concrete with replacement (lime stone powder) at age 90 days.

4.2.1.5 Compressive Strength for Concrete with replacement Ground Granulated Blast Furnace Slag (GGBS)

The test results of the compressive strength of concrete in Table (4 - 5)

Table (4 - 5): Summary of compressive strength for concrete replacement ground granulated blast furnace slag GGBS (10%,20%,30% and 40%)

Symbol of specimens	Ratio content replacement GGBS from cement %	Temp. (C°)	Compressive strength (MPa)			
			28 days	% Drop in compressive strength	90 days	% Drop in compressive strength
G1	10%	23	16.66	-	28	-
		150	16	3.96	24.5	12.50
		350	14.62	12.24	21	25.00
		550	11	33.97	17	39.29
G2	20%	23	20.5	-	32	-
		150	19.5	4.88	29	9.38
		350	19	7.32	27.5	14.06
		550	18	12.20	24	25.00
G3	30%	23	19.5	-	32.5	-
		150	19	2.56	31	4.62
		350	16.8	13.85	23	29.23
		550	12	38.46	22.5	30.77
G4	40%	23	22	-	31.5	-
		150	21	4.55	28	11.11
		350	19	13.64	25.5	19.05
		550	17	22.73	24	23.81

The results are plotted in Figure (4 - 14), which shows the compressive strength at different ages and temperature with GGBS (10%,20%,30% and 40%) replacements. Figure (4 - 15) and Figure (4 - 16) showed drop percent in compressive strength after adding metakaolin at ages (7, 28 and 90) respectively.

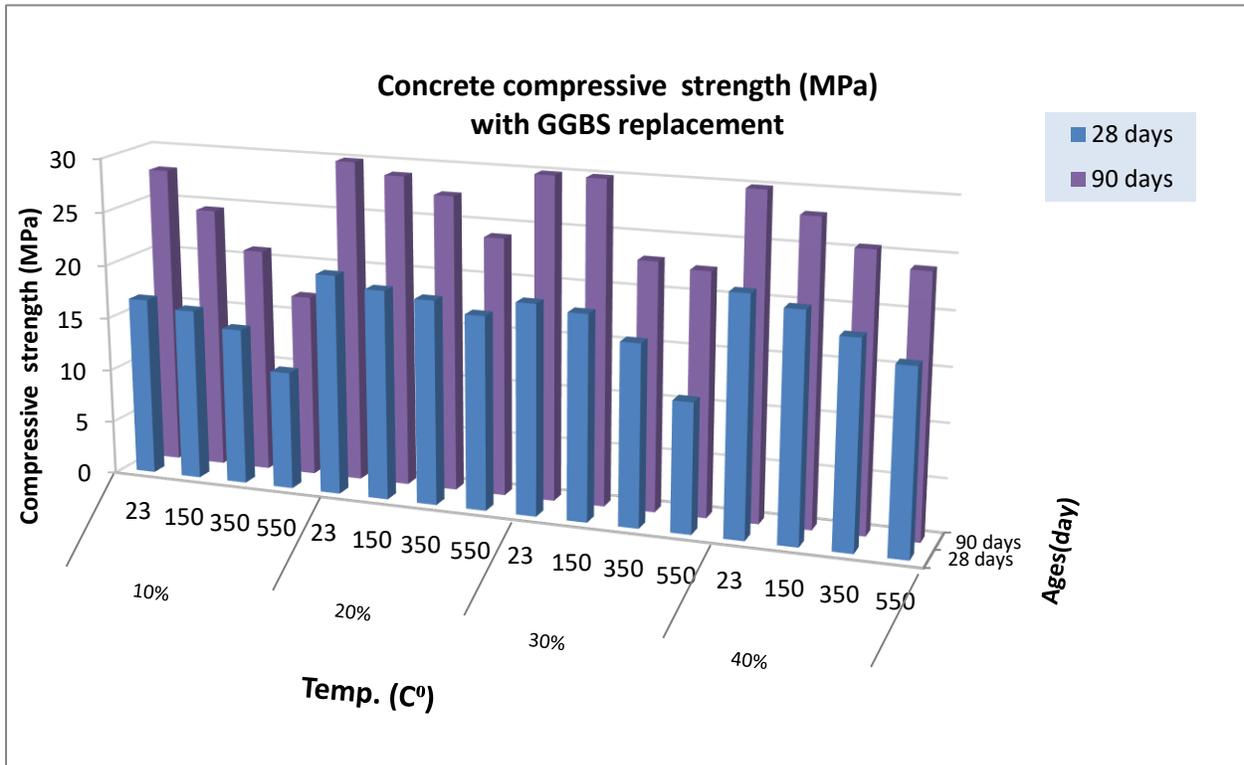


Figure (4 - 14): Results of compressive strength test for concrete with GGBS replacements.

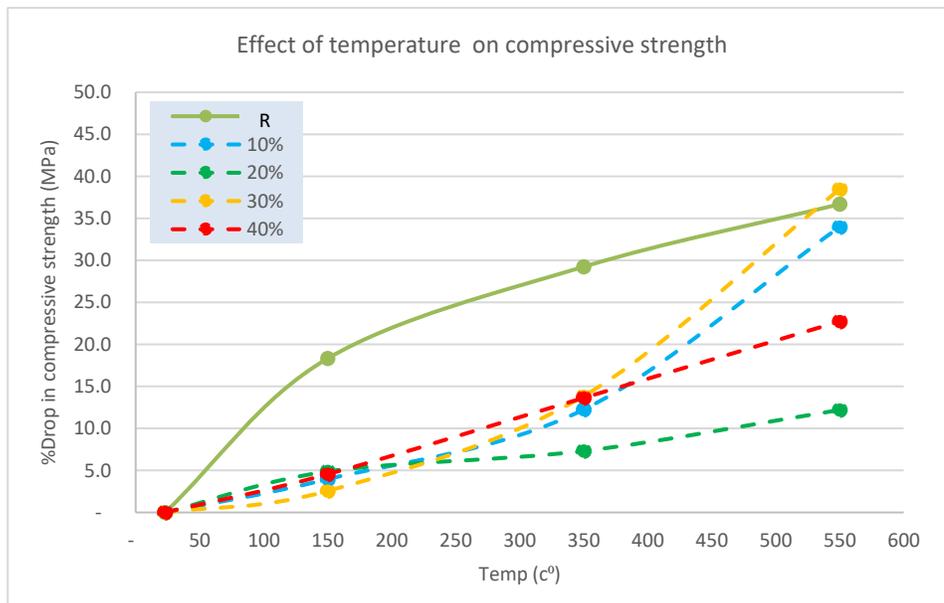


Figure (4 - 15): Drop in compressive strength for concrete with replacement (GGBS) at age 28 days.

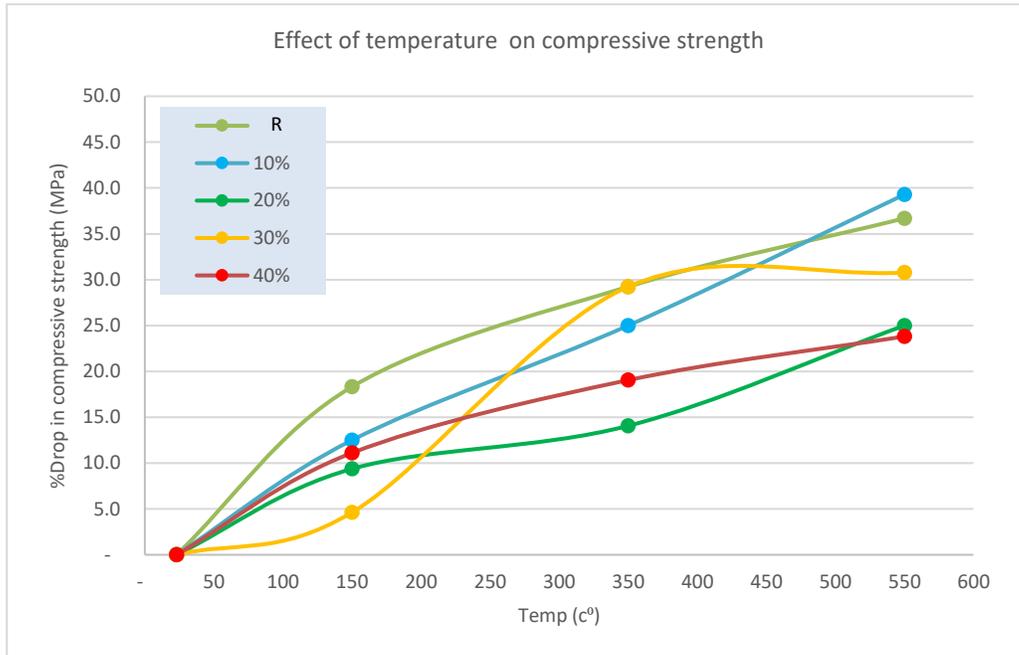


Figure (4 - 16): Drop in compressive strength for concrete with replacement (GGBS) at age 90 days.

Failure of the specimens of compressive strength after test was shown in **plate (4-1)**.



Plate (4 - 1): Failure of the specimens of compressive strength after test

4.2.1.6 Results Summery

Compressive strength results can be summarized as shown in figures below. This summery discussed compressive strength at (7, 28 and 90 days) age to explain concrete deterioration by increasing temperature with different supplementary cementitious materials.

Figure (4 - 1) to Figure (4 - 16) it can conclude that:

- 1- The minimum drop in compressive strength at age 7 days for temperature 550 C° (28.74%) with 20% silica fume as replacement of cement and minimum drop (12.19%) at age 28 days for temperature 550 C° with 30% replacement of cement (silica fume) and minimum drop (10.48%) at age 90 days for temperature 550 C° with 30% silica fume as replacement of cement.
- 2- The minimum drop in compressive strength at age 7 days for temperature 550 C° (20.66%) with 10% metakaolin as replacement of cement and minimum drop (26.02%) at age 28 days for temperature 550 C° with 20% metakaolin as replacement of cement and minimum drop (23.29%) at age 90 days for temperature 550C° with 20% metakaolin as replacement of cement.
- 3- The minimum drop in compressive strength at age 7 days for temperature 550 C° (25.28%) with 10% lime stone powder as replacement of cement and minimum drop (25.07%) at age 28 days for temperature 550 C° with 30% lime stone powder as replacement of cement and minimum drop (27.80%) at age 90 days for temperature 550C° with 20% lime stone powder as replacement of cement.
- 4- The minimum drop in compressive strength at age 28 days for temperature 550 C° (12.20%) with 20% GGBS as replacement of cement and minimum drop (23.81%) at age 90 days for temperature 550 C° with 40% GGBS as replacement of cement

4.2.1.7 Discussion the Results of compressive strength for concrete with replacement with different supplementary cementitious materials

From Figure (4-17) to Figure (4-19) represents a comparison between the percentages of descent in compressive strength in concrete exposed to high temperatures with various supplementary cementitious materials at different ages (7, 28 and 90 days). and the above results, it was noted that the minimum drop and lowest percentage of reduction in compressive strength was when using silica fume with a ratio of replacement (30%) with cement when concrete was exposed to a temperature (550 C°), especially at the age of 90 days. The interaction of silica fume ($SiO_2 + Al_2O_3$) with cement hydration products (Calcium hydroxide) increases with the age of concrete to form strong compounds, especially at 90 days and beyond, which makes concrete that uses silica fume by 30% as a replacement for cement resist high temperature. In addition, the chemical composition of silica fume contains high percentage of compound ($SiO_2=89.41\%$) more than other substituted materials.

As for the substituted material (metakaolin and GGBS), it was observed that its effect was less than that of silica fume in obtaining the lowest percentage of drop or decrease in compressive strength when concrete was exposed to high heat (550 C°) because its strength Activity Index (SAI) is less than that of silica fume.

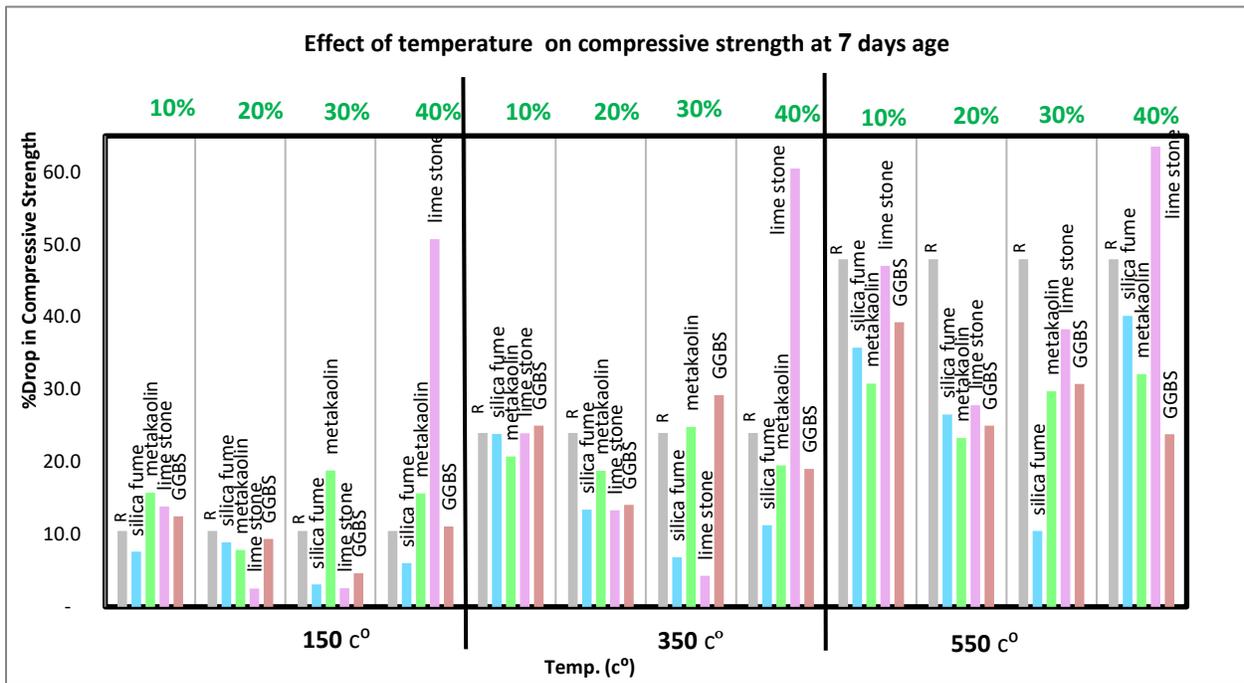


Figure (4 - 17): Effect of temperature on compressive strength at 7 days age for all replacement material

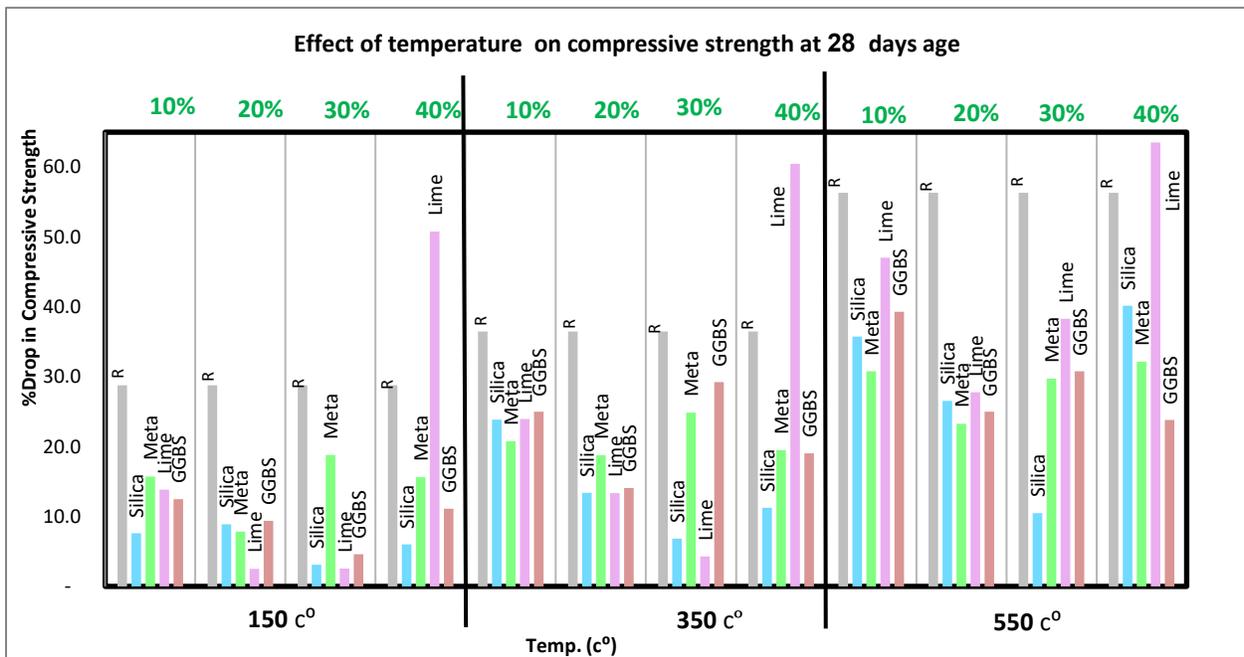


Figure (4 - 18): Effect of temperature on compressive strength at 28 days age for all replacement material

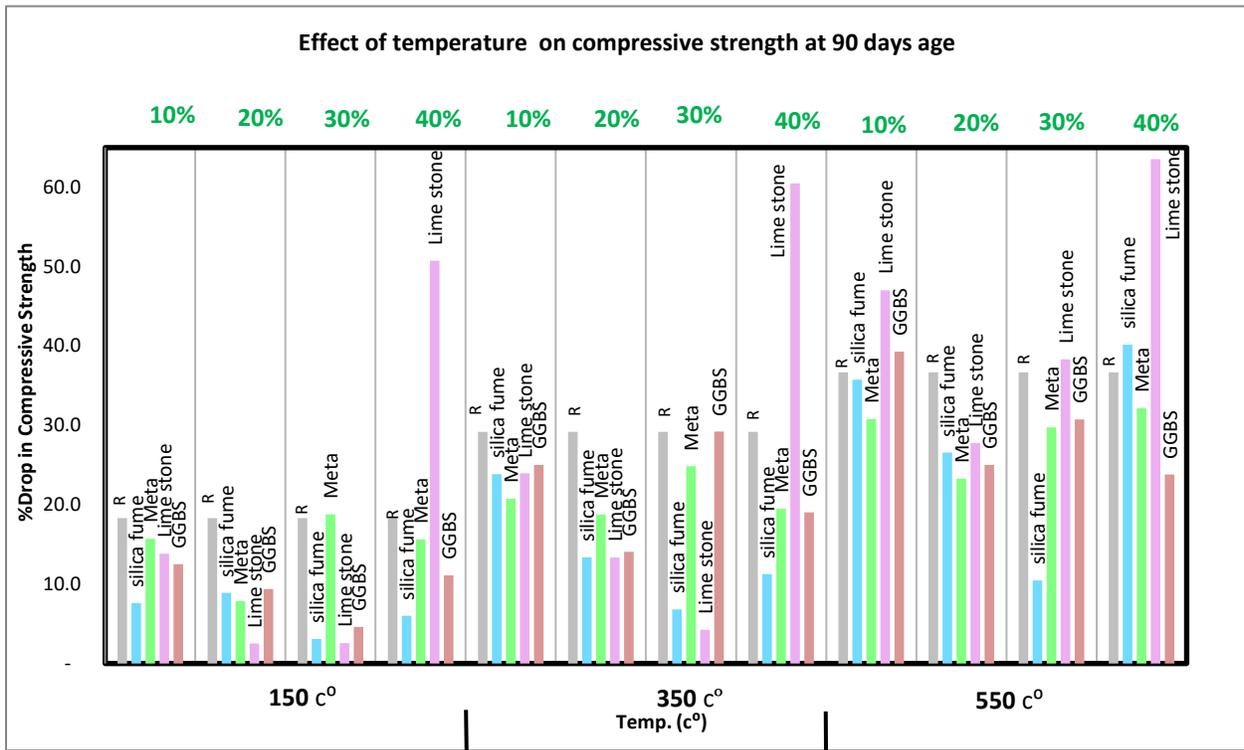


Figure (4 - 19): Effect of temperature on compressive strength at 90 days age for all replacement material

4.2.2. Splitting tensile strength

Splitting strength is one of an important test method, that used to determine the tensile strength of concrete due to direct tension test is accompanied by difficulties during carrying out. Cylinder specimens was used with (100×200mm) for concrete and with supplementary cementitious materials (silica fume with, metakaolin, lime stone powder, GGBS) with (10%,20%,30%, and 40%) as replacement with cement at age (28,90 days) in temperature (23c°,150c°,350c°,550c°). The cylinders were exposed to high temperature at duration of (1.5 hr.).

