Ministry of Higher Education

And Scientific Research

AL-Anbar University

Mechanical and Some Thermal Properties of Fiber Concrete Containing Polymer

A Thesis

Submitted to
the Department of Civil Engineering
College of Engineering - AL-Anbar University
in Partial Fulfillment of the Requirements
for the Degree of Master in
Concrete Design and Technology

By:
Ghassan Subhi AL-Kubaysi

Supervised By:

Dr. Abdulkader Ismail Al-Hadithi

1429 A.H. 2008 A.D.

EXAMINATION COMMITTEE CERTIFICATE

We clarify that we have read this thesis entitled "Mechanical and some Thermal Properties of Fiber Concrete Containing Acrylic Polymer" and as an examining committee, we examined the student "**Ghassan S. Jameel Al-Kubaysi**" in its content and the associate matters, which in our opinion meets the standard of a thesis for the degree of Master of science in concrete design and technology.

Signature I. A. Aljumaily
Name: Asst. Prof. Dr. Ibrahim A. S. Al-Jumaily
Date: 18 / 11 / 2008
(Chairman)

Signature Bayan S. AlNuman
Name: Asst. Prof. Dr. Bayan S. Al-Nu'man
Date: 19 / 11 / 2008
(Member)

Signature Khaleel
Name: Dr. Khaleel I. Aziz
Date: 18 / 11 / 2008
(Member)

Signature Abdulkade
Name: Dr. AbdulKader Ismail Al-Hadithi
Date: / / 2008
(Supervisor)

Approved by the dean of the college of engineering:

A. N. ABID
Signature
Name: Asst. Prof. Dr. Adil N. Abid
Date: 4 / / 2009

Acknowledgements

First of all, I have to thank our God (Allah, the Most Gracious, the Most Compassionate) for giving me the health to achieve this work.

I would like to express my great gratitude and appreciation to my supervisor **Dr. AbdulKader Ismail Abdulwahab Al-Hadithi** for his continuous guidance throughout the experimental work of this thesis and his assistance to complete this study.

Thanks are also extended to the staff of The Engineering College for their great assistance. Also I highly thank the staff of The Civil Engineering Department. Also special thanks are due to the staff of concrete and building material laboratory of Engineering College, Al-Anbar University.

Special thanks are presented to Dr. Tariq Al-Ani, Dr. Thari Al-Jumayli, Dr. Ibraheem Al-Jumayli, Dr. Kahlil I. Aziz, Dr. Adel Nhair Al-Hadithi, Mr. Muhammed Hmood, Mr. Mahmood Al-Ani and Mr. Ahmed H. Farhan for their great help they gave my during the fulfillment of this work.

Abstract

This research includes the study improvement of the mechanical properties and resistance to high temperatures of concrete using steel fibers with different ratios of volume (0.5%, 1%, 1.5%) and polymer with different weight ratios of polymer to cement (3%, 7%, 10%). The samples were made as follows: (100, 100, 100mm) cubes for compressive strength tests, (100, 200mm) cylinders for splitting tensile strength tests and (100, 100, 500mm) prisms for flexural strength tests.

The results show an improvement in all properties of steel fiber concrete with and without polymer as compared with reference concrete. In compressive strength, the increase was (14.2% - 40.6%) for steel fiber concrete, while the increase was (44.8% - 86.64%) for steel fiber concrete containing polymer. In splitting tensile strength, the increase was (50% - 91%) for steel fiber concrete, while the increase was (102.4% - 124.7%) for steel fiber concrete containing polymer. For flexural strength, the increase was (24.2% - 48.3%) for steel fiber concrete, while the increase was (62% - 78%) for steel fiber concrete containing polymer.

As concerns the effect of temperature on concrete tests, steel fiber concrete containing polymer gained compressive, tensile, and flexural strength greater than reference concrete specimens for all temperatures (100, 300, 500, 700C°). The increase in compressive strength was (82%, 54%, 69.8%, 171.4%), respectively; while the increase in tensile strength was (119.2%, 132.6%, 99%, 52.3%), respectively; and the increase in flexural strength was (87.3%, 194.4%, 115.8%, 164%), respectively.

I certify that the thesis titled ***“Mechanical and Some Thermal Properties of Fiber Concrete Containing Polymer”***, submitted by ***Ghassan Subhi Jameel Al-Kubaysi*** was prepared under my supervision at the Civil **Department, Engineering College, University of Al-Anbar** as a partial requirement for the ***degree of Master in Concrete Design and Technology.***

Signature:

Name: **Dr.** ***Abdulkader Ismail Abdulwahab Al-Hadithi***

(Supervisor)

Date: 16 / 6 / 2008

Supervisor Certificate

We certify that the thesis entitled ***"Mechanical and Some Thermal Properties of Fiber Concrete Containing Polymer"***, submitted by ***Ghassan Subhi Jameel Al-Kubaysi*** was prepared under my supervision at the Civil **Department, Engineering College, University of Al-Anbar** as a partial requirement for the ***degree of Master in Concrete Design and Technology.***

Signature:

Name: **Dr.** ***Abdulkader Ismail Abdulwahab Al-Hadithi***

(Supervisor)

Date: / / 2008

In view of the available recommendations, we forward this thesis for debate by examining committee .

Signature:

Name: **Dr.** ***Khalil I. Aziz***

Head of Civil Engineering Department

Date: / / 2008

Certification

I certify that this thesis, entitled ***((Mechanical And Some Thermal Properties of Fiber Concrete Containing Polymer))***, by the student ***"Ghassan Subhi Jameel"*** was prepared under my linguistic supervision. Its language was emended to meet the style of the engineering language.