4.2.2.1 Splitting tensile strength for concrete without replacement

Splitting tensile strength for concrete without replacement.

Table (4 - 6) and Figure (4-10) showed the results of splitting strength.

Table (4 - 6): The splitting tensile strength for concrete without replacement

Symbol of specimens	Temp (C°)	splitting tensile strength (MPa)			
		28 days	% Drop in tensile strength	90 days	% Drop in tensile strength
R	23	1.42	-	2.14	-
	150	1.21	14.8	1.82	14.95
	350	1.02	28.2	1.21	43.46
	550	0.75	47.2	0.92	57.01

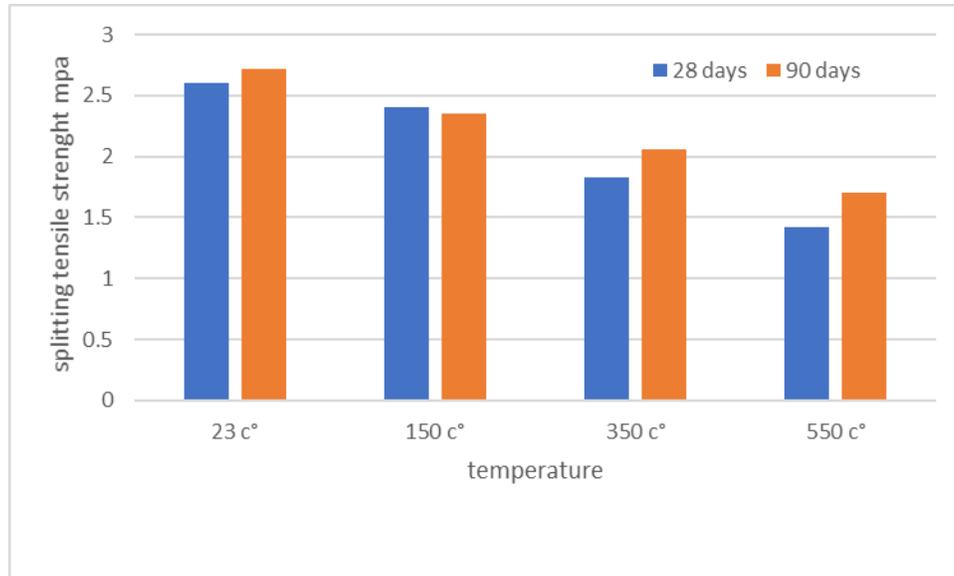


Figure (4 - 20): Results of splitting tensile strength for concrete without replacement

4.2.2.2 Splitting tensile strength for concrete with replacement (silica fume)

The splitting tensile strength for concrete with silica fume (10%, 20%, 30% and 40%) as replacement. Table (4 - 7) and Figure (4 - 21) showed the results of splitting strength. Figure (4 - 22) and Figure (4 - 23) showed drop percent in tensile strength after adding silica fume at ages (28,90 days) respectively.

Table (4 - 7): Splitting tensile strength for concrete with silica fume as replacement

Symbol of specimens	Ratio content replacement silica fume from cement %	Temp (C°)	splitting tensile strength (MPa)			
			28 days	% Drop in tensile strength	90 days	% Drop in tensile strength
S1	10%	23	1.38	-	2.02	-
		150	1.14	17.39	1.96	2.97
		350	1.08	21.74	1.59	21.29
		550	0.85	38.41	1.42	29.70
S2	20%	23	2.13	-	2.73	-
		150	1.54	27.70	2.15	21.25
		350	1.33	37.56	1.94	28.94
		550	1.28	39.91	1.3	52.38
S3	30%	23	2.29	-	2.75	-
		150	2.07	9.61	2.5	9.09
		350	1.77	22.71	1.97	28.36
		550	1.4	38.86	1.5	45.45
S4	40%	23	1.31	-	2.41	-
		150	1.19	9.16	1.79	25.73
		350	1.14	12.98	1.65	31.54
		550	1.02	22.14	1.12	53.53

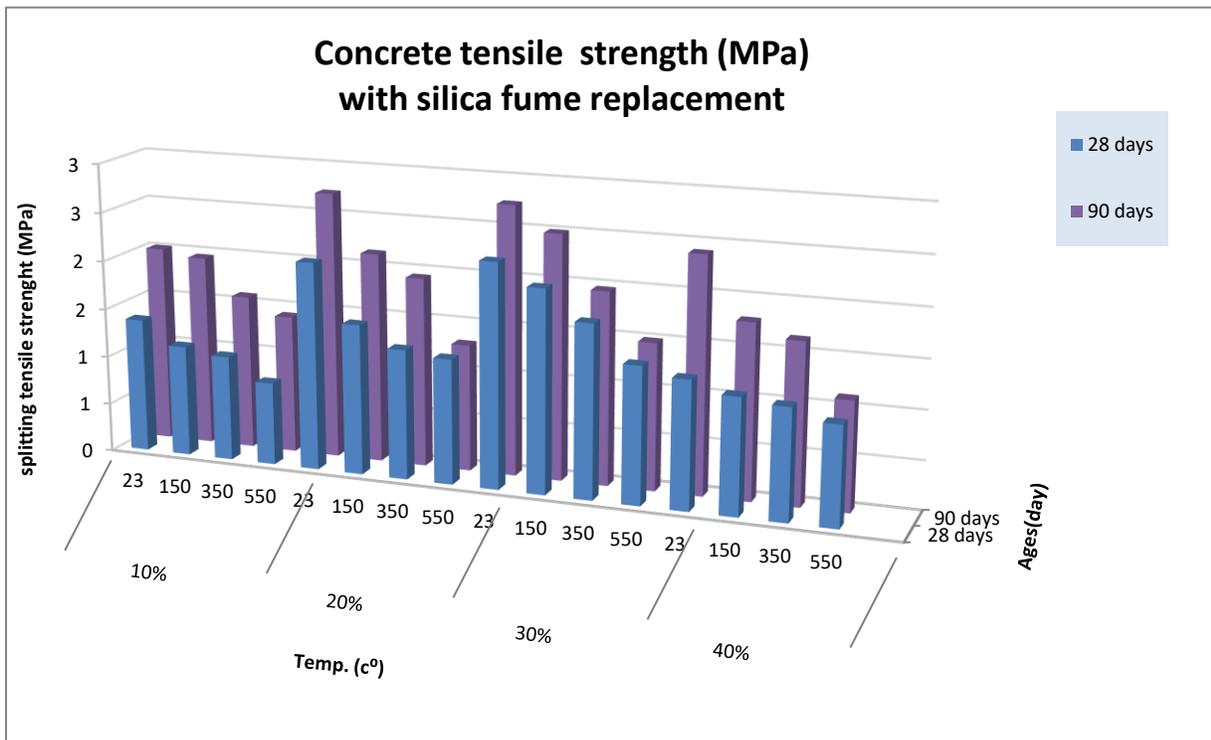


Figure (4 - 21): Results of splitting tensile strength concrete with silica fume as replacement

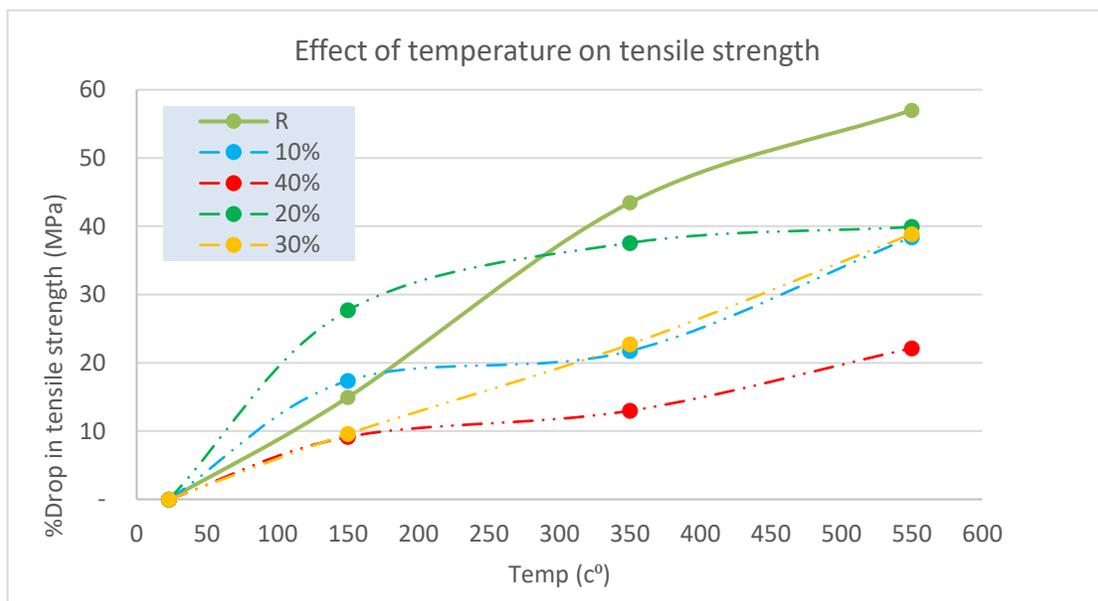


Figure (4 - 22): Drop in splitting tensile strength for concrete with replacement (silica fume) at age 28 days.

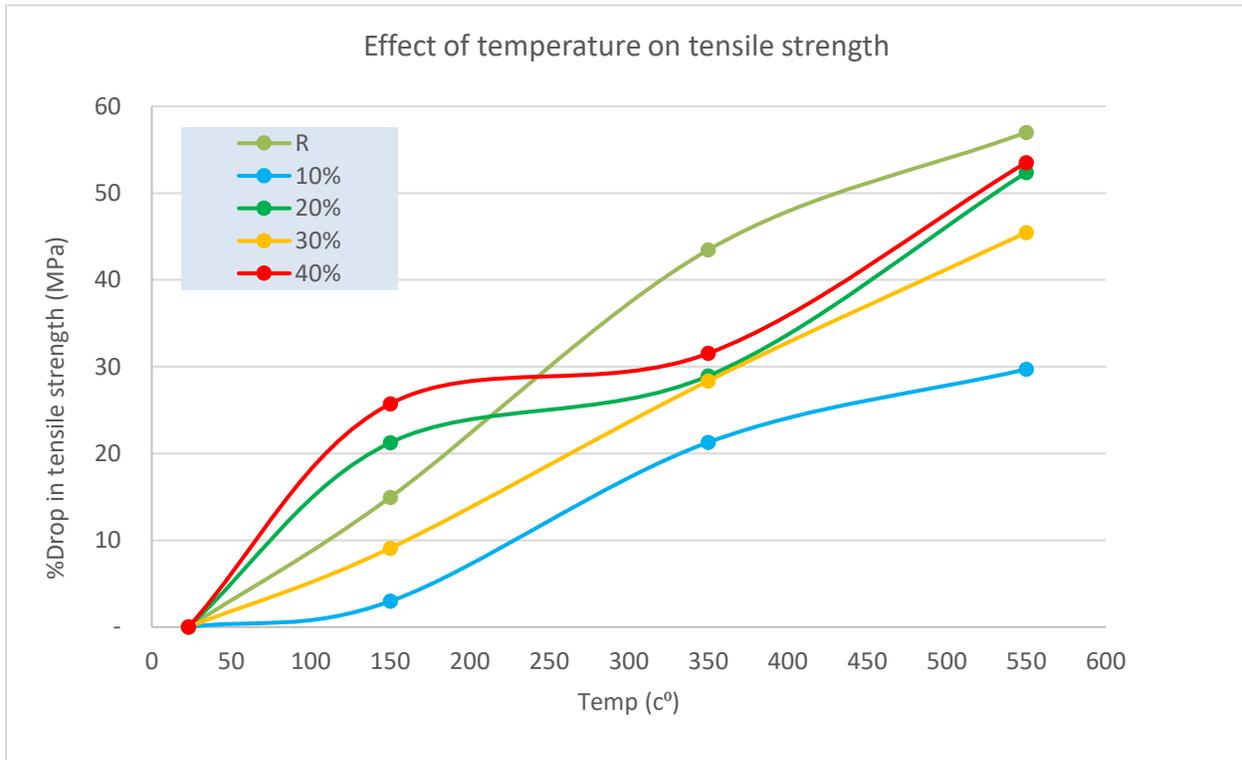


Figure (4 - 23): Drop in splitting tensile strength for concrete with replacement (silica fume) at age 90 days

4.2.2.3 Splitting tensile strength for concrete with replacement (metakaolin)

The splitting tensile strength for concrete with metakaolin (10%,20%,30% and 40%) as replacement were listed in Table (4-8) and Figure (4-24).

Figure (4 - 25) and Figure (4 - 26) showed drop percent in tensile strength after adding metakaolin at ages (28, 90 days) respectively.

Table (4 - 8): Splitting tensile strength concrete with metakaolin as replacement

Symbol of specimens	Ratio content replacement metakaolin from cement %	Temp. (C°)	splitting tensile strength (MPa)			
			28 days	% Drop in tensile strength	90 days	% Drop in tensile strength
L1	10%	23	1.12	-	1.71	-
		150	0.68	39.29	1.6	6.43
		350	0.62	44.64	1.5	12.28
		550	0.59	47.32	0.72	57.89
L2	20%	23	1.44	-	1.9	-
		150	0.95	34.03	1.36	28.42
		350	0.67	53.47	1.24	34.74
		550	0.57	60.42	0.74	61.05
L3	30%	23	1.29	-	1.75	-
		150	1	22.48	1.62	7.43
		350	0.75	41.86	1.37	21.71
		550	0.64	50.39	0.7	60.00
L4	40%	23	1.55	-	2.6	-
		150	1.5	3.23	2	23.08
		350	1.16	25.16	1.1	57.69
		550	1	35.48	0.86	66.92

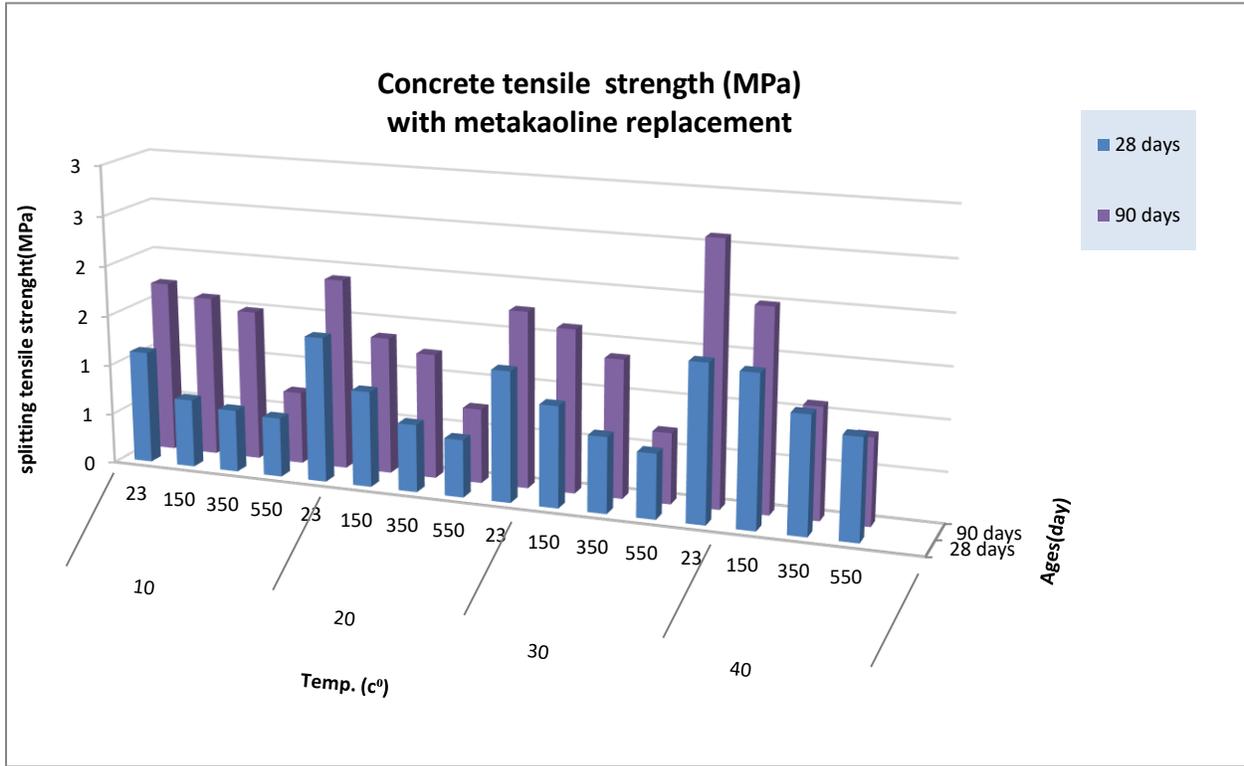


Figure (4 - 24): Results of splitting tensile strength concrete with metakaolin as replacement