Signature :

Linguistic supervision Assist: Prof. Dr. Muslih Shwaysh Ahmed

Date : / / 2008

Signature :

Dr. Khalil I. Aziz

Head of Civil Engineering Department

Date : / / 2008

Table of Contents

Chapter One

Introduction

1.1 General

Construction was an important element since the emergence of civilizations. It continues its vital role, especially in industry which contributes in the rapid changing to modern society. Materials are at the heart of the construction industry. Innovation in construction is highly linked with development of advanced construction materials[(1)] . Cement and concrete are among the most important building and construction materials because of their comparative cheapness and easiness to make fire proof and water tight cement-based product which posses excellent compressive strength but, their flexural, tensile and impact strength are limited[(2)] . This led to improving materials which are used in concrete by various methods. A number of variables in concrete can cause change in the mechanical properties as concrete, the more notable ones are aggregate type and shape, admixture and fiber reinforcement.

Several approaches have been adopted to improve concrete properties resulted in using different materials. Some of these approaches are[(3)] :

1. Polymer impregnation concrete (PIC) which involves filling the capillary pores of hardened concrete with polymer.

2. latex modified concrete (L.M.C) which is made by incorporating a polymer latex with fresh concrete which improves the tensile properties in concrete.

3. Fiber-reinforced concrete (FRC) which is made by adding fibrous materials (usually steel or glass) to fresh concrete which improves the crack resisting property.

1.2 Polymer and Polymer Concrete

Polymer is now well-established alongside metals and ceramics as one of the major classes of manufactured materials. They are used widely throughout industry and engineering[4] .

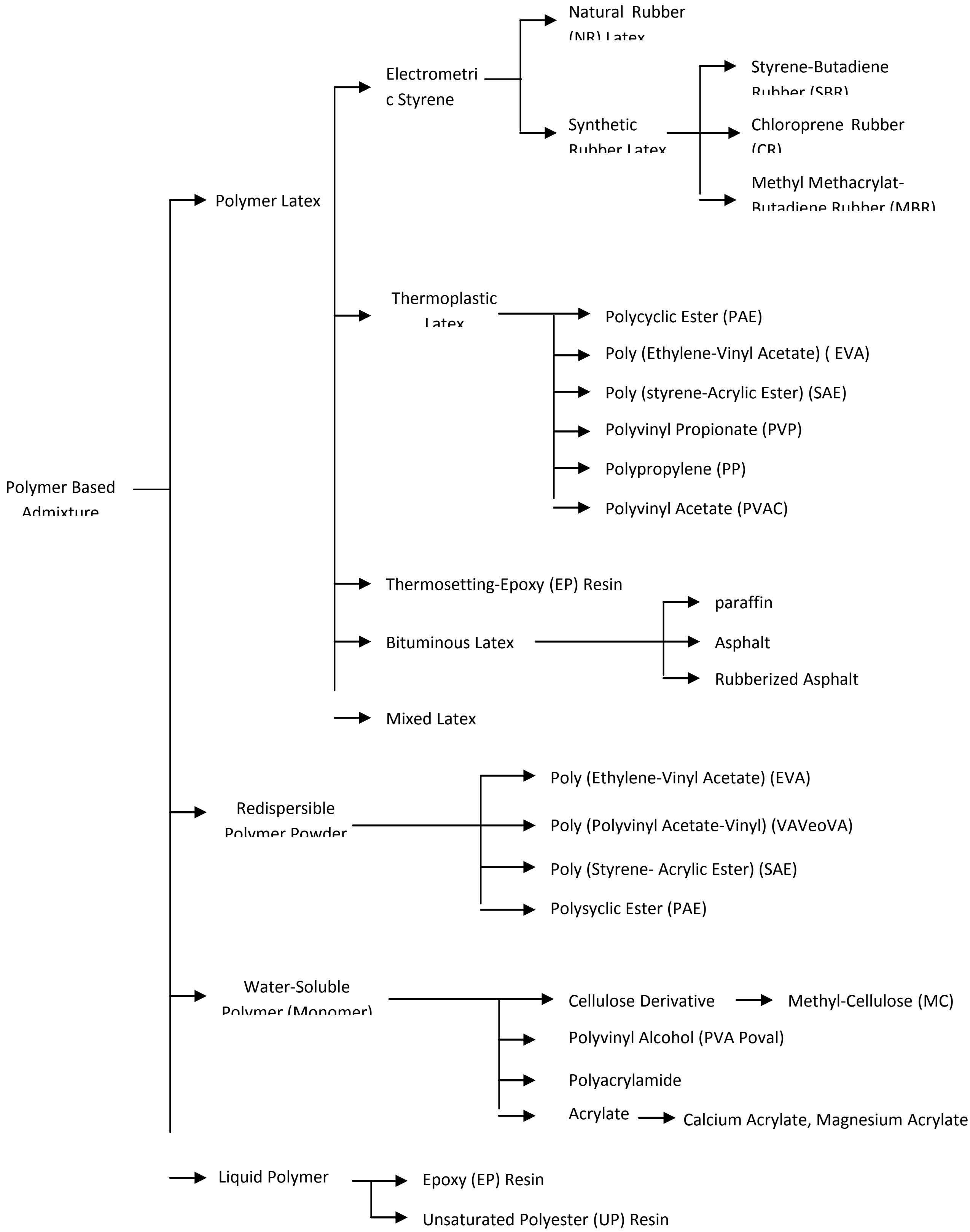
Polymer is defined as chemical materials with different forms (powder, liquid, latex, etc), the most common particles are ch, ch2 particles connected together with chemical bond. The Latin word (polymer) means many particles joined together by a chemical bond[5].

Generally, the properties of the polymer concrete materials are high in strength and good in cohesiveness. Excellent in durability, and resistance to water, acid and alkalis, and so on. These materials can be used to mend the damaged concrete structures, such as highways, bridges, railroads, river and sea banks as well a many kinds of cement concrete structures. Also this materials can be used in corrosive environment as corrosion-resisting material.

1.2.1 Classification of Polymeric admixtures

Figure (1.1) represents the classification of polymeric admixtures of modifiers since polymer modifies mortar and concrete. The polymer desperations widely used are styrene-butadiene rubber (S.B.r) latex, ethylene-vinyl acetate (EVA) and poly acrylic ester (PAt) emulsion in Japan and Europe and (S.B.Y) and (P.A.E) and epoxy (EP) resin in united states[6,7] . Various water-soluble polymers such as poly acryl amide;

acrylic monomer, hydroxyl ethyl cellulose (HEC); methyl cellulose (MC) and poly vinyl alcohol (PVAL) are used as polymeric admixtures for plastering work or under water concreting work.



Fig(1-1)Classification Of Polymeric Admixtures [8]

1.2.2 Concrete Polymer Composites

Concrete polymer composites are the materials which are made by replacing a part or all of the elements hydrate binder of conventional mortar or concrete with polymers. The concrete polymer composites are generally classified into the following three types by principles of their process technology[8] .

1. Polymer impregnation mortar (PIM) and concrete (PIC).
2. Polymer mortar (PM) and concrete (PC).
3. Polymer Portland Cement Concrete (PPCC).

1.2.3 Acrylic Polymer and Acrylic concrete

Acrylic latex is widely used in the world because of its very good properties such as the very high stability of both chemical and mechanical properties, good workability and high adhesion with cement hydration particles and surface of aggregate.

Acrylic latex decreases water cement ratio and increases strength of concrete.

Acrylic concrete is defined as a hardened acrylic mortar and fiberglass screen or wire mesh or any other mesh[9] .

Acrylic concrete has many uses. The structural membrane can be built to form roofs, arched shelters, walls, water tank, and covers, and in any strength desired when built up by additional layers of mesh and mortar .

1.3 Fiber-Reinforced Concrete

(FRC) is a concrete mix that contains short discrete fibers that are uniformly distributed and randomly oriented. Fiber materials can be steel, cellulose, carbon, polypropylene, glass, nylon and polyester[(10)] .

Fiber improves the performance of concrete by acting as bridging ligaments in crack. The crack bridging behavior is usually studied with the fiber pullout test[(11)] and increases compressive, tensile and flexural strength. Figure (1-2) shows that the plain concrete fails in a brittle manner with little warning. With the proper incorporation of fibers, the failure mode of concrete can change from brittle to quasi-ductile

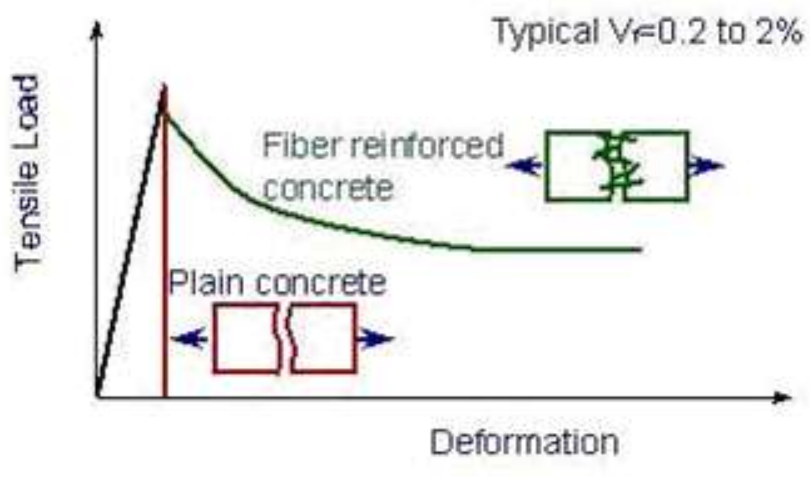


Figure (1-2) Tensile Load versus Deformation for Plain and Fiber Reinforced Concrete

1.3.1 Steel-Fiber Reinforced Concrete

Steel-Fiber Reinforced Concrete (SFRC) is cement based material reinforced with short steel fibers. When steel fibers are added to a concrete mix, they are randomly distributed and act as crack arrestors. Debonding and pulling out of fiber require more energy, giving a substantial increase in toughness and resistance to cyclic and dynamic loads(12) .

Steel-Fiber is the most common type of fiber used in practice. The crack bridging efficiency of a steel fiber depends on its length, radius, interfacial properties, and geometry as well as steel properties such as yield strength and ductility(13) .

1.3.2 Mechanical Properties

The mechanical properties of materials are the response of the materials to external loads.

All materials deform in response to load, however, the specific response of a material depends on its properties, the magnitude and type of load, and the geometry of the element.

The compressive strength of concrete made with aggregate of adequate strength is governed, in general, by the strength of either the cement paste or of the bond between the paste and the aggregate particles. At the early ages, the bond strength is lower than the paste strength; at later ages the reverse may be the case.

Tensile strength is one of the found material properties of concrete. In determining the tensile strength of concrete, three types of tests have been used: direct, flexural and splitting tension(14) .

1.4 Aim and Scope of the Work

The aim of this work is to investigate the improvement in mechanical and thermal properties by using steel fiber with and without polymer.

The influences of the following test variables were considered.

1. Fibers content.
2. Polymer latex (Acrylic) content.

For this purpose:

- Cubes (100*100*100mm) were tested for compressive strength.
- Cylinders (100*200mm) for splitting tensile strength.
- prisms (100*100*500) for flexural strength.

1.5 Research Layout

This thesis includes the following characters.

Chapter one	Introduction
Chapter two	Literature review
Chapter three	Experimental program
Chapter four	Analysis and discussion of results
Chapter five	Conclusions and recommendations

Chapter Two

Literature Review

2.1- Introduction

The literature survey presented in this chapter covers briefly the following aspects:

1- Polymeric concrete.

2- Steel Fiber reinforced concrete.

3- Fiber-Reinforced latex modified concrete.

4- The effect of temperature on the concrete.

2.2.1 Polymeric Impregnation concrete (PIC)

(PIC) is made by impregnation concrete of precast hardened Portland cement concrete with low viscosity monomers (either liquid or gaseous form) that is converted to solid polymer under the influence of physical agents (ultraviolet radiation or heat) or chemical agents (catalysts)[(15)] .

Production of (PIC) requires the following sequence of operations[(16)]:

1. Cast the concrete.
2. Dry the concrete.
3. Impregnate the concrete with monomer.
4. Polymerize the monomer.

An investigation was made by Ohama and Fukuchi[(17)] for studying high strength (PIC) concretes. They found that the polymer impregnation concrete gave a high compressive; flexure, and tensile strength.