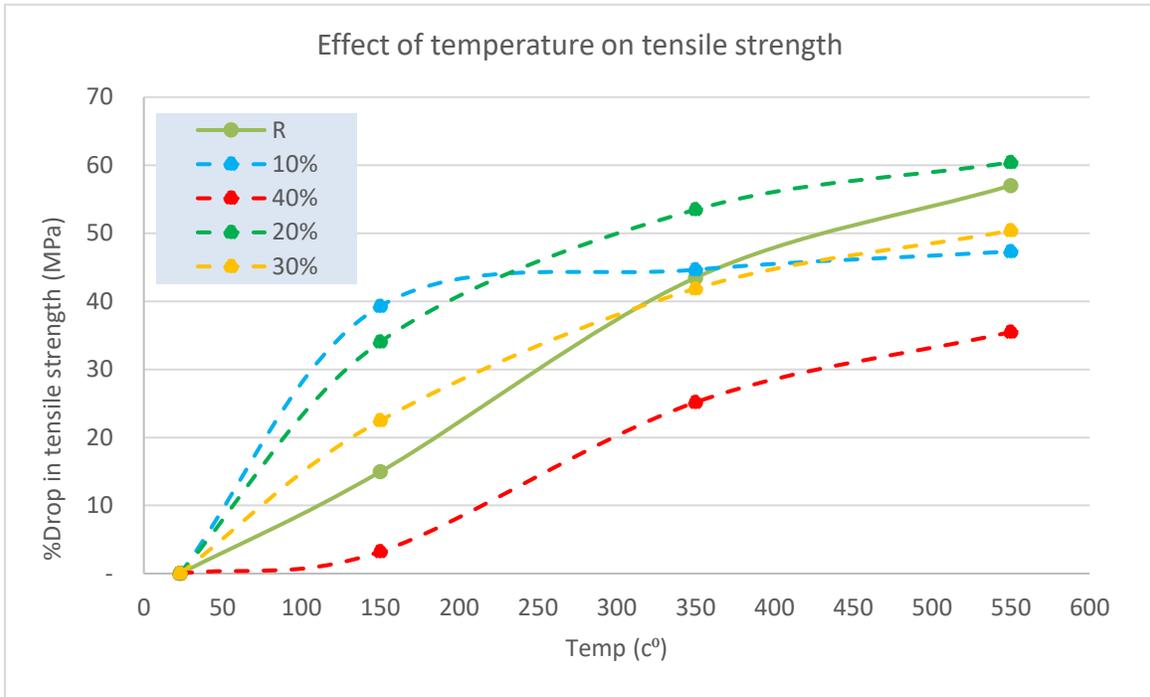


Figure (4 - 25): Drop in splitting tensile strength for concrete with replacement (metakaolin) at age 28 days

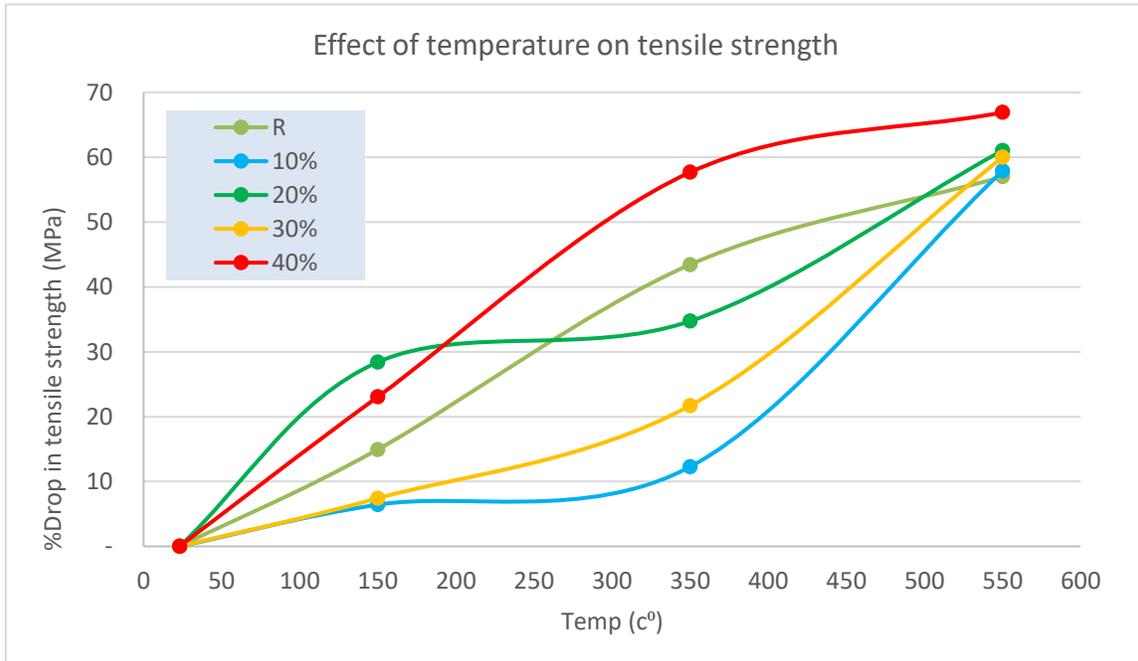


Figure (4 - 26): Drop in splitting tensile strength for concrete with replacement (metakaolin) at age 90 days

4.2.2.4 Splitting tensile strength for concrete with replacement (lime stone powder)

The splitting tensile strength for concrete with replacement lime stone powder (10%,20%,30% and 40%

) Were listed in Table (4 - 9) Figure (4 - 27). Figure (4 - 28) and Figure (4 - 29) showed drop percent in temperatures after adding lime stone at ages (28, 90 days) respectively.

Table (4 - 9): Splitting tensile strength concrete with lime stone powder as replacement

Symbol of specimens	Ratio content replacement lime stone powder from cement %	Temperature (C°)	splitting tensile strength (MPa)			
			28 days	% Drop in tensile strength	90 days	% Drop in tensile strength
W1	10%	23	1.1	-	2	-
		150	1.07	2.73	1.59	20.50
		350	1.05	4.55	1.2	40.00
		550	0.75	31.82	0.85	57.50
W2	20%	23	1.6	-	1.74	-
		150	1.46	8.75	1.5	13.79
		350	0.9	43.75	1.1	36.78
		550	0.84	47.50	0.9	48.28
W3	30%	23	1.03	-	1.2	-
		150	0.93	9.71	1.14	5.00
		350	0.72	30.10	0.8	33.33
		550	0.63	38.83	0.77	35.83
W4	40%	23	0.51	-	0.86	-
		150	0.48	5.88	0.6	30.23
		350	0.46	9.80	0.56	34.88
		550	0.42	17.65	0.46	46.51

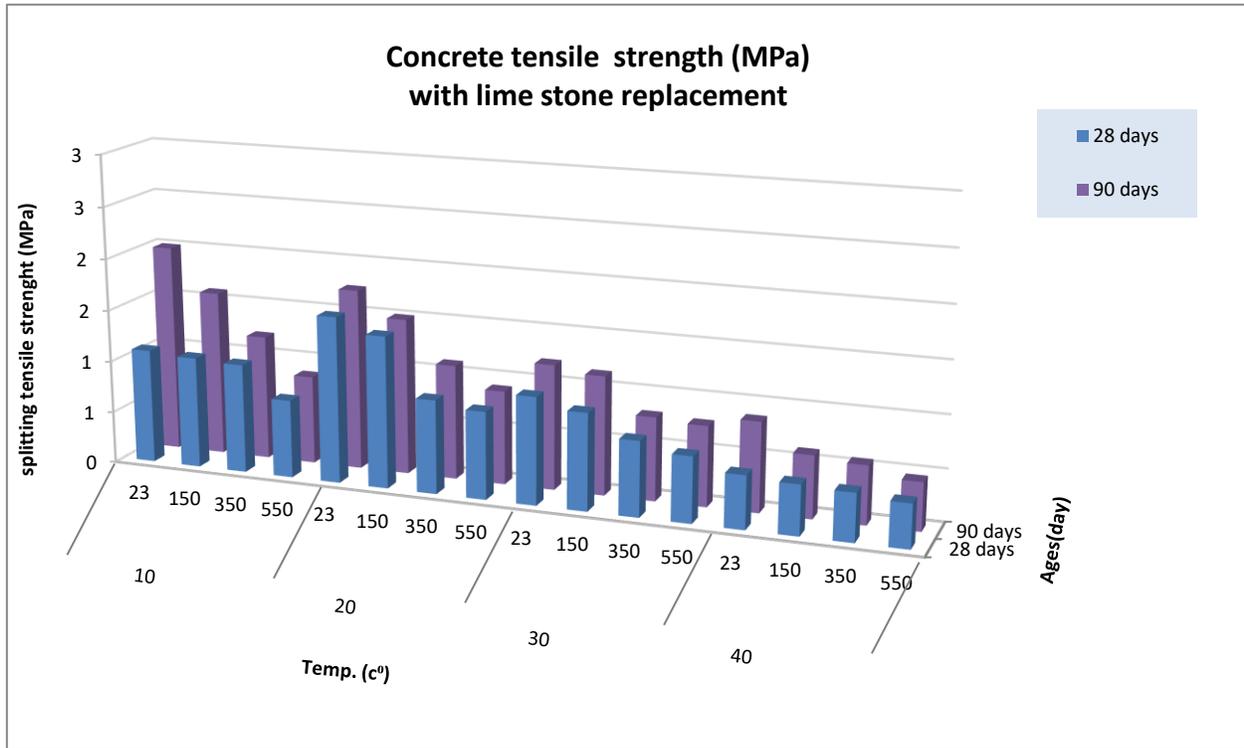


Figure (4 - 27): Results of splitting tensile strength concrete with lime stone powder as replacement

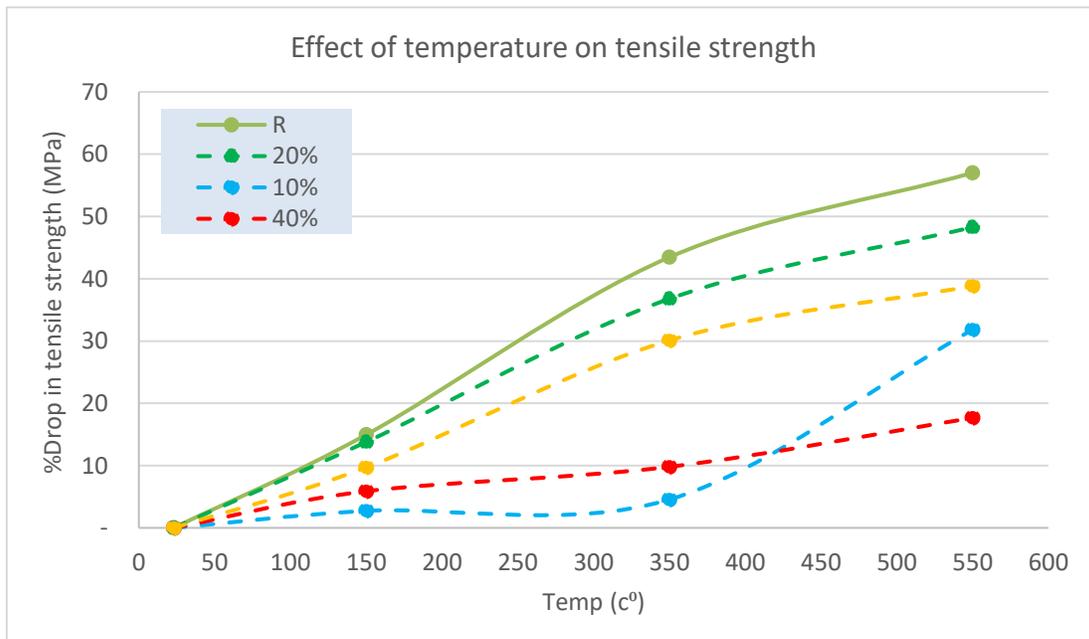


Figure (4 - 28): Drop in splitting tensile strength for concrete with replacement (lime stone powder) at age 28 days

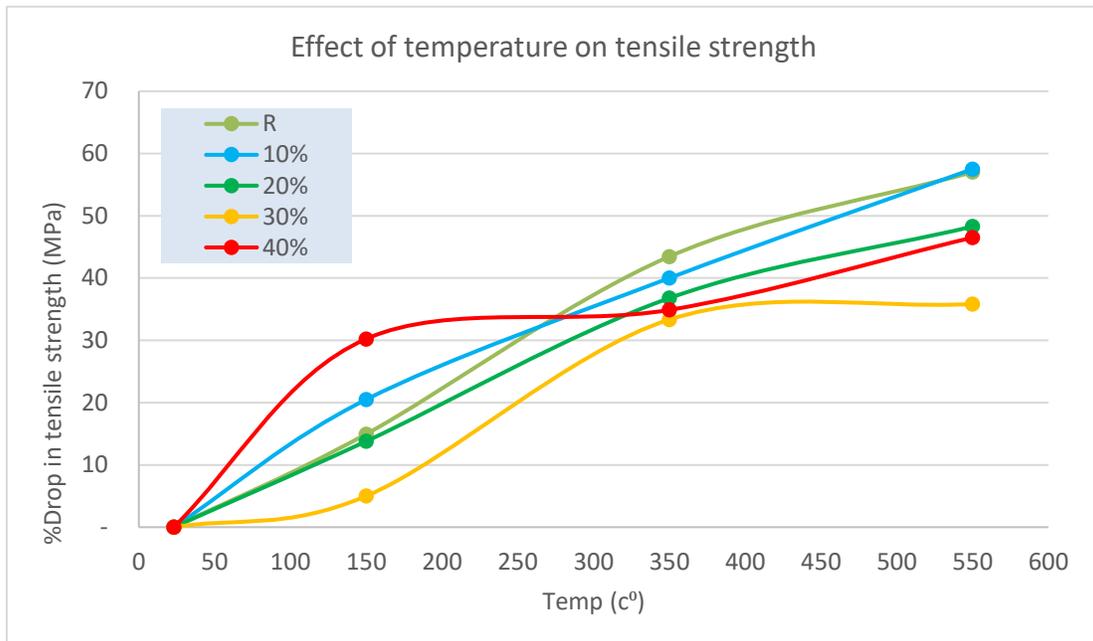


Figure (4 - 29): Drop in splitting tensile strength for concrete with replacement (lime stone powder) at age 90 days

Failure of the specimens of splitting tensile strength after test was shown in **plate (4-2)**



Plate (4 - 2): Failure of specimens of concrete after splitting tensile strength test

4.2.2.5 Results summery

From Figure (4 - 20) to Figure (4 - 28), can conclude that:

- 1- The minimum drop in splitting tensile strength at age 28 days for temperature 550 C° (22.14%) in 40% silica fume as replacement with cement and minimum drop (29.70%) at age 90 days for temperature 550 C° in 10% silica fume as replacement with cement.
- 2- The minimum drop in splitting tensile strength at age 28 days for temperature 550 C° (35.48%) in 40% metakaolin as replacement with cement and minimum drop (57.89%) at age 90 days for temperature 550 C° in 10% metakaolin as replacement with cement.
- 3- The minimum drop in splitting tensile strength at age 28 days for temperature 550 C° (17.65%) in 40% lime stone powder as replacement with cement and minimum drop (35.83%) at age 90 days for temperature 550 C° in 30% lime stone powder as replacement with cement.
- 4- Replacement with GGBS not investigated because of unavailability.

4.2.2.6 Discussion the Results of splitting strength for concrete with replacement with different supplementary cementitious materials

From Figure (4 - 30) and Figure (4 - 31) represents a comparison between the percentages of descent in splitting tensile strength in concrete exposed to high temperatures with various supplementary cementitious materials at different ages (28 ,90 days). the best drop in splitting tensile strength of concrete is (29.70%) in with using 10% replacement of cement (silica fume) compared to others supplementary cementitious materials (metakaolin, lime stone powder). Because the high content of SiO_2 in silica fume component (89.41%).

Observing that the effect of the materials replaced with cement (various supplementary cementitious materials) for all ratios (10%, 20%, 30% and 40%) of concrete exposed to high temperatures (23, 150, 350 and 550 C°) on the splitting tensile strength was less compared to the compressive strength, and this is obvious due to the fact that the concrete is of a brittle material and does not resist the tensile stresses.

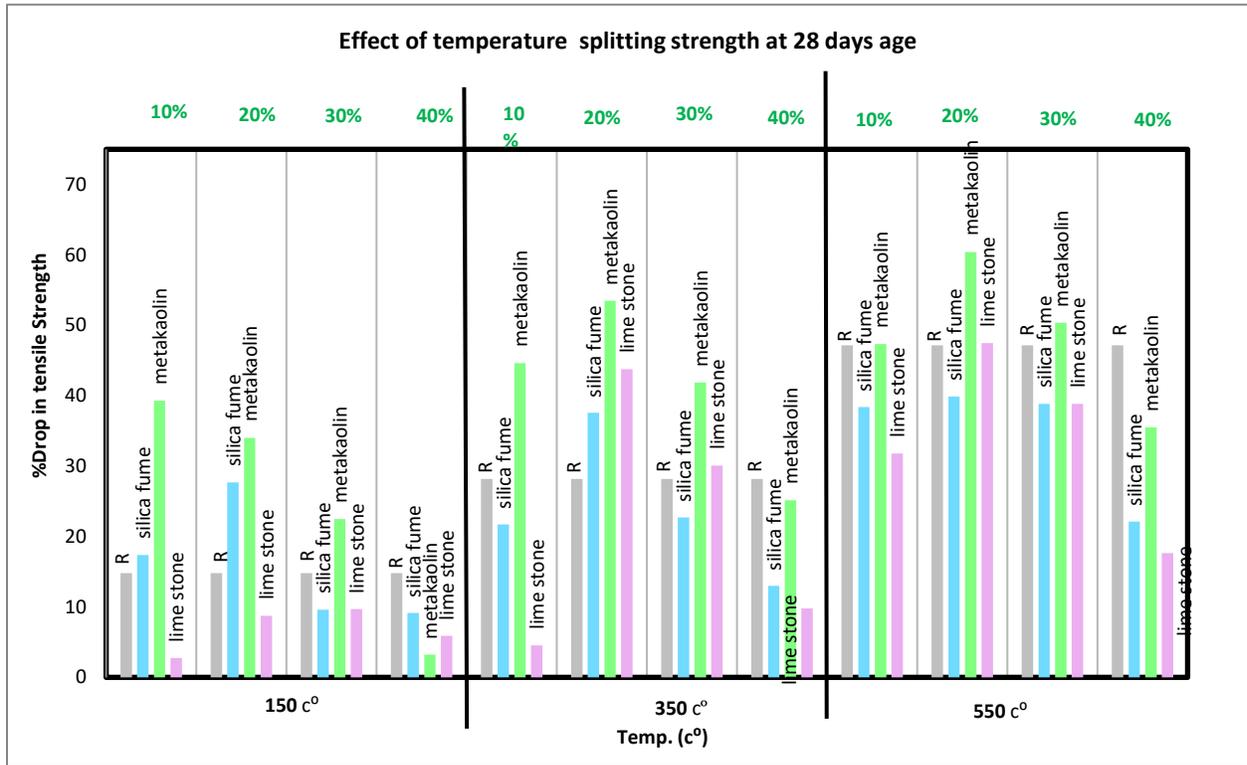


Figure (4 - 30): Effect of temperature on tensile strength at age 28 days for all replacement material

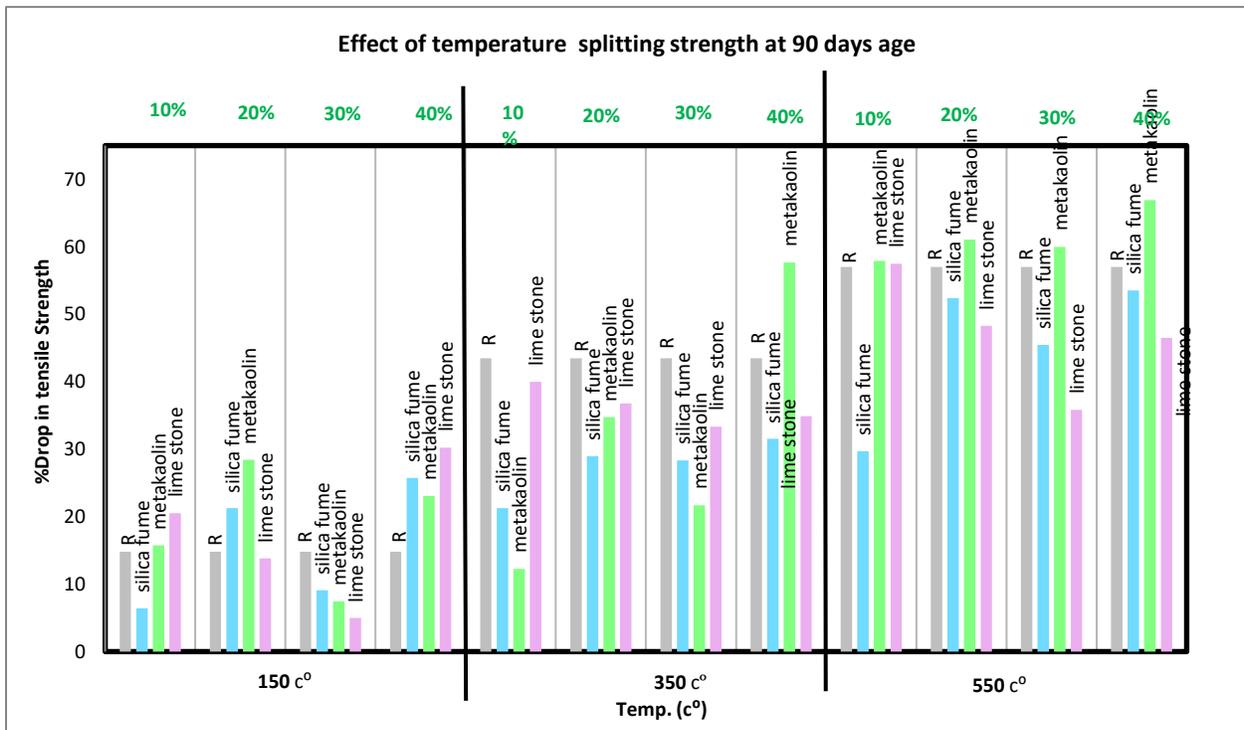


Figure (4 - 31): Effect of temperature on tensile strength at age 90 days for all replacement material

4.2.3. Flexural strength

Flexural testing is used to determine bending resistance of concrete, it is applied by placing a prism between two points Using Simple Beam with Third-Point Loading and imitating to applied load until fracture specimen.