2.2.1 Polymer Mortar and Concrete (PC):

(PC) is defined as a composite material where aggregates bound with a polymer binder instead of Portland cement as a conventional concrete. The use of (PC) began in (1970) in Japan and U.S.A and became popular all over the world[(18)] .

C. Vipulanandan and Eliza Paul[(19)] studied the behaviour of polymers such as epoxy and polyester polymers under various curing conditions and temperatures. The compositions of polymer concrete were about (15-20%) of polyester or epoxy polymer as a binder. Agent and grading aggregate was (80-85%). The polyester polymer and epoxy content is taken by weight. Some results of this research are:

- Epoxy-polymer and polyester polymer concrete systems are very much influenced by the curing method and temperature and testing temperature. Properties of polymer concrete system are related to testing temperature.

- For the range of fine aggregates investigation, polymer concrete with a gap graded aggregate system had the highest strength.

- The split tensile strength and compressive have been increased.

K.S. Rebitet al[20] produced polymer concrete using fly ash fillers. The P.C was investigated for its compressive strength and flexural strength. The effect of thermal cycling on bond strength also was investigated. Study results show that fly ash actually improves the strength properties and performance of P.C fly ash slightly improves the thermal cycling and creep deformation.

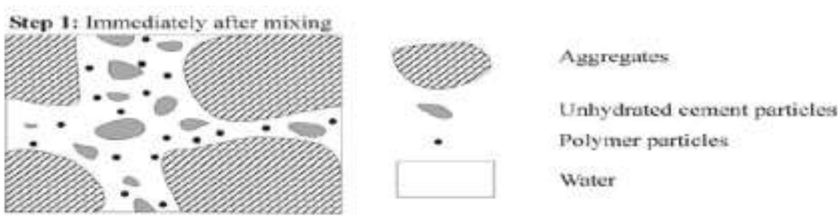
Meburkias, S.Vipulandan,C.[21] studied the behaviour of the polymer concrete (PC) by using polyester polymer that exposed to water for duration (1-3) years respectively. They studied chemical solutions, including water on this concrete. The solution was represented in decreasing the compressive strength. The reduction amount depends on the kind of the Hydrogen power and its concentration on the attaching solutions.

2.2.2 Polymer Portland Cement Concrete (PPCC)

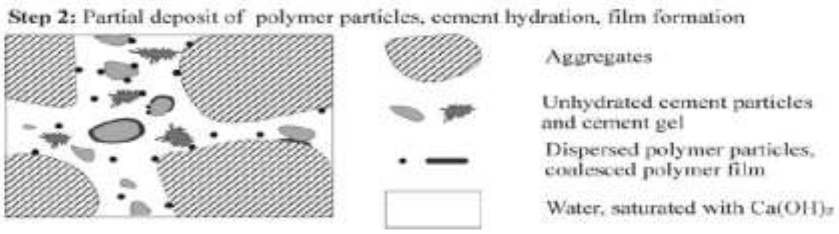
(ACI) manual of concrete practice part (5-1990) defined polymer Portland cement concrete (PPCC) mixture as a normal Portland cement concrete to which a water soluble or emulsified polymer has been added during the mixing process. As the concrete cures, hardening of polymer also occurs, forming a continuous matrix of polymer through the concrete[22].

2.2.3 Polymer Modification for Morter and Concrete

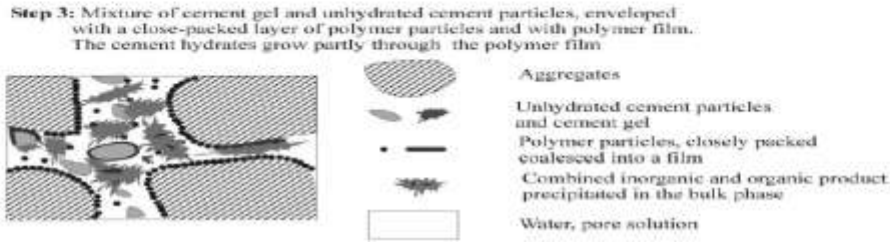
Polymer latex modification of cement and concrete is governed by both cement hydration and polymer film formation. The cement hydration process generally precedes the polymer film formation process by the coalescence of polymer particles in polymer latex[23] . Due to course, both cement hydration and polymer film formation processes form a co-matrix phase. The co-matrix phase is generally formed according to the simplified model given by Ohama[24], and also by Schwiete[25]. Figure (2-1) shows some chemical reactions between polymer and cement hydration that lead to improve the bond between cement hydration and aggregates[26].



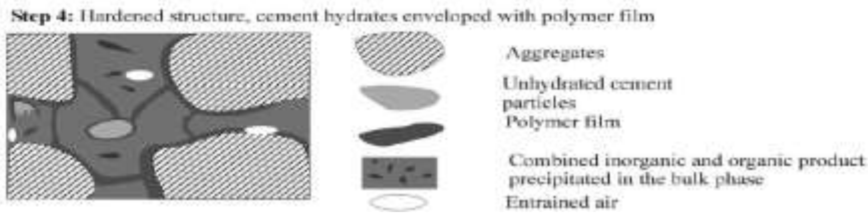
(a) Immediately after Mixing



(b) Partial Deposit of Polymer Particles, Cement Hydration, Film Formation



(a) Cement Hydration Proceeds, Polymer Film Formation Starts on Specific Spots



(b) Cement Hydration Continuous, the Polymer Particles Coalesce into a Continuous Film

Fig.(2-1) Some Chemical Reactions between Polymer and Cement Hydration

Ala'a A.Laetif[27] studied the effect of adding a polymer on the properties of concrete. It was found that the epoxy-modified concrete has higher mechanical properties especially the splitting tensile strength.

The test result exhibited excellent improvement in durability properties of epoxy-modified concrete. In general, the study results indicate that the use of epoxy resin in concrete as an admixture improve many properties of Portland cement concrete.