The prisms with dimension (100×100×400mm), was used to determine Flexural strength for concrete and with supplementary cementitious materials (silica fume, metakaolin, lime stone powder, GGBS) with (10%,20%,30%, and 40%) as replacement with cement at age (90 days) in temperature (23c°,150c°,350c°,550c°). The prisms were exposed to high temperature at duration of (1.5 hr.).

4.2.3.1 Flexural strength concrete for concrete without replacement

Flexural strength for concrete without replacement. Table (4 - 10) and Figure (4 - 32) showed the results of flexural strength

Table (4 - 10) Flexural strength for concrete without replacement

Symbol of specimens	Temperature (C°)	Flexural strength (MPa) at 90 days	%Drop in flexural strength
R	23	2.32	-
	150	1.82	21.55
	350	1.12	51.72
	550	0.76	67.24

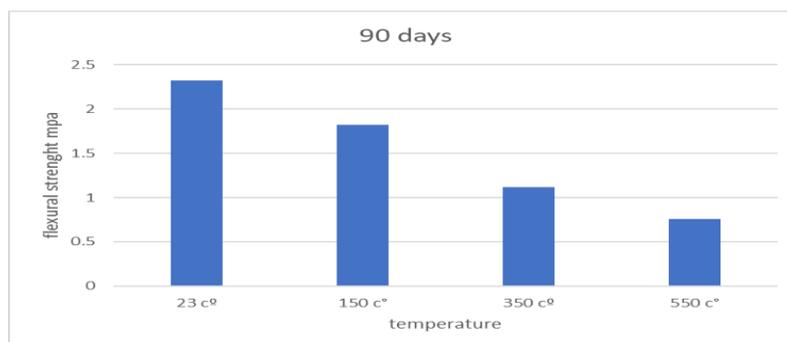


Figure (4 - 32): Results of flexural strength for concrete without replacement

4.2.3.2 Flexural strength for concrete with replacement (silica fume)

The Flexural strength for concrete with replacement silica fume (10%,20%,30% and 40%). Table (4 - 11) and Figure (4 - 33), showed the results of flexural strength.

Table (4 - 11) Flexural strength concrete with silica fume as replacement

Symbol of specimens	Ratio content replacement silica fume from cement %	Temp. (C°)	Flexural strength (MPa) 90 days	% Drop in flexural strength
S1	10%	23	2.46	-
		150	2.2	10.57
		350	1.5	39.02
		550	0.65	73.58
S2	20%	23	3.1	-
		150	2	35.48
		350	1	67.74
		550	0.4	87.10
S3	30%	23	3.5	-
		150	2.1	40.00
		350	0.55	84.29
		550	0.26	92.57
S4	40%	23	2.2	-
		150	1.8	18.18
		350	0.87	60.45
		550	0.5	77.27

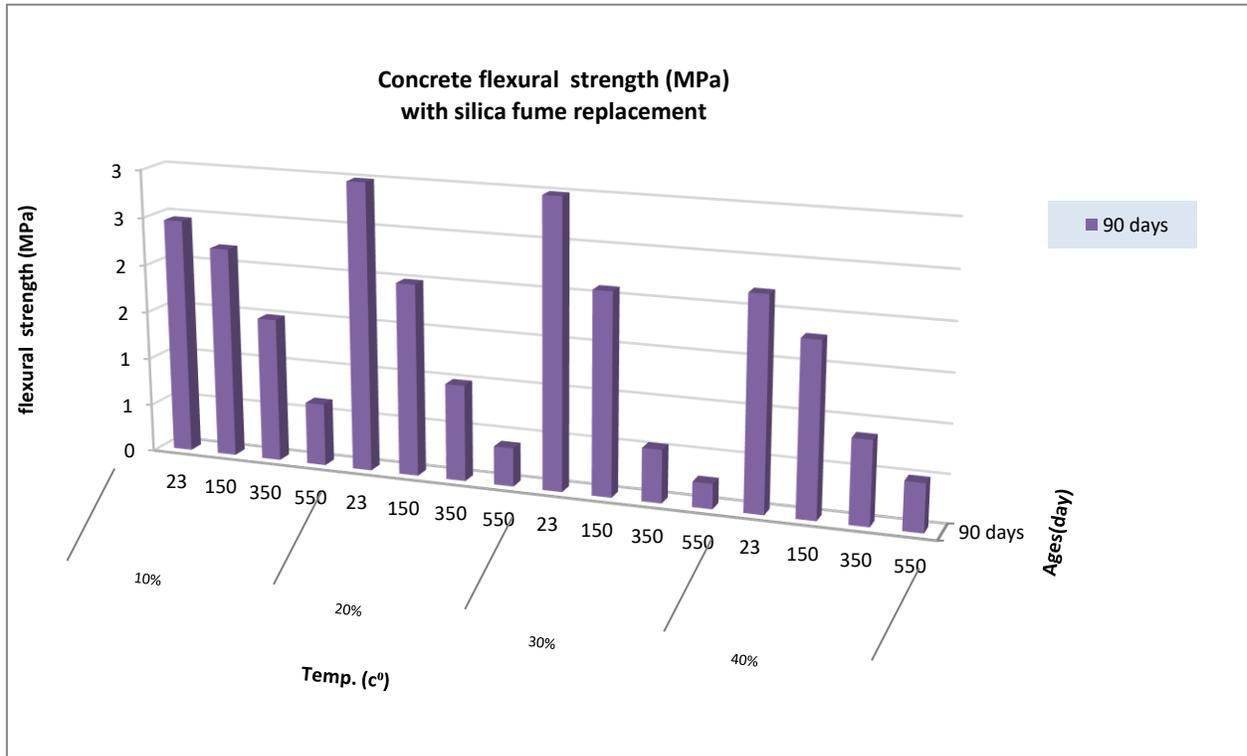


Figure (4 - 33): Results of flexural strength concrete with silica fume as replacement

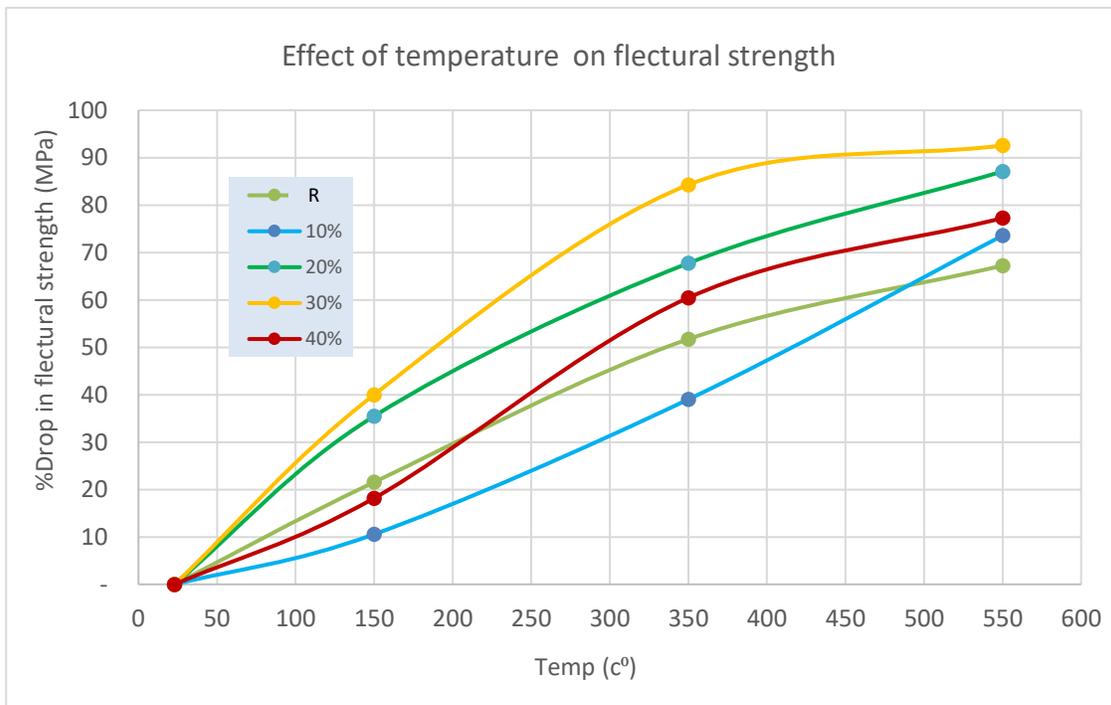


Figure (4 - 34): Drop in flexural strength for concrete with replacement (silica fume) at age 90 days

4.2.3.3 Flexural strength for concrete with replacement (metakaolin)

The Flexural strength for concrete with replacement metakaolin (10%,20%,30% and 40%). Table (4 - 12) and Figure (4 - 35), showed the results of flexural strength.

Table (4 - 12) Flexural strength concrete with metakaolin as replacement

Symbol of specimens	Ratio content replacement metakaolin from cement %	Temp. (C°)	Flexural strength (MPa) at 90 days	% Drop in flexural strength
L1	10%	23	1.54	-
		150	1.4	9.09
		350	1.21	21.43
		550	1	35.06
L2	20%	23	2.15	-
		150	2	6.98
		350	0.58	73.02
		550	0.12	94.42
L3	30%	23	2.13	-
		150	1.1	48.36
		350	0.6	71.83
		550	0.2	90.61
L4	40%	23	2.6	-
		150	2.1	19.23
		350	1.1	57.69
		550	0.86	66.92

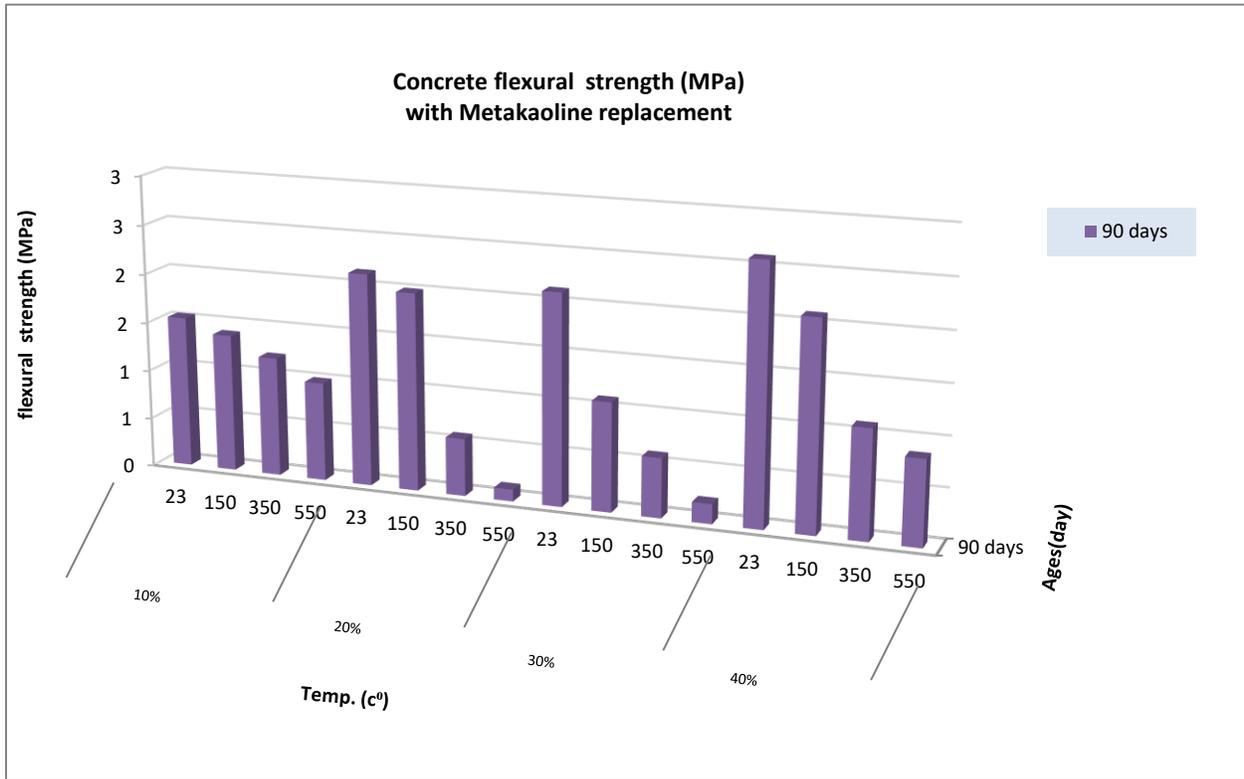


Figure (4 - 35): Results of flexural strength concrete with metakaolin as replacement

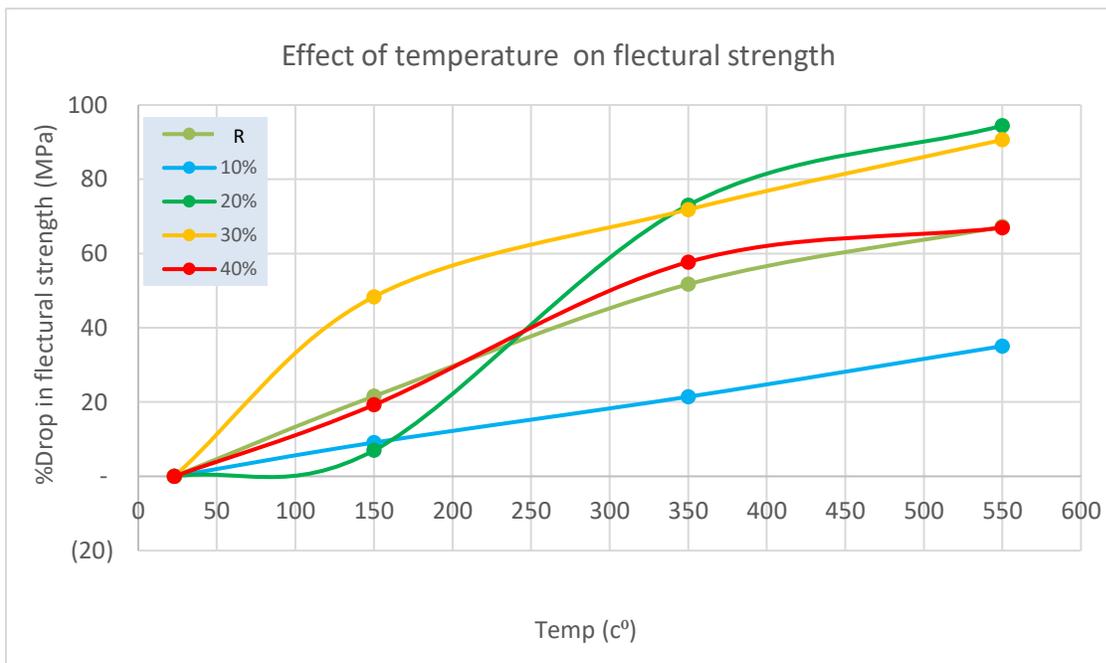


Figure (4 - 36): drop in flexural strength for concrete with replacement (metakaolin) at age 90 days

4.2.3.5 Flexural strength for concrete with replacement (lime stone powder)

The Flexural strength for concrete with replacement lime stone powder (10%,20%,30% and 40%). Table (4 - 13) and Figure (4 - 37), showed the results of flexural strength.

Table (4 - 13): Flexural strength concrete with lime stone powder as replacement

Symbol of specimens	Ratio content replacement lime stone powder from cement %	Temperature(C°)	Flexural strength (MPa) at 90 days	% Drop in flexural strength
W1	10%	23	2.26	-
		150	1.72	23.89
		350	1.2	46.90
		550	0.46	79.65
W2	20%	23	2.16	-
		150	2	7.41
		350	1.69	21.76
		550	1.1	49.07
W3	30%	23	1.75	-
		150	1.72	1.71
		350	1	42.86
		550	0.67	61.71
W4	40%	23	1.15	-
		150	1.1	4.35
		350	0.83	27.83
		550	0.5	56.52

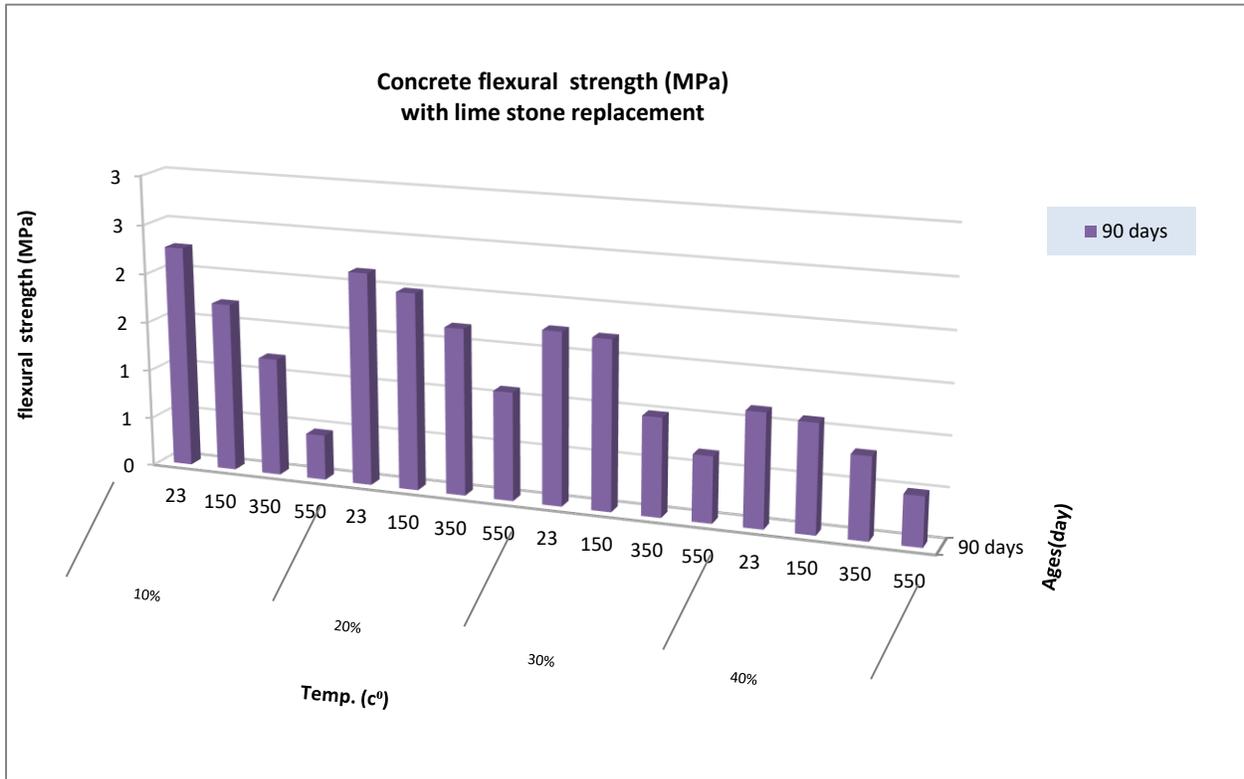


Figure (4 - 37): Results of flexural strength concrete with lime stone powder as replacement

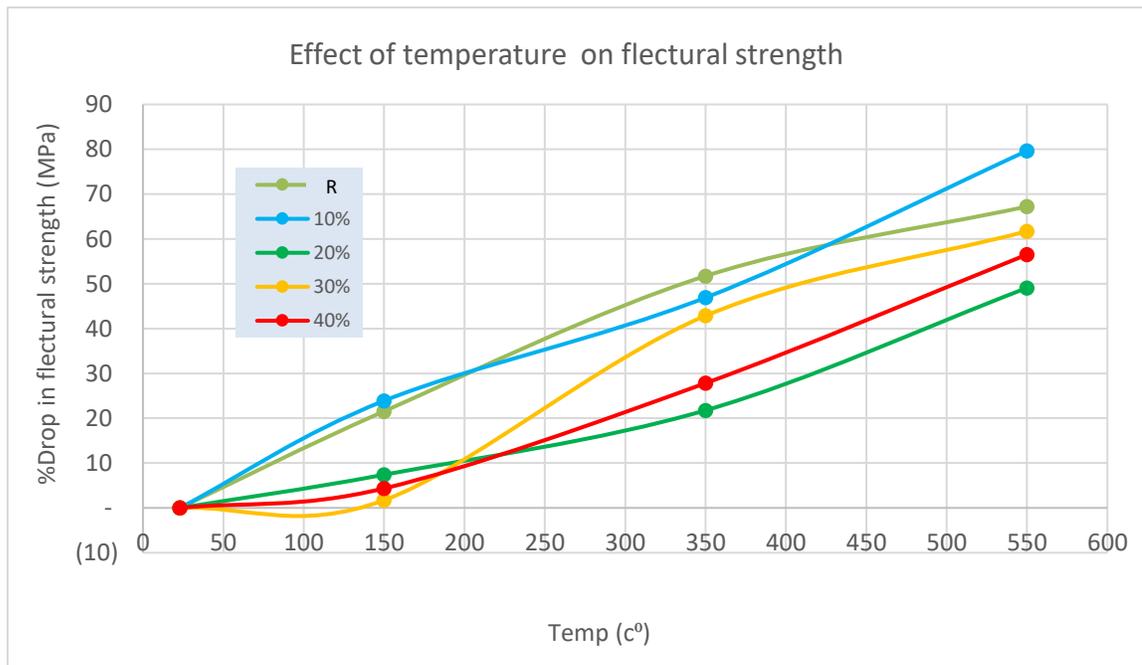


Figure (4 - 38): drop in flexural strength for concrete with replacement (lime stone powder) at age 90 days

4.2.3.5 Flexural strength for concrete with replacement (ground granulated blast furnace slag GGBS)

The Flexural strength for concrete with replacement GGBS (10%,20%,30% and 40%). Table (4 - 14) and Figure (4 - 39) showed the results of flexural strength.

Table (4 - 14) Flexural strength concrete with GGBS as replacement

Symbol of specimens	Ratio content replacement GGBS from cement %	Flexural strength (MPa)		
		Temp (C°)	at 90 days	% Drop in flexural strength
G1	10%	23	2.34	-
		150	1.96	16.24
		350	1.3	44.44
		550	1.19	49.15
G2	20%	23	2.55	-
		150	2.18	14.51
		350	1.73	32.16
		550	0.93	63.53
G3	30%	23	3.1	-
		150	2.18	29.68
		350	1.54	50.32
		550	1.27	59.03
G4	40%	23	3.7	-
		150	3.29	11.08
		350	1.74	52.97
		550	1.6	56.76

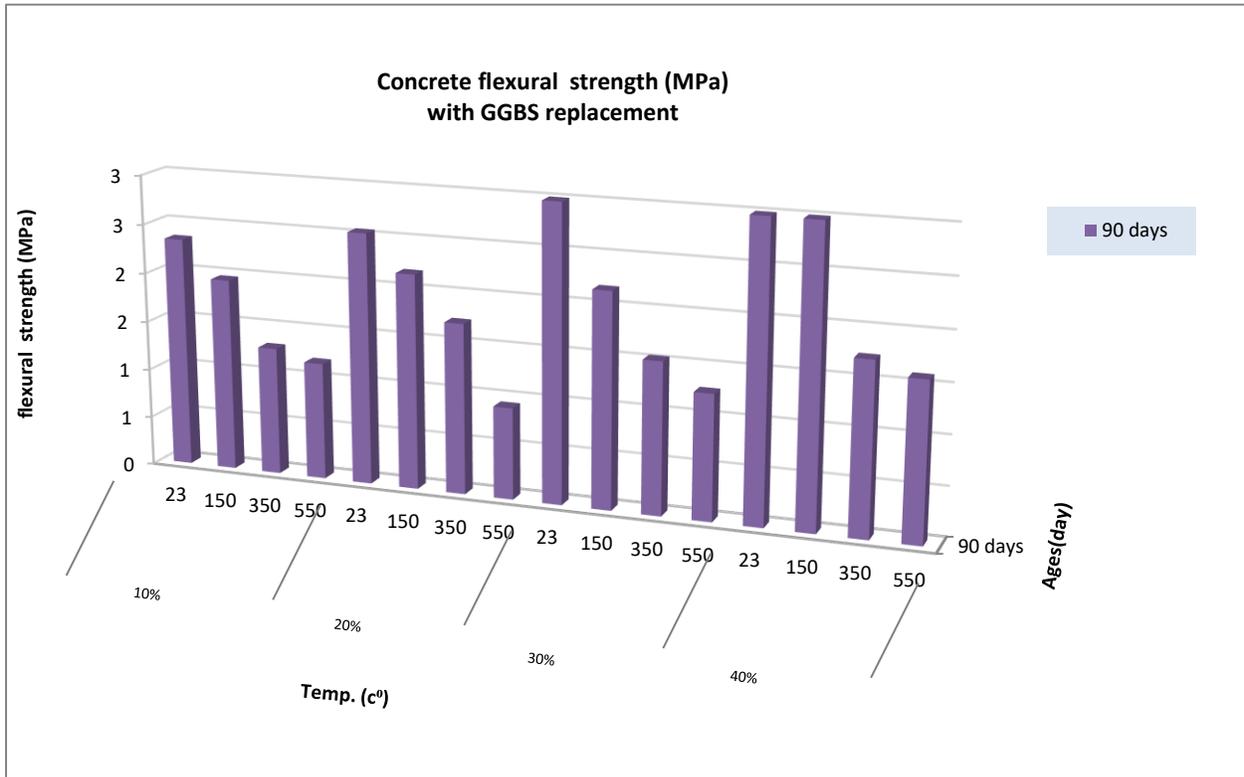


Figure (4 - 39): Results of flexural strength concrete with GGBS as replacement

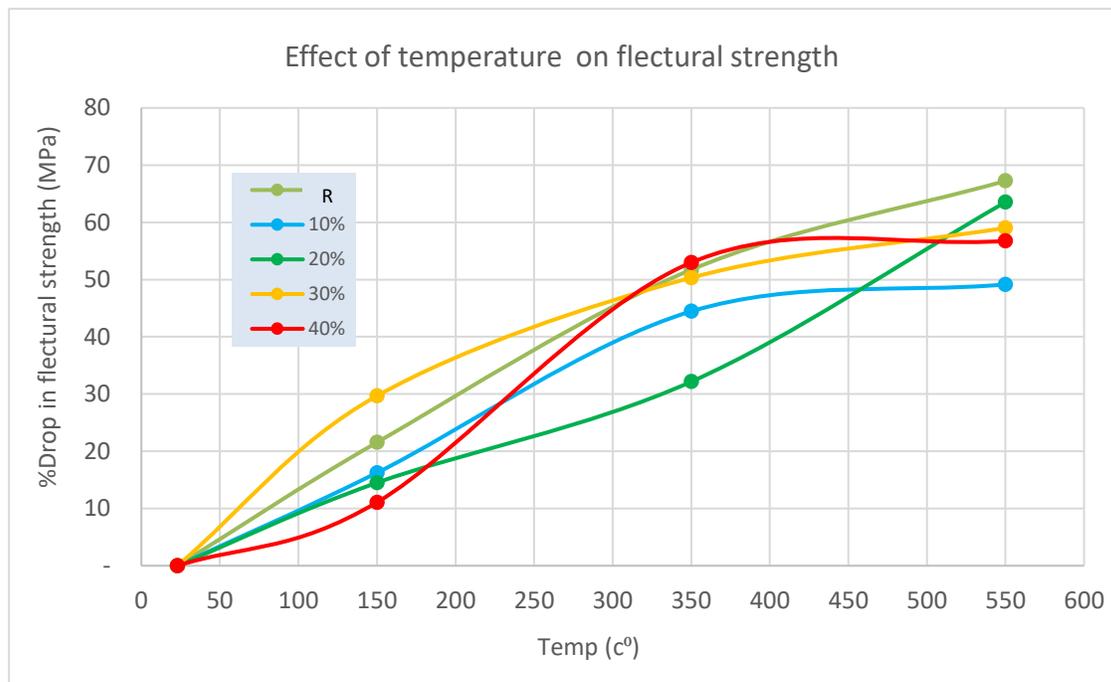


Figure (4 - 40): drop in flexural strength for concrete with replacement (GGBS) at age 90 days

Flexural strength test failure of specimens was shown in plate (4-3).



Plate (4 - 3): Failure of specimens of concrete after flexural test.

4.2.3.6 Results summary

From Figure (4 - 32) to Figure (4 - 40), we can conclude that:

- 1- The minimum drop in flexural strength at age 90 days for temperature 550 C° (73.58%) in 10% silica fume as replacement with cement.
- 2- The minimum drop in flexural strength at age 90 days for temperature 550 C° (36.06%) in 10% metakaolin as replacement with cement.
- 3- The minimum drop in flexural strength at age 90 days for temperature 550 C° (49.07%) in 20% lime stone powder as replacement with cement.
- 4- The minimum drop in flexural strength at age 90 days for temperature 550 C° (49.15%) in 10% GGBS as replacement with cement.

4.2.3.7 Discussion the Results of flexural strength for concrete with replacement with different supplementary cementitious materials

From Figure (4 - 41) the minimum drop in flexural strength of concrete is (36.06%) in 10% metakaolin as replacement with cement compared to others supplementary cementitious materials (silica fume, lime stone powder, GGBS). Because metakaolin has large content of SiO_2 (51.2%) and Al_2O_3 (45.3%) which leads to an increase in the production of compounds (cement compounds) that are responsible for increasing the compressive strength of concrete and thus increasing the flexural strength slightly.

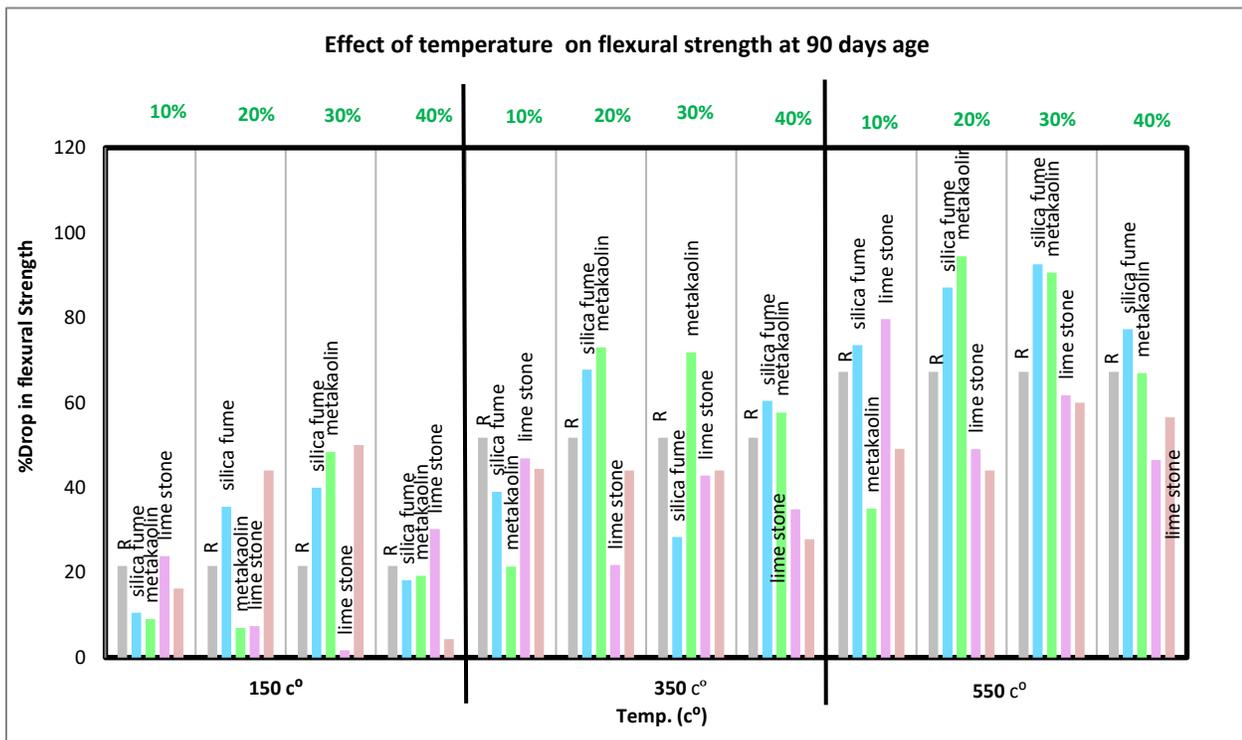


Figure (4 - 41): Effect of temperature on flexural strength at age 90 days for all replacement material

4.3. pH concrete

pH is an important parameter to indicate the alkalinity level of concrete, The pH of the pure solution of concrete is a key parameter for the durability of reinforced concrete structures. The test of pH concrete at age (1,7,28,90 days) in temperature (23c°,150c°,350c°,550c°), The specimen was exposed to high temperature at duration of (1.5 hr.).

4.3.1 pH concrete for concrete without replacement

The pH concrete test for concrete without replacement. Table (4 - 15) and Figure (4 - 42) showed the results of pH concrete.

Table (4 - 15): Summary of results pH concrete test for concrete without replacement

Symbol of specimens	Temp (c°)	Apparent pH concrete						
		1days	7 days	% Drop in pH	28 days	% Drop in pH	90 days	% Drop in pH
R	23	11	11.3	-	12.0	-	12.1	-
	150		11.2	0.9	11.8	1.7	11.9	1.7
	350		11.1	1.8	11.6	3.3	11.7	3.3
	550		11.0	2.7	11.4	5.0	11.5	5.0

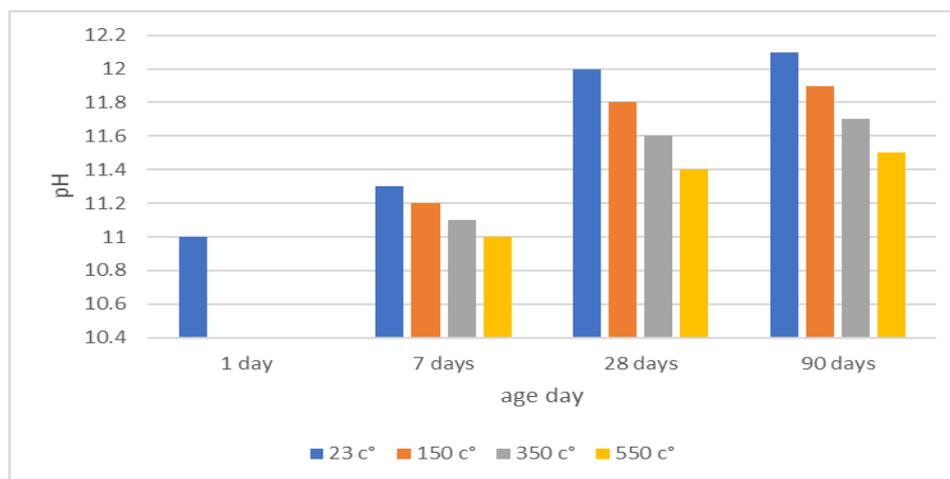


Figure (4 - 42): Results apparent pH concrete for concrete without replacement

4.3.2 pH concrete for concrete with replacement (silica fume)

The pH concrete test for concrete with replacement silica fume (10%,20%,30% and 40%). Table (4 - 16) and Figure (4 - 43) showed the results of pH concrete.