Khalid B.N(28). studied the Effect of admixture type on compressive strength and modulus of Elasticity of Rubber-Tire-Concrete

It was clear that the effect of addition admixtures (superplasticizer and polymer to Chopped Worn-Out Tire concrete as a partial replacement of cement weight. Superplasticizer was added by (4%) and polymer (SBR) by (15%).

Ordinary Portland cement, sand of (4.75 mm) maximum size, the washed coarse aggregate of (10 mm) maximum size, the maximum size of chopped worn-out tires particles of (6.35 mm) high way water reducing agent (HRWRA) and styrene butadiene rubber were used. The proportion concrete mixture was (1 : 2 : 2.5).The test results indicated that the use of admixture led to significant improvement in concrete properties in general. Superplasticizer gave best results as compared with polymer, for example, at (28) days the compressive strength of superplasticizer Ch.W.T. concrete was (32.5 MPa), while compressive strength of polymer modified Ch.W.T. concrete was (28 MPa) and compressive strength of Ch.W.T. concrete (C25.25) was (21.2 MPa).

Abdulkader I. Al-Hadithi(29) studied the effect of adding SBR polymer on some properties of no-fines concrete like density, compressive strength, flexural strength , water absorption and thermal conductivity .That research includes also the study of the flexural behaviour of No-fines polymer reinforced concrete.

Aggregates of 10-mm maximum size were used to produce concrete. The concrete mixes by weight were (1:5), (1:6) and (1:7) (cement: aggregate), respectively . The polymer was added as percentages of cement weight and they were 5%, 7.5% and 10%. Reference mixes were made for every case.

The mixes that gave the best results of compressive and flexural strengths were adopted to study the structural behaviour of reinforced polymer no–fines concrete with different reinforcement ratios using one-point and two-points load tests.

Appreciable improvement was recorded in compressive and flexural strengths. The 28-days compressive strength for polymer no-fines concrete ranged between (7.65-17.65) MPa whereas the reference concrete ranged (3.05-14.72) MPa. The 28-days flexural strength for no-fines polymer concrete ranged (0.375-2.935) MPa corresponding to (0.4605-0.493)MPa for reference concrete. The density of concrete ranged between (2030-2170) kg/m3 corresponding to about (1950-2096) kg/m3 for reference no-fines concrete.

The concrete of this work gave thermal conductivity values which were compared to those values recommended for structural lightweight concrete under ACI committee (213R-87)(30).

2.2.4 Acrylic Polymer

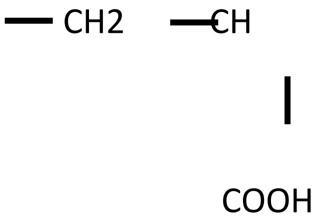
Acrylic Polymer is found as a sludge in the bottom of paint factories or found in market as a quick Crete material with many commercial names(31).

It acts as a plasticizer which enables less water, increases strength and makes it more water proof and also increases adhesion (for example when applying new concrete to an older piece of concrete).

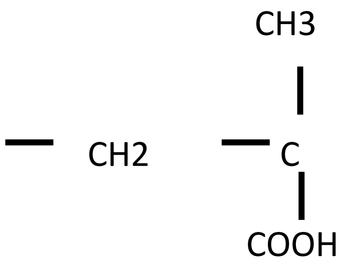
2.2.4.1 Acrylic in More Formula's Like:

Acrylic in many formula's like[32]:

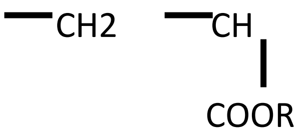
1. Poly acrylic acid.



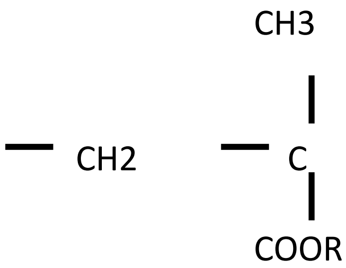
2. Poly methacrylic acid.



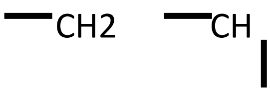
3. Poly acrylate or Acrylic acid Ester.



4. Poly methacrylate or methacrylic acid Ester.



5. Poly Acrylo Nitrile.



CN

6. Poly Acrylic Amide.

— CH2 — CH
|
CONH2

Acrylic is added to cement. It has a very fast setting to be called "latex cement grout" and to trowel onto fly screen mesh form both sides to be called "Acrylic Mortar".

Hardned Acrylic Mortar on Fiber or any other screen is called "Acrylic Concrete".

2.2.4.2 A Brief Account about Acrylic:

Acrylic is a new structural substance at least in our country. The term "Acrylic" is generally used to describe glass-like, thermoplastic resins and resulting behavior. Derivatives are made by polymerizing esters of Acrylic or methacrylic acid. Acrylic that can be polymerized to form materials which become hard crystal-like with properties can be tailored use as a variety of applications and requirement.

When acrylic monomers are polymerized by a mechanism which occurs in one of three basic polymerization processes: bulk, which can be carried out by single phase dilute solution, or multi phase dilute solution.