Table (4 - 16) pH concrete for concrete with silica fume as replacement

Symbol of specimens	Ratio content replacement silica fume from cement %	Temp (c°)	Apparent pH concrete						
			1day	7 days	% Drop in pH	28 days	% Drop in pH	90 days	% Drop in pH
S1	10%	23	11	11.1	-	11.6	-	11.1	-
		150		11	0.90	11.5	0.86	11	0.90
		350		11	0.90	11.4	1.72	10.9	1.80
		550		10.9	1.80	11.3	2.59	10.8	2.70
S2	20%	23	11.1	11.2	-	11.4	-	10.5	-
		150		11.1	0.89	11.3	0.88	10.4	0.95
		350		11	1.79	11.1	2.63	10.4	0.95
		550		11	1.79	10.9	4.39	10.3	1.90
S3	30%	23	11.2	11.2	-	10.7	-	10.5	-
		150		11.1	0.89	10.4	2.80	10.4	0.95
		350		11	1.79	10.2	4.67	10.3	1.90
		550		11	1.79	10.1	5.61	10.3	1.90
S4	40%	23	11	11.3	-	10.5	-	10.2	-
		150		11.2	0.88	10.3	1.90	10	1.96
		350		11.1	1.77	10.1	3.81	9.6	5.88
		550		10.9	3.54	10	4.76	9.5	6.86

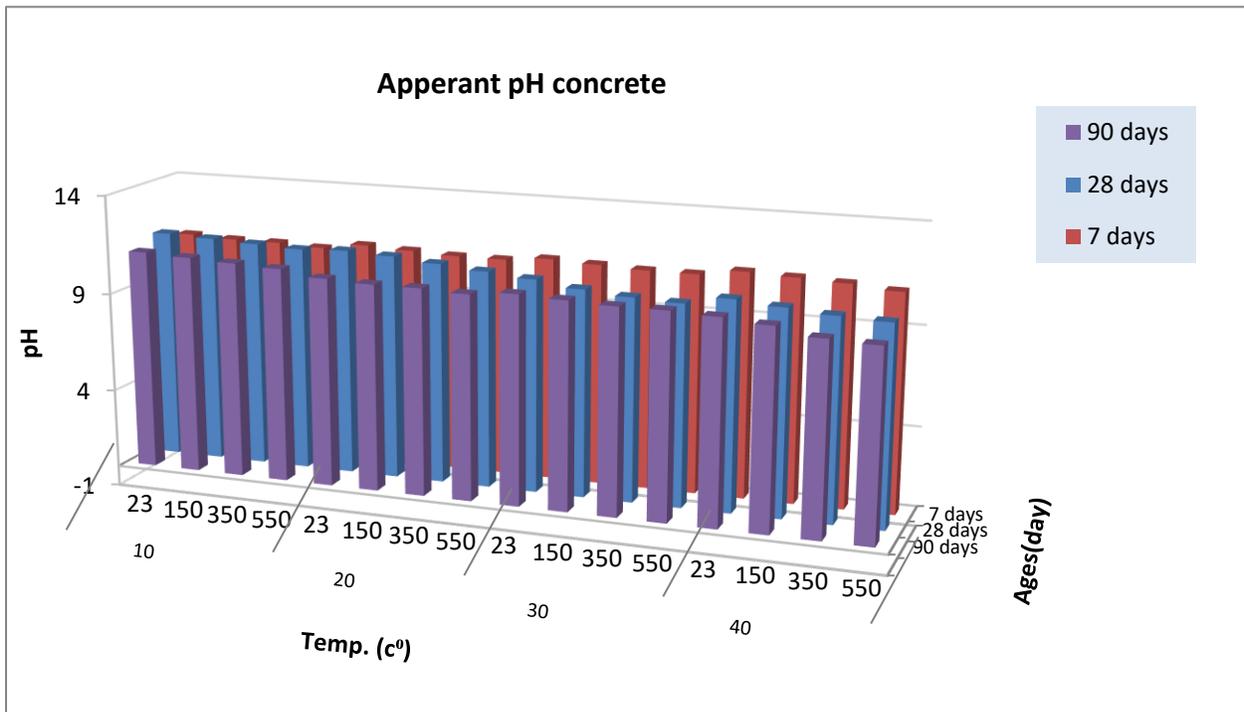


Figure (4 - 43): Results apperant pH concrete for concrete with silica fume as replacement

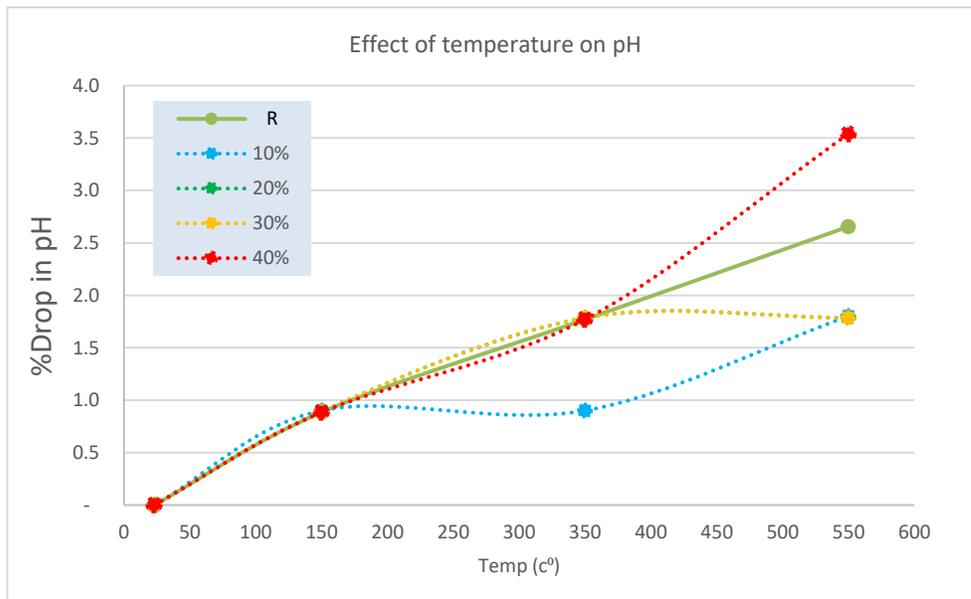


Figure (4 - 44): Drop in apperant pH for concrete with replacement (silica fume) at age 7 days

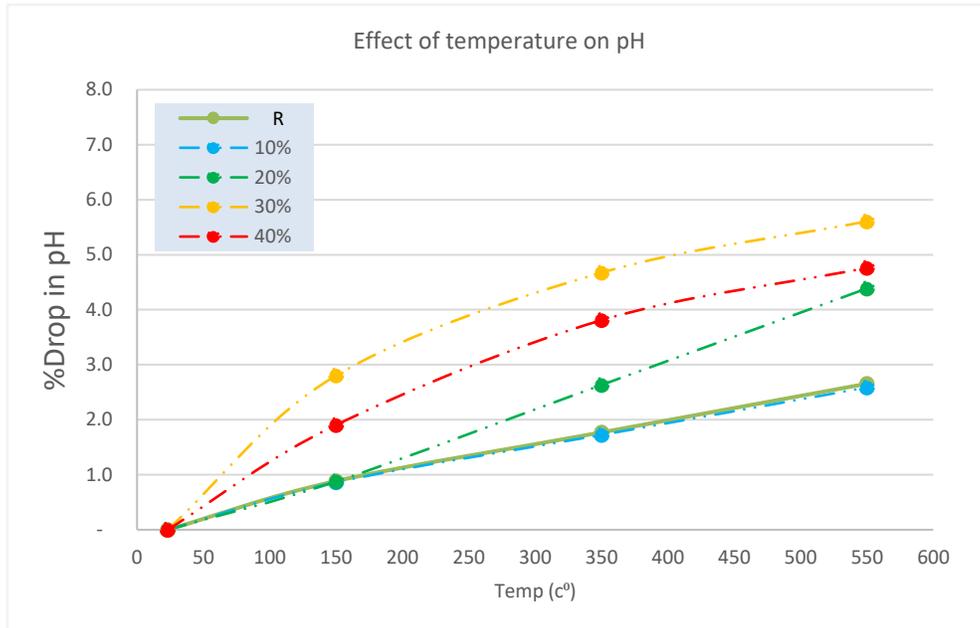


Figure (4 - 45): Drop in apparent pH for concrete with replacement (silica fume) at age 28 days

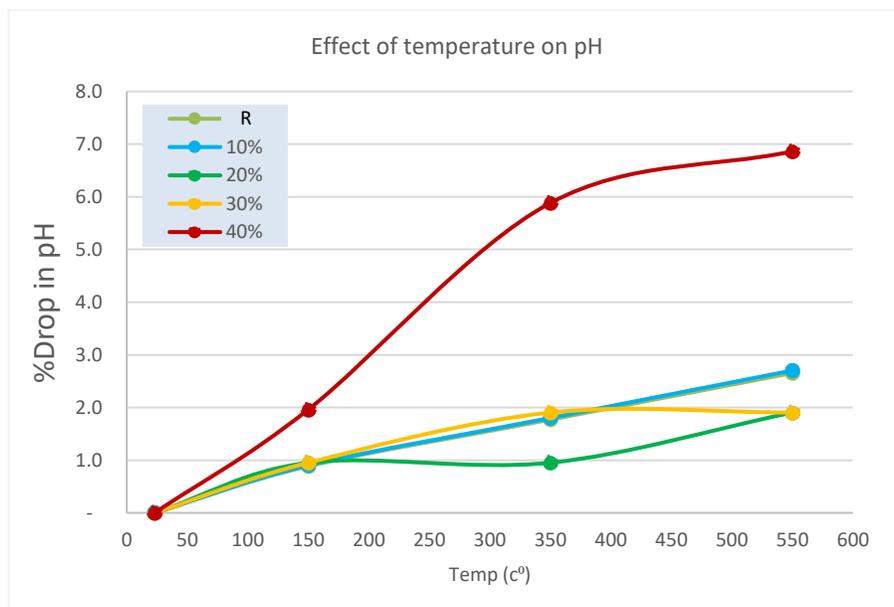


Figure (4 - 46): Drop in apparent pH for concrete with replacement (silica fume) at age 90 days

4.3.3 pH concrete for concrete with replacement metakaolin

The pH concrete test for concrete with replacement metakaolin (10%,20%,30% and 40%). Table (4 - 17) and Figure (4 - 47) showed the results of pH concrete.

Table (4 - 17) pH concrete for concrete with metakaolin as replacement

Symbol of specimens	Ratio content replacement metakaolin from cement %	Temp	Apparent pH concrete						
			1day	7 days	% Drop in pH	28 days	% Drop in pH	90 days	% Drop in pH
L1	10%	23	11	11.5	-	10.7	-	10.3	-
		150		11.3	1.74	10.5	1.87	10	2.91
		350		11.1	3.48	10.3	3.74	9.9	3.88
		550		11	4.35	10.1	5.61	9.8	4.85
L2	20%	23	11	11	-	11.2	-	10.4	-
		150		11	-	10.9	2.68	10.3	0.96
		350		11	-	10.7	4.46	10.1	2.88
		550		11	-	10.6	5.36	10	3.85
L3	30%	23	11	11	-	11.2	-	10.2	-
		150		10.9	0.91	11	1.79	10.1	0.98
		350		10.8	1.82	10.9	2.68	10	1.96
		550		10.7	2.73	10.6	5.36	9.8	3.92
L4	40%	23	11	11.2	-	11.1	-	10.3	-
		150		11.1	0.89	11	0.90	10.1	1.94
		350		11	1.79	10.8	2.70	10	2.91
		550		10.9	2.68	10.7	3.60	9.7	5.83

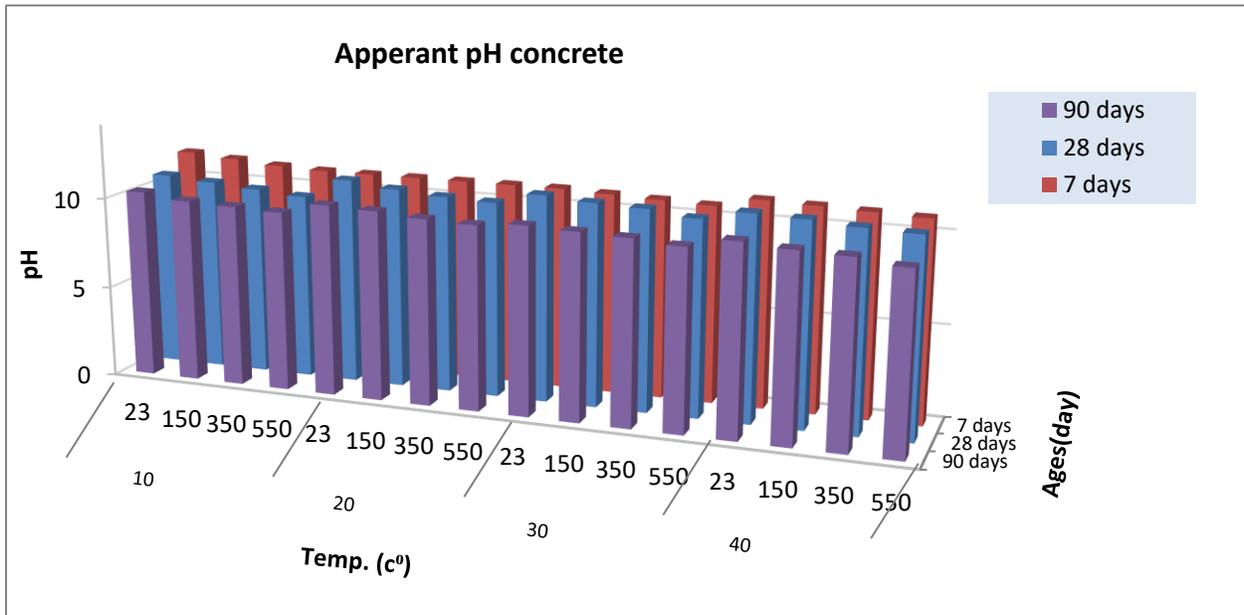


Figure (4 - 47): Results apperant pH concrete for concrete with metakaolin as replacement

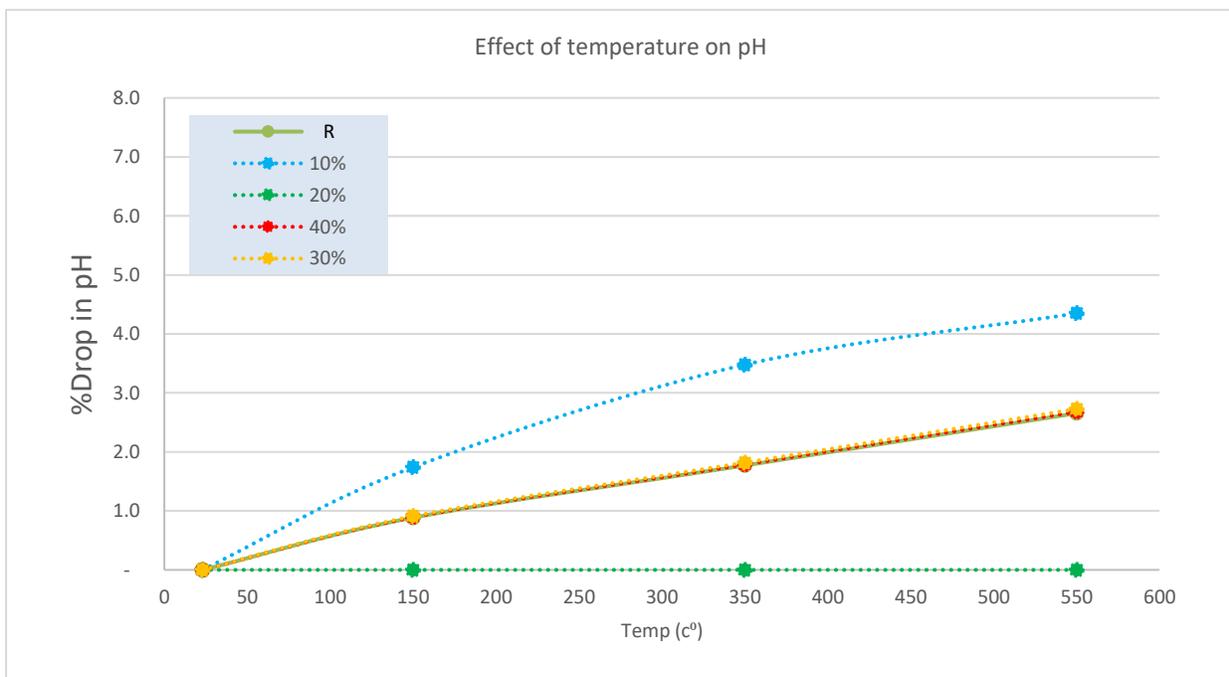


Figure (4 - 48): Drop in apperant pH for concrete with replacement (metakaolin) at age 7 days

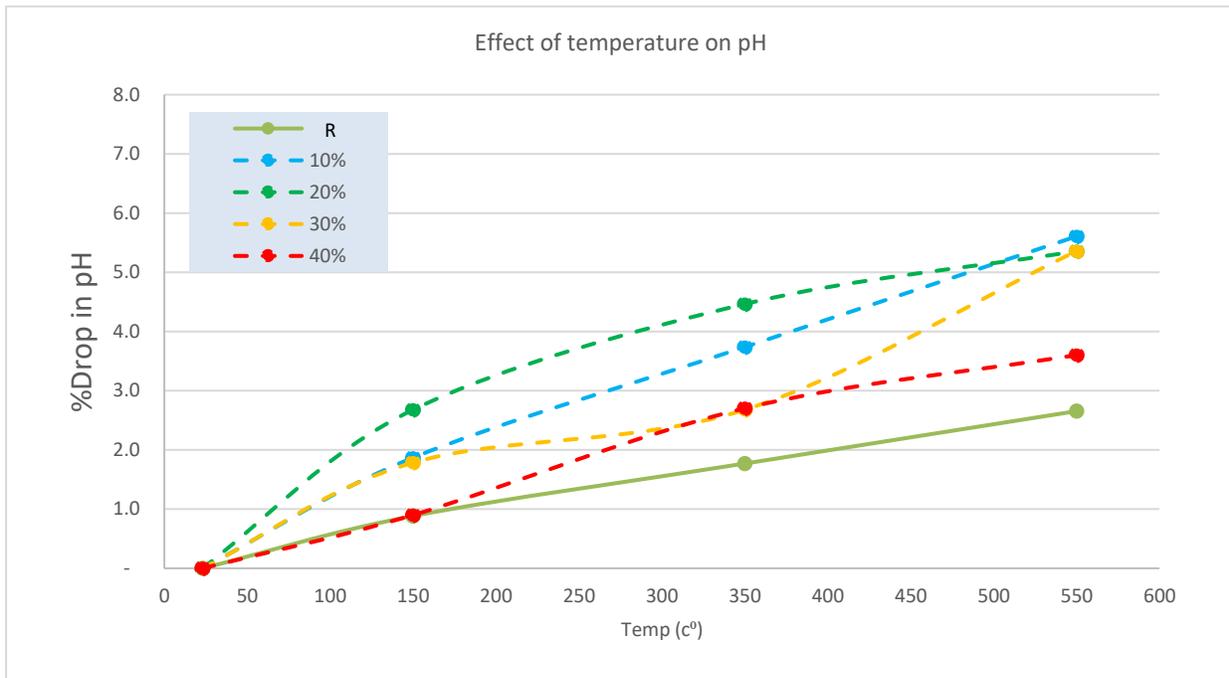


Figure (4 - 49): Drop in apparent pH for concrete with replacement (metakaolin) at age 28 days

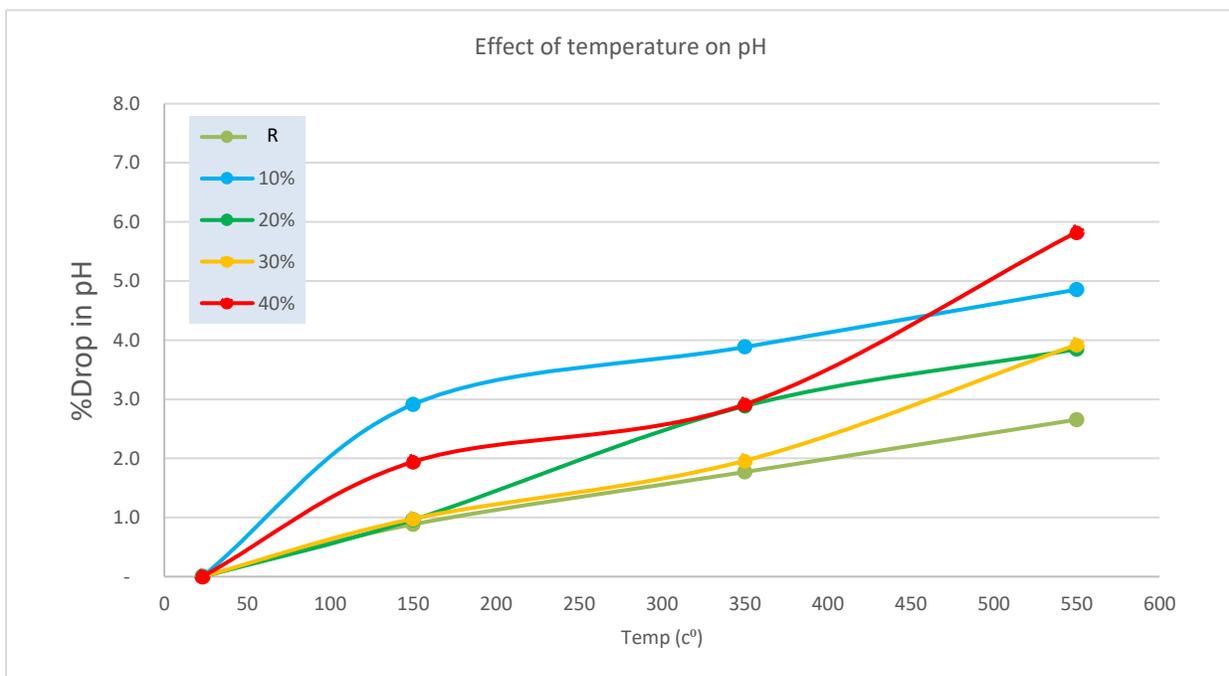


Figure (4 - 50): Drop in apparent pH for concrete with replacement (metakaolin) at age 90 days

4.3.4 pH concrete for concrete with replacement (lime stone powder)

The pH concrete test for concrete with replacement lime stone powder (10%,20%,30% and 40%). Table (4 - 18) and Figure (4 - 51) showed resulting pH concrete.