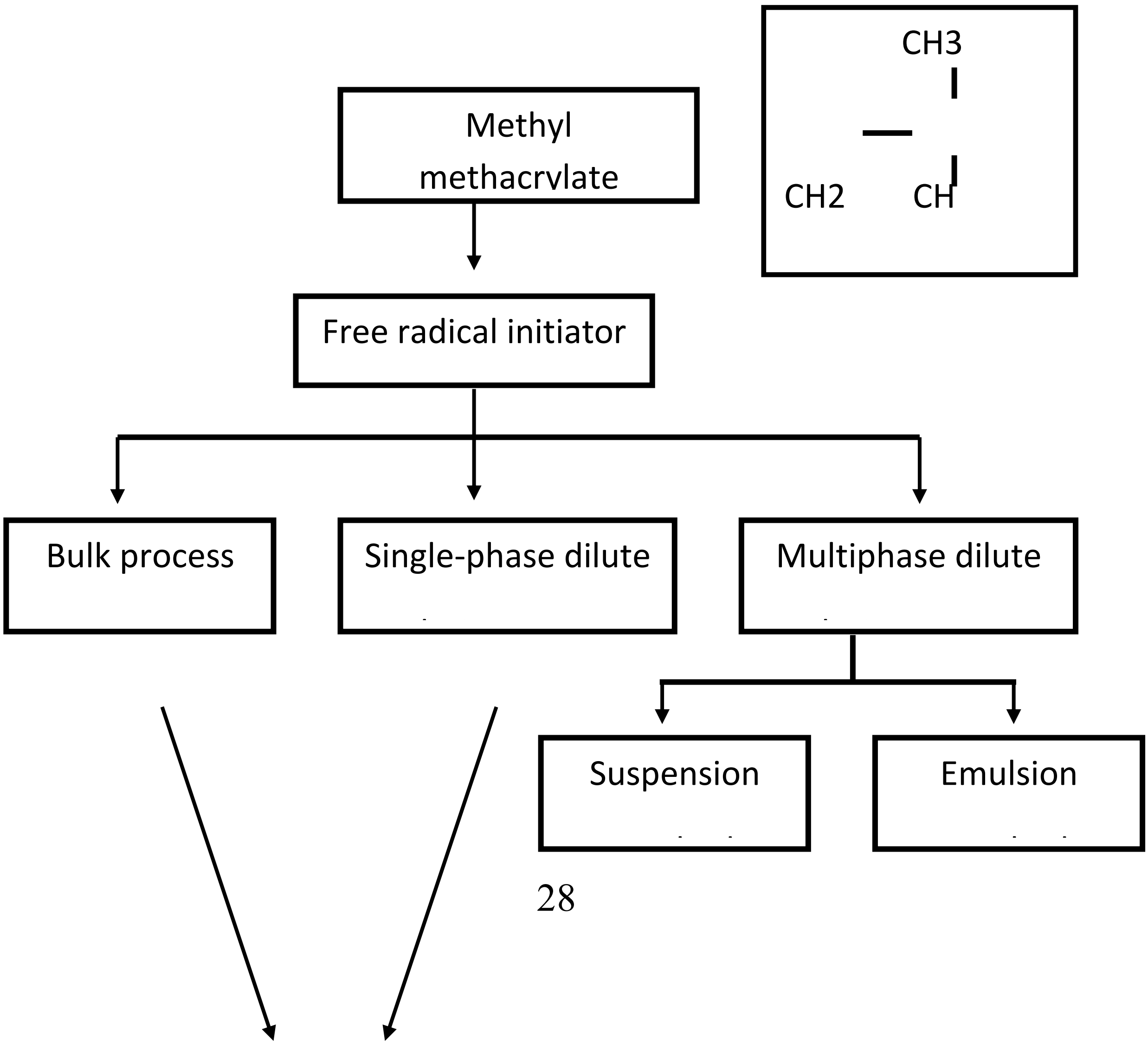
Single phase polymerization uses a non-polymerizable solvent in conjunction with the monomer to reduce the viscosity and control the rate of heat production. The process is carried out in chemical reactor or kettle and directly produces material such as coating adhesives and cement, i.e, acrylic polymer solution.

Multiphase solution polymerization is performed using a monomer insoluble phase, such as water as a carrier, and is divided into suspension and emulsion methods.

In the emulsion method, the polymer remains dispersed in the water mixture, and in the suspension method polymeric beads are formed and extracted from the water mixture.

The advantage of this process lies in the economy and safety derived from the use of water as the polymerization medium and the completeness of the polymerization reaction[33].

- **Polymerization of Acrylic**[32]



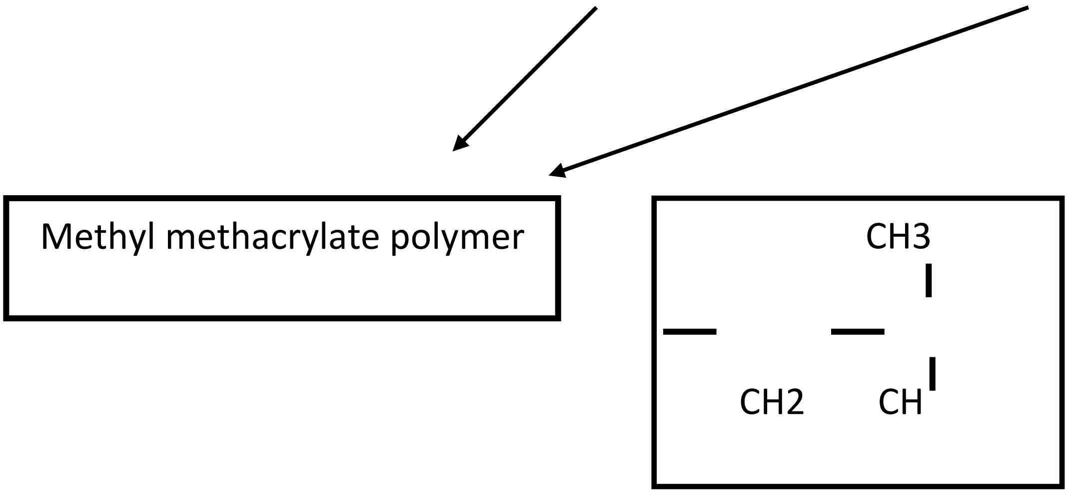


Figure (2.2) Illustrates the Polymerization of Acrylic

Low Molecular weight polymers are used as the Pellets for extrusion and compression molding.

While high molecular weight polymers usually have improved resistance to weathering and improved physical properties.

In this case of cross-linking in polymethyl, methacrylate, the resulting polymer has improved thermal resistance; excellent solvents resistance and improved physical properties.