Table (4 - 18) pH concrete for concrete with lime stone powder as replacement

Symb ol of specim ens	Ratio content replacem ent lime stone powder from cement %	Temp (C°)	Apparent pH concrete						
			1day	7 days	% Drop in pH	28 days	% Drop in pH	90 days	% Drop in pH
W1	10%	23	10.9	11.1	-	11.4	-	10.6	-
		150		11	0.90	11.3	0.88	10.4	1.89
		350		10.9	1.80	11.1	2.63	10.3	2.83
		550		10.8	2.70	10.9	4.39	10.2	3.77
W2	20%	23	11	11.2	-	11.4	-	10.7	-
		150		11.3	0.89	11.3	0.88	10.5	1.87
		350		11.1	0.89	11.2	1.75	10.3	3.74
		550		11.1	0.89	11.2	1.75	10.1	5.61
W3	30%	23	11	11	-	11.5	-	10.5	-
		150		10.9	0.91	11.2	2.61	10.3	1.90
		350		10.9	0.91	11.1	3.48	10.2	2.86
		550		10.8	1.82	10.9	5.22	10	4.76
W4	40%	23	11	10.9	-	11.3	-	10.8	-
		150		10.7	1.83	11.1	1.77	10.5	2.78
		350		10	8.26	11	2.65	10.3	4.63
		550		9.9	9.17	10.9	3.54	10	7.41

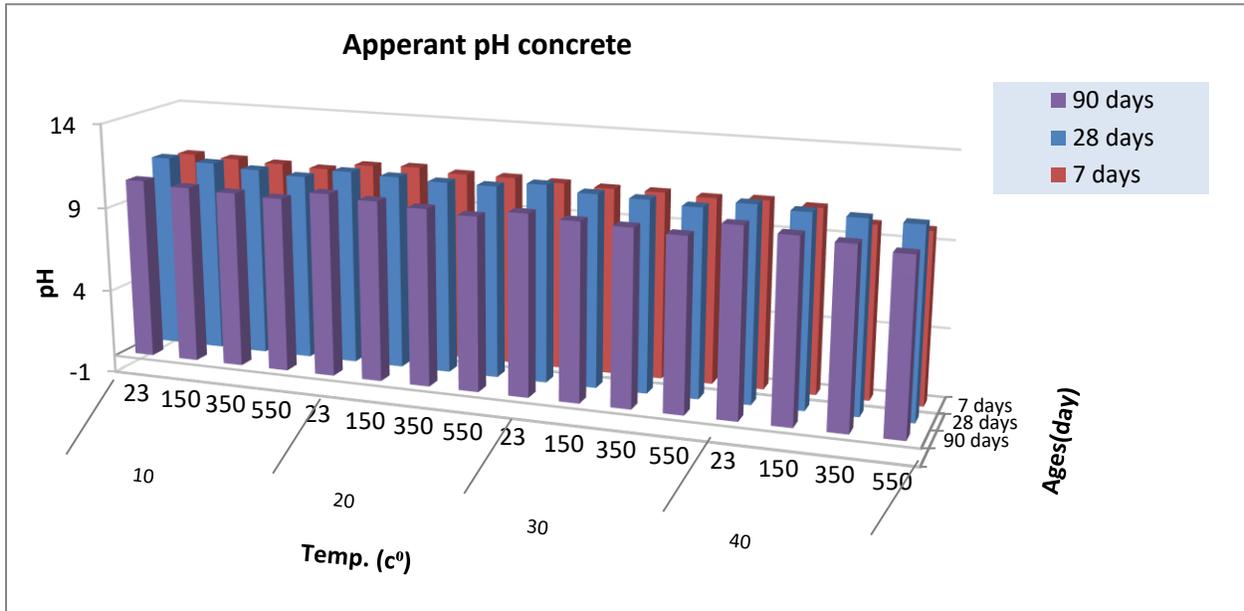


Figure (4 - 51): Results apperant pH concrete for concrete with lime stone powder as replacement

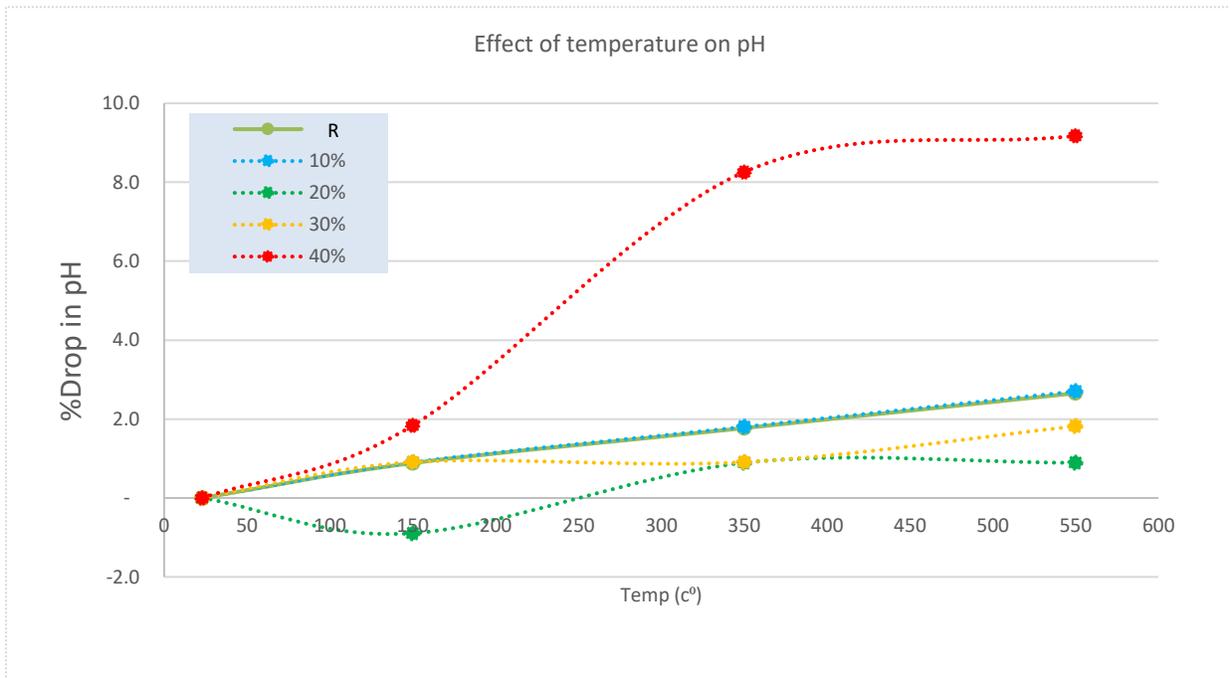


Figure (4 - 52): Drop in apperant pH for concrete with replacement lime stone at age 7 days

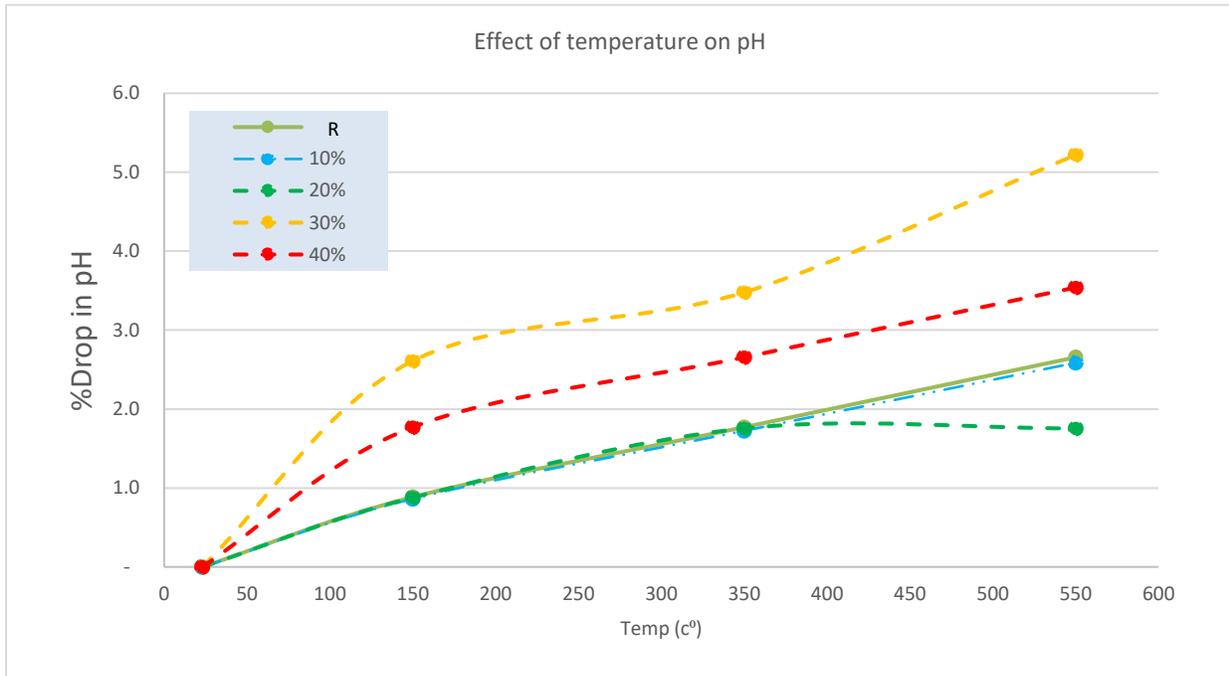


Figure (4 - 53): Drop in apparent pH for concrete with replacement lime stone at age 28 days

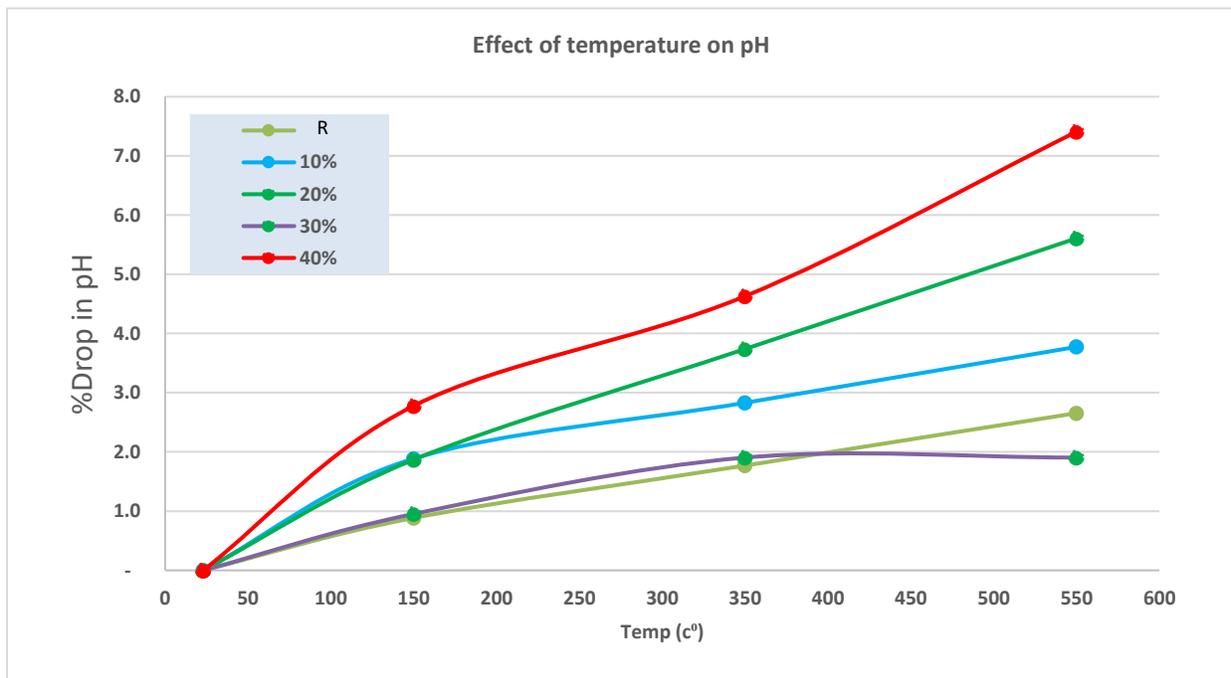


Figure (4 - 54): Drop in apparent pH for concrete with replacement lime stone at age 90 days

4.3.5 pH concrete for concrete with replacement ground granulated blast furnace slag (GGBS)

The pH concrete test for concrete with replacement GGBS “ground granulated blast furnace slag” (10%,20%,30% ,40%). Table (4 - 19) and Figure (4 - 55) showed resulting pH concrete.

Table (4 - 19) pH concrete for concrete with GGBS as replacement

Symbol of specimens	Ratio content replacement GGBS from cement %	Temp (C°)	Apparent pH concrete				
			1day	28 days	% Drop in pH	90 days	% Drop in pH
G1	10%	23	11.1	11.3	-	10.7	-
		150		11.2	0.88	10.5	1.87
		350		11.1	1.77	10.4	2.80
		550		11	2.65	10.3	3.74
G2	20%	23	11	11.1	-	10.8	-
		150		11	0.90	10.5	2.78
		350		10.9	1.80	10.3	4.63
		550		10.8	2.70	10.2	5.56
G3	30%	23	10.9	10.9	-	10.6	-
		150		10.8	0.92	10.5	0.94
		350		10.7	1.83	10.3	2.83
		550		10.7	1.83	10.1	4.72
G4	40%	23	11	10.9	-	10.4	-
		150		10.7	1.83	10.3	0.96
		350		10.7	1.83	10.1	2.88
		550		10.6	2.75	10	3.85

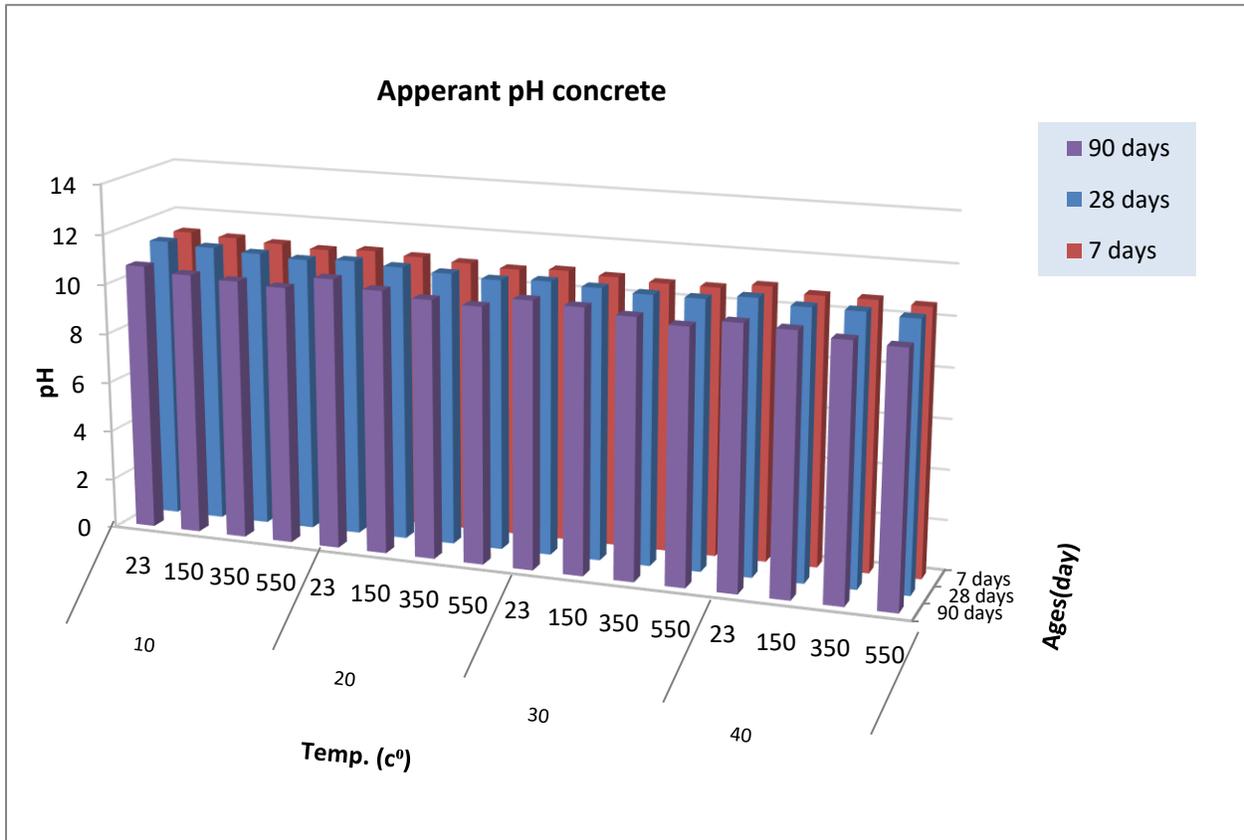


Figure (4 - 55): Results apperant pH concrete for concrete with GGBS as replacement