Haddad and Paul[34] studied the strength of methyl methacrylate polymer concrete and concluded that casting temperature, testing temperature, aggregate type, and gradation had varying effects on the strength. They also clearly demonstrated the ductile and brittle natural, there was a great percentage of reduction in polymer compressive strength and modulus of elasticity with an increase in temperature than in PC.

Han, wu; Brooman; Eric W. in (1993) studied the effect of methyl methacrylate. On the concrete with by ultrasound, the result researched to enhancement of properties of concrete.

2.3 Steel-Fiber Reinforced Concrete (CFRC)

Steel fibers have been used in concrete since the early (1900). The uses were round and smooth and the wire is cut or chopped to the required length. The use of straight, smooth fibers has largely disappeared and modern fibers have either rough surface hooked ends or crimped. Steel fibers have been used in concrete to improve the tensile or flexural strength, impact strength, control cracking, the mode of failure by means of post-cracking ductility and to change the rheology or flow characteristic of the material in the fresh state(35).

The behaviour of fiber reinforced concrete and its use depends on the following factors(36):

1. Aspect ratio = (fiber length/equivalent diameter fiber), where the equivalent diameter is the diameter of the circle having the same cross-steel in area as the fiber.

2. Minimum effective length; Lm = minimum length is the length which is fibers have any effect on the first-crack strength of the concrete matrix.

3. Critical length; LC = is the length above which the fibers will fracture rather than pull out when the crack intersects the fiber at mid

point. It has been shown that they are approximated by: Lc = $\frac{d}{2I}$ f ……

(2-1)

Where:

d = fiber diameter

I = the interfacial bond stress

F = the fiber strength

Some terms:

1. Volume fraction: is the ratio of fiber volume to the total volume of fiber and matrix. It is usually expressed as a percentage of total volume of composite material.

2. Orientation factor: fiber efficiency factor = efficiency with which randomly oriented fibers can carry a tensile force in any one direction. This can be shown to be (0.412) where (2) is the fiber length.

3. spacing factor(s): if the fibers are closed enough together, the first cracking strength is higher than that of matrix alone because the fibers effectively reduce the stress intensity factor, which controls fracture.

S = 13.8d $\frac{\sqrt{l}}{p}$ where: d = fiber diameter; p = percent fiber by volume

L = fiber length

Khalid B. N.(2007)[37] studied the effect of steel fiber concrete on the dynamic properties of high performance steel fiber concrete by using non-destructive tests, ordinary Portland cement, natural sand of (4.75mm) maximum size washed coarse aggregate hooked end steel fibers with (30mm) length, (0.5mm) diameter and superplasticizer were used. The proportion concrete mixture (1 : 1.16 : 1.75) with w/c ratio of (0.43). The result were:

- The addition of steel fibers (0.5 and 1%) leads to increase the compressive strength, while the rate decreases at (1.5%) steel fibers.
- The optimum volume fraction of steel fiber was (1%).
- (8%) and (6%) superplasticizer was used to improve the compressive strength.
- The percentages of increasing in compressive strength with comparing to the reference concrete were (2.5%, 6.6%, 5.8%) with (0.5%, 1% and 1.5%) steel fiber by volume of concrete respectively .

2.3.1 Engineering Properties of Fiber Reinforced Concrete

Fiber reinforcement of cementitious materials has its roots in ancient history when straw was used for reinforcement. In recent decades, fundamental studies have led to the development of specially fibers that are compatible with the concrete matrix[1].

Bentur (1990) found that the low contents (0.1% volume) of low modulus polymeric fibers are used commercially for control of plastic shrinkage cracking; while higher contents of steel fiber (0.5 to 1.5% by volume) are used for reinforcement of hardened concrete to replace conventional steel mish in applications such as slabs on grade and shotcrete.

Krishnamoor thyetal[38] used four types of steel fibers. The materials were ordinary Portland cement, river sand passing through (2.36mm) sieve, aggregate passing through (10mm) sieve and crimped, rough-shaped and straight fibers with aspect ratio with 75. (mix 1: 1.63: 3, $\frac{w}{c}$ = 0.45).

The flexure toughness test was carried out in accordance with ASTM-C-1018. The results indicated that the first crack load and the ultimate flexure strength were found to increase with the increase in fiber volume fraction.

Al-Jugaifi[39] (2002) studies the properties of high performance concrete containing steel-fiber. The result exhibited that the addition of steel fiber to concrete up to (1%) by volume with (6%) and (8%) by weight of cement super plastesizer and Rice Husks Ash respectively; increase the compressive strength (11.5%) significantly. The splitting tensile (59.66%) flexural strength here increases with the increase of steel fiber content.

Mahmoud. Kh. M.[40] (2007) studied the effect of adding steel fiber on plain structural light weight concrete (SLWC) produced by using crashed bricks as a coarse light weight aggregate.

Mix proportional was (1: 1.12: 3.53) by volume . The (W: C) was equal to (0.5) and cement content was (550) kg/m^3. Steel fiber was (straight, 30mm length, 0.5 mm diameter) with two percentages (0.5% and 1%) by volume.

The results were:

- The effect of steel fiber was more pronounced on the tensile strength of (SLWC) than the compressive strength of such concrete.
- The maximum increase of compressive, splitting tensile and flexural strength at (28) days were (38.8%, 77.12% and 111.2%) in the (SLWC) containing (1%) steel fiber.
- The rate of strength gain between (3 and 28) days was constant on compressive strength of plain concrete and that containing steel fiber while this rate was clearly increased on tensile strength especially flexural strength.

2.4 Fiber-Reinforced Latex Modified Concrete

Fiber reinforced polymer modified cement and concrete is produced using steel, glass, polymer and carbon fiber to improve the workability, drying shrinkage and durability of fiber-reinforced cement and concretes, or increasing the flexural strength, thoroughness and impact resistance of latex modified mortar and concretes(15).

A very few researches have been carried out to investigate the properties of fiber reinforced polymer modified concrete.

Ohama et. al.(41) studied the flexural behavior of steel fiber reinforced polymer modified concrete (SFRPC) which is made by adding polymer dispersion to conventional steel fiber reinforced concrete.

(SFRPC) specimens of (SBR) latex were prepared and tested for flexural strength of (SFRC) with the steel fiber content of (2%) by volume and the polymer cement ratio of (20%) to attain about (2.5) times that of ordinary cement concrete, and other properties in flexural of (SFRPC) which are also extremely improved with the increase steel fiber content and polymer-cement ratio.

Ohama et. al.[42] studied the drying shrinkage reduction effect on concrete brought by steel fiber reinforced cement and polymer modification. Polymer was (SBR). The result was that the drying shrinkage of (SFRC) tends to decrease significantly by increasing steel fiber content and polymer cement ratio, and the drying shrinkage reduction effect is remarkable at the steel fiber content of (19) by volume and the polymer cement ratio (5%) or more. The drying shrinkage of (SFRC) with the steel fiber content of (2%) by volume and the polymer cement ratio (20%) reduced to about one-half of that of un-reinforced unmodified concrete. The drying shrinkage is strongly affected by steel fiber content, polymer-cement ratio and water ratio.

Fukuchi et. al.[43] studied the properties of steel fiber reinforced polymer modified concrete using polymeric ester (PAE) emulsion and steel fiber (size 0.5 * 30mm). He found that the consistency of (SFRC) is reduced with the increase in the steel fiber content and is improved with rising the polymer-cement ratio. The direct tensile, flexural, impact strength and toughness of (SFRPC) are elevated by increasing both the steel fiber content and the polymer-cement ratio.

Ohama et. al.[44] studied the properties of steel fiber and polyethylene fiber hybrid reinforced polymer (SBR) modified concrete (S-PE/FHRPC). The results were the flexural toughness and maximum tensile strain of (S-PE / FHRRC) which tended to remarkable improvement with an increase in polyethylene fiber content, direct tensile strength and compressive strength of (S-PE / FHRPC) which were affected by polymer latex modified rather than polyethylene fiber reinforcement, and generally increased with rising polymer-cement ratio.

Soroushian et. al.(45) studied the effect of polymer (S.B. latex) on performance characteristics of carbon fiber mortars in corporating silica fume. Flexural toughness increased through latex modified and reduced in water absorption and drying shrinkage.

Ohama et. al.(46) studied the physical of steel fiber (0.25 * 25mm) reinforced polymer (SBR) modified mortars and ethylene vinyl acetate (EVA) emulsion. It was concluded from the test result that the flexural and compressive strength of (SFRPM) increased with the increase in steel fiber content and polymer-cement ratio .

AL-Gassani Q.(47) studied the mechanical properties and impact of steel fiber reinforced concrete modified polymer. He used ordinary Portland cement of Kubaisa factory; natural sand, gravel with maximum size (12.5mm), mix operation (1: 1.3: 2.5), crimp steel fiber with aspect ratio (100) with ration (1%) by volume and polymer (S.B.R) with ratios (4%, 8%, 12%) by weight.

The Results were:

- An increase in (28) days compressive strength from (15%) to (30%) over control specimens for polymer modified concrete while the increase by using (1%) by volume steel fibers, was (18%) to (38%).

- An increase in the (28) days splitting-tensile strength from (13%) to (40%) over control specimens for polymer modified concrete while the increase by using (1%) by volume steel fibers, was (52%) to (85%).

- Increase in the (28) days flexural strength from (14%) to (32%) over control specimens for polymer modified concrete while the increase by using (1%) by volume steel fibers, was (44%) to (61%).

- He found that there is an improvement in impact resistance.

2.5 The Effect of Temperature on the Concrete

Properties of concrete under temperature have been studied by many investigators. The effect of temperature on the concrete is the subject of considerable research in recent years.

Harada et al(48) shows that the strength of concrete generally decreases with the increase in temperature, although exceptions to this rule have been found below (100C̊). The effect of temperature on the residual compressive strength was (60%) at (450C̊).

Furmula et al(49) investigated the strength elasticity, and thermal properties of concrete subjected to elevated temperatures. The compressive strength at (400C̊) reached about (60%) from its initial value. The modulus of elasticity and thermal diffusivity decreased when temperature increased.

Malhotra(50) studied the effect of water-cement ratio, cement aggregate ratio, state of stress, an age, on the compressive strength of concrete exposed to fire. He concluded that both water-cement ratio and age of concrete had no significant effect on the compressive strength. The low cement-aggregate ratio [lean mixes] losses less strength due to heating than the high cement-aggregate ratio (richer mixes).

M. S. Abrames[51] investigated the compressive strength of concrete at temperature up to (871C̊) with variables included aggregate type (carbonate, siliceous light weight), and he found that the sanded light weight concrete had similar strength properties at high temperature to those of carbonate concrete and at temperature above (427C̊) the siliceous aggregate concrete had lower strength than carbonate and lightweight aggregate concretes. He also noted that the original concrete strength between (27.6 Mpa) and (44.8 Mpa) has little effect on the percentage of strength retained at test temperature.

Further research is being carried out to determine the optimum fiber content for different types of concrete.

Castillo and Durani[52] (1990) studied the effect of elevated temperatures on concrete strength Portland cement with natural river sand and crushed limestone which were used for preparing the concrete specimens in the form of 51mm×102mm cylinders. The result showed that at temperatures in the range of (100C̊) to (300C̊), no loss of compressive strength. At temperature above (400C̊), concrete lost its compressive strength which dropped to about 30 percent of the room temperature strength at (800 C̊).

Abrams[53] (1971) conducted a study of three variables including aggregate types (carbonate dolomite sand and gravel, siliceous, and expanded shale lightweight aggregates), concrete strengths (ranging from (22.8 MPa) to (44.8 MPa). The specimens were 75mm×150mm cylinders.

The following conclusions were reported: Up to about (480C°), all three concretes exhibited similar strength loss characteristics. Above (480C°), the siliceous aggregate concrete had greater strength loss. Specimens made of carbonate aggregates and lightweight aggregates behaved about the same over the entire temperature range and retained (42%) more than (75%) of their original strength at temperatures up to (649C°). For