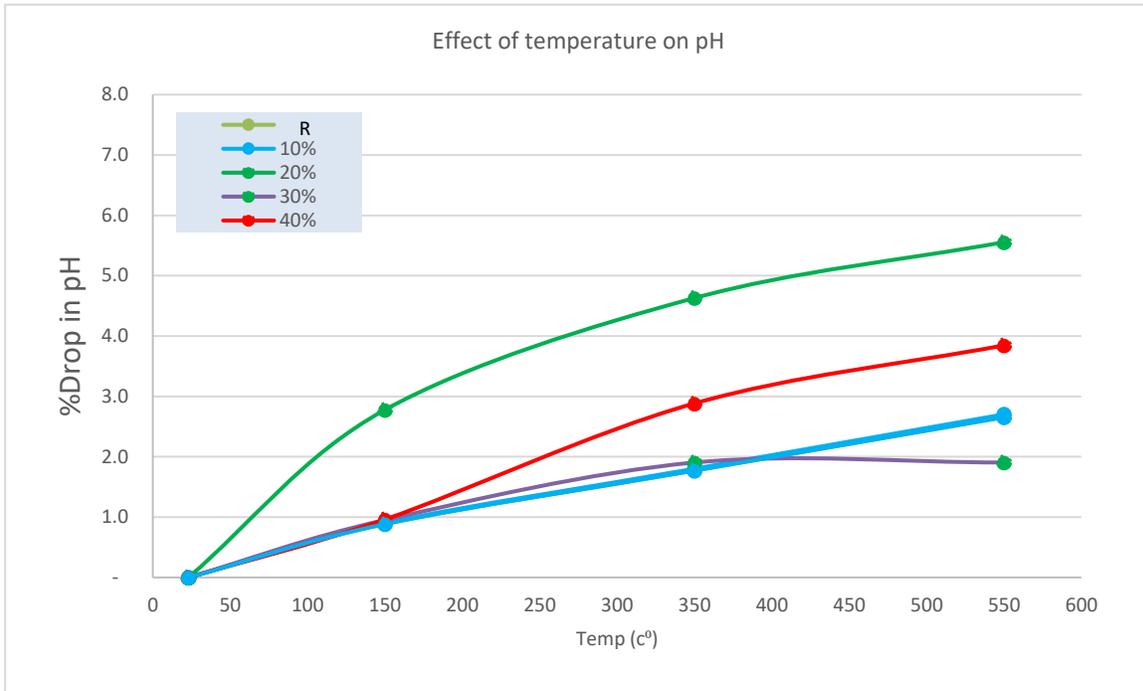


Figure (4 - 56): Drop in apparent pH for concrete with replacement GGBS at age 28 days

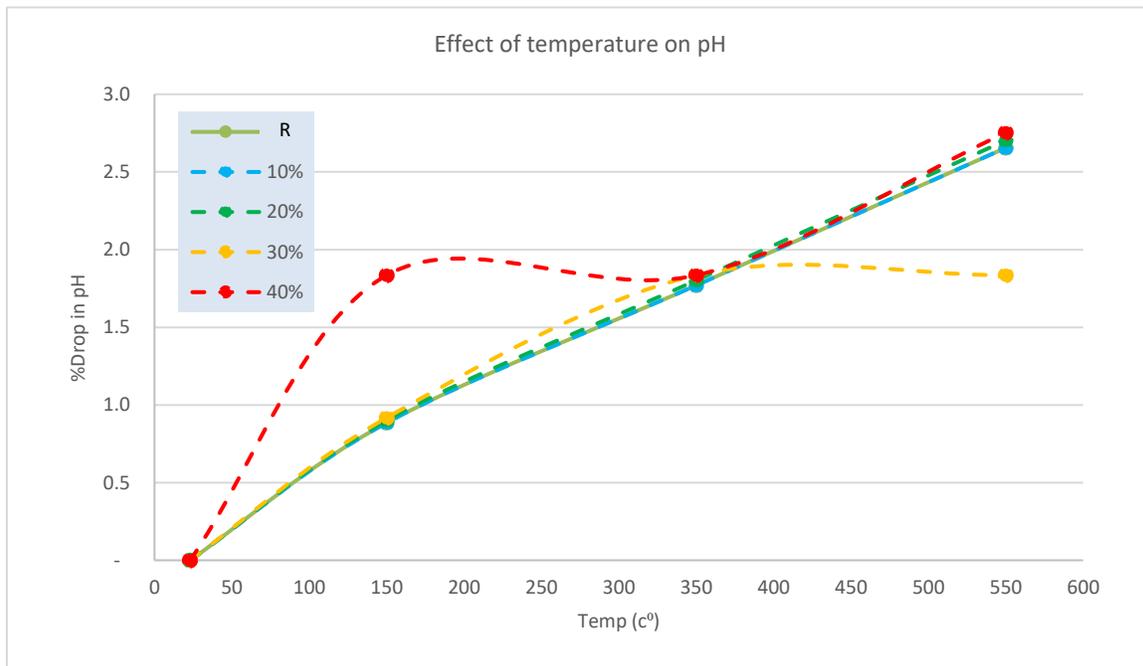


Figure (4 - 57): Drop in apparent pH for concrete with replacement GGBS at age 90 days

4.3.6 Results Summary

From Figure (4 - 42) to Figure (4 - 57), we can conclude that:

- 1- The large descend in apparent pH vale at age 7 days for temperature 550 C° (3.54 %) with 40% replacement of cement (silica fume) and large descend (5.61%) at age 28 days for temperature 550 C° with 30% replacement of cement (silica fume) and large descend (6.86%) at age 90 days for temperature 550 C° with 40% replacement of cement (silica fume).
- 2- The large descend in apparent pH vale at age 7 days for temperature 550 C° (4.35%) with 10% metakaolin as replacement of cement and large descend (5.61%) at age 28 days for temperature 550 C° with 10% metakaolin as replacement of cement and large descend (5.83%) at age 90 days for temperature 550 C° with 40% metakaolin as replacement of cement.
- 3- The large descend in apparent pH vale at age 7 days for temperature 550 C° (9.17%) with 40% lime stone powder as replacement of cement and large descend (5.22%) at age 28 days for temperature 550 C° with 30% lime stone power as replacement of cement and large descend (7.41%) at age 90 days for temperature 550 C° with 40% lime stone powder as replacement of cement.
- 4- The large descend in apparent pH vale at age 28 days for temperature 550 C° (2.75 %) with 40% GGBS as replacement of cement and Large descend (5.56 %) at age 90 days for temperature 550 C° with 20% GGBS as replacement of cement.

4.3.7 Discussion the Results of Apparent pH concrete with replacement with different supplementary cementitious materials

From Figure (4 - 58) represent a comparison of the apparent pH values of concrete exposed to high temperatures (23, 150, 350 and 550 C°) using different supplementary cementitious materials (Silica fume, metakaolin, lime stone powder and GGBS) and at different ages (7, 28 and 90) days. The large descend in apparent pH vale of concrete was (7.41%) at lime stone powder as replacement of cement compared to others supplementary cementitious materials (metakaolin, silica fume, GGBS). Because the lime stone powder has low content of SiO_2 (6.84%). while the minimum drop in pH of concrete is (1.9%) in 30% silica fume as replacement with cement compared to others supplementary cementitious materials (metakaolin, lime stone powder, GGBS).

And so it can be concluded that the addition of different supplementary cementitious materials to concrete mixtures with replacement rates of more than 20% of cement leads to a decrease in the apparent alkalinity level of concrete due to the interaction between the compounds of these materials with the hydration products of cement (Calcium hydroxide, responsible for the alkalinity medium of concrete), which leads to its decrease as it turns Compound (Calcium hydroxide) to cement compounds with low alkalinity.

In addition, also find that the effect of high temperatures with different supplementary cementitious materials as replacement, both of which reduce the alkalinity level of concrete. High heat works to dismantle the compound (Calcium hydroxide) responsible for the alkalinity level of concrete and the supplementary cementitious materials also reduce this compound.

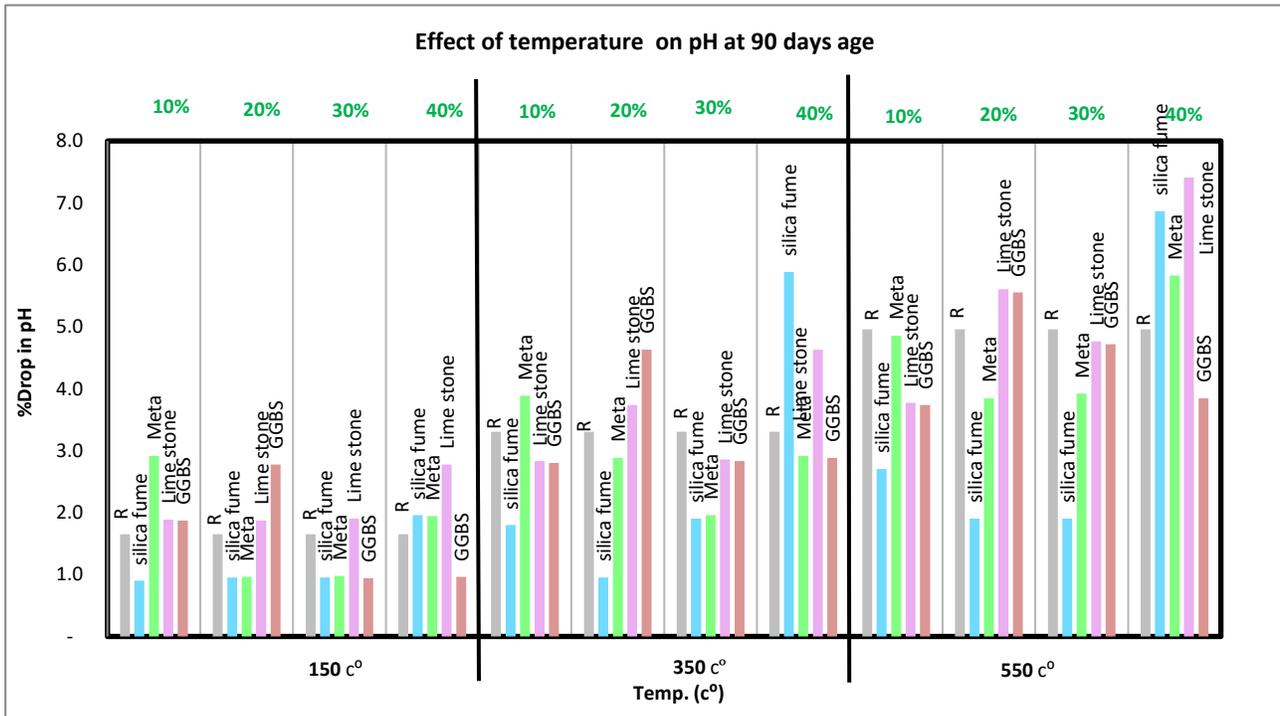


Figure (4 - 58): Effect of temperature on pH at age 90 days for all replacement material

Chapter Five

Conclusions &

Recommendations

Chapter Five

Conclusions & Recommendations

5.1 Introduction

The main conclusions from experimental and analytical results, and some recommendations and suggestions for future work, are covered in this chapter.

5.2 Conclusions

1. The use of these materials (supplementary cementitious materials) in concrete as a partial replacement for cement leads to the production of concrete with good mechanical properties (compressive strength, splitting tensile strength and flexural strength) compared to ordinary concrete, in addition to the fact that this concrete is sustainable and environmentally friendly concrete.
2. The use of these supplementary cementitious materials in concrete as a partial replacement for cement leads to concrete with better compressive strength, splitting tensile strength and flexural strength when exposed to high temperatures up to 550 °C
3. Among the best supplementary cementitious materials used, the use of silica fume as a replacement for cement by 30% leads to the production of concrete that resists exposure to high temperatures up to 550 degrees Celsius (the lowest decrease in compressive strength reaches (10.48%) better than ordinary concrete without replacement and especially at older ages (90 days).
4. Using metakaolin and GGBS as replacement from cement by 20% and 40% respectively lead that drop in compressive strength (23.29%) and (23.81%) respectively after using material silica fume in 90 days ages at 550C^o temperature.
5. While using limestone powder is large descend in compressive strength (27.80%) with replacement 20% from cement compered to author SMCs (silica fume, metakaolin, GGBS) at high temperature 550C^o in 90 days ages.
6. The effect of these (SMCs) materials on splitting tensile strength and flexural is less compared to the compressive strength when concrete is exposed to high temperatures.

7. The minimum drop in splitting tensile strength of concrete is (29.70%) in use 10% silica fume as replacement with cement compared to concrete without replacement and others supplementary cementitious materials (metakaolin, lime stone powder).
8. The minimum descend in flexural strength of concrete is (36.06%) in 10% metakaolin as replacement with cement compared to the concrete without replacement and others supplementary cementitious materials (silica fume, lime stone powder, GGBS).
9. The effect of these materials (supplementary cementitious materials) as a replacement (10%,20%,30%, and 40%) for cement in concrete leads to a decrease in the apparent pH value when concrete is exposed to high temperatures up to 550 C° especially for later ages (more than 28 days).
10. When limestone powder is used as a 40% replacement for cement, the apparent pH value decreases by (7.41%) when concrete is exposed to high temperatures up to 550 C°.
11. While the lower drop in pH of concrete is (1.9%) in 30% silica fume as replacement with cement compared to others supplementary cementitious materials (metakaolin, lime stone powder, GGBS).

5.3 Recommendations

1. Studying the effect of the direct fire flame with supplementary cementitious materials on the pH and some mechanical properties of concrete.
2. Studying effect supplementary cementitious materials by using mixed proportions combined (silica fume, GGBS, metakaolin and lime stone powder) in pH and mechanical properties.
3. Studying the effect of fly ash instead of lime stone powder on pH concrete.
4. Studying the effect of supplementary cementitious materials on concrete at ages of more than three months.
5. Studying the effect of high temperature more than 1.5 hours and more than 550 C°.

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الخلاصة

في الآونة الأخيرة ونتيجة للتطور الكبير الذي حدث، خاصة فيما يتعلق بإنتاج الخرسانة المستدامة من خلال تقليل كمية الأسمنت التي تولد كميات كبيرة من غاز ثاني أكسيد الكربون أثناء تصنيعها، والمواد الأسمنتية التكميلية المختلفة (دخان السيليكا، ثم استخدام الميتاكوولين ومسحوق الحجر الجيري وخبث الأفران العالية الحبيبية وغيرها) كبديل للأسمنت لإنتاج الخرسانة بمواصفات مميزة وصديقة للبيئة. مع العلم أن هذه المواد الأسمنتية التكميلية المختلفة في الخرسانة تتفاعل ببطء مع نواتج تفاعلات الماء (هيدروكسيد الكالسيوم) لإنتاج مركبات أسمنتية تساهم في تحسين بعض الخواص الميكانيكية للخرسانة.

في هذا البحث دراسة الفعل المزدوج لدرجات الحرارة المرتفعة والمواد الإسمنتية المكملة المختلفة (دخان السيليكا، ميتاكوولين، مسحوق الحجر الجيري وخبث فرن الصهر العالي الحبيبي) كمواد بديلة للأسمنت في الخرسانة بأعمار خرسانية مختلفة (7، 28، 90) يوماً. نسب الاستبدال كانت (10%، 20%، 30% و 40%). تمت دراسة خصائص الخرسانة المتصلبة: مقاومة الانضغاط، مقاومة الانثناء، وقوة الشد. تم دراسة جميع العينات عند 23 درجة مئوية وثلاث درجات حرارة عالية (150 درجة مئوية، 350 درجة مئوية، 550 درجة مئوية).

التأثير المشترك لدرجات الحرارة المرتفعة (150 درجة مئوية، 350 درجة مئوية، 550 درجة مئوية) مع استخدام نسب مختلفة (10%، 20%، 30% و 40%) مواد أسمنتية مختلفة (دخان السيليكا، ميتاكوولين، حجر الجير وخبث مسحوق الحبيبات والأفران العالية) كما تمت دراسة كبديل للأسمنت وتأثيره على مستوى قلوية الخرسانة. تم اختبار الرقم الهيدروجيني الظاهر أو السطحي لعدة أعمار من الخرسانة (7، 28، 90) يوماً.

أظهرت النتائج أن انخفاض الخواص الميكانيكية للخرسانة انخفض مع زيادة درجة الحرارة مع زيادة نسبة المواد الإسمنتية المكملة (دخان السيليكا، ميتاكوولين، حجر الجير وخبث مسحوق الحبيبات والأفران العالية) الحد الأدنى لأقل انخفاض في مقاومة الانضغاط للخرسانة هو (10.48%) في الاستخدام 30% دخان السيليكا كبديل للأسمنت مقارنة بالمواد الأسمنتية المكملة الأخرى (ميتاكوولين، حجر الجير وخبث مسحوق الحبيبات والأفران العالية)

من بين أفضل المواد الأسمنتية التكميلية المستخدمة، فإن استخدام دخان السيليكا كبديل للأسمنت بنسبة 30% يؤدي إلى إنتاج الخرسانة التي تقاوم التعرض لدرجات حرارة عالية تصل إلى 550 درجة مئوية (أقل انخفاض في مقاومة الانضغاط يصل إلى (10.48%)). أفضل من الخرسانة العادية بدون استبدال وخاصة في الأعمار الأكبر (90) يوماً.

استخدام الميتاكوولين وخبث مسحوق الحبيبات والأفران العالي كبديل للأسمنت بنسبه 20% و 40% على التوالي يؤدي الى انخفاض في مقاومه الانضغاط (23.29%) و (23.81%) على التوالي بعد تعرضها الى

حراره عاليه 550 درجة مؤيه في عمر 90 يوم تكون افضل بعد استخدام ماده دخان السليكا، بينما استخدام مسحوق الحجر الجيري يعطي انخفاض كبير في مقاومه الانضغاط (27.80%) مقارنة مع باقي المواد الأسمنتية المكمله (دخان السليكا، ميتاكولين، خبث مسحوق الحبيبات والافران العالي) بنفس درجه الحراره العاليه 550 درجة مؤيه في عمر 90 يوم.

تأثير هذه المواد الاسمنتيه المكمله على مقاومه الشد والانحناء أقل مقارنة بمقاومه الانضغاط عند تعرض الخرسانة لدرجات حرارة عاليه ، وأقل انخفاض في مقاومه الشد للخرسانة هو (29.70%) في الاستخدام 10% دخان السليكا من الاستبدال بالأسمنت مقارنة بالخرسانة بدون استبدال والمواد الأسمنتية المكمله الأخرى (ميتاكولين ، مسحوق الحجر الجيري ، خبث مسحوق الحبيبات والافران العالي) ، بينما أقل هبوط في مقاومه الانحناء للخرسانة هو (36.06%) في 10% ميتاكولين كبديل للأسمنت مقارنة بالخرسانة بدون استبدال و مواد اسمنتيه المكمله أخرى (دخان السليكا، مسحوق الحجر الجيري ، خبث مسحوق الحبيبات والافران العالي).

ان تأثير هذه المواد (المواد الأسمنتية المكمله) كبديل (10% ، 20% ، 30% ، 40%) للأسمنت في الخرسانة يؤدي إلى انخفاض قيمة الأس الهيدروجيني الظاهرة عند تعرض الخرسانة لدرجات حرارة عاليه تصل إلى 550 درجة مؤيه خاصة للأعمار اللاحقة (أكثر من 28 يومًا) .

وكان الانخفاض الكبير في قيمه الأس الهيدروجيني الظاهر للخرسانة (7.41%) في مسحوق الحجر الجيري كبديل للأسمنت مقارنة بالمواد الأسمنتية التكميلية الأخرى (دخان السليكا، ميتاكولين، خبث الافران الحبيبي العالي) بينما أقل انخفاض في الأس الهيدروجيني للخرسانة هو (1.9%) في أدخنة السليكا بنسبة 30% كبديل للأسمنت مقارنة بالمواد الأسمنتية التكميلية الأخرى (ميتاكولين ، حجر الجير وخبث مسحوق الحبيبات والافران العاليه) ، مما يؤدي إلى أفضل خصائص الخرسانة تصلبًا. مع تقدم العمر للخرسانة من 7 ايام الى 90 يوم النقصان في خصائص التصلب يقل تدريجياً.

أخيرًا، أظهرت النتائج أن الأس الهيدروجيني ينخفض بشكل طفيف في العمر (1، 7، 28، 90) يومًا لجميع درجات الحرارة.



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

التأثير المشترك للحرارة العالية والمواد الأسمنتية المكاملة المختلفة على الأس الهيدروجيني وبعض الخواص الميكانيكية للخرسانة

رسالة

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

من قبل

رواد عادل جبر

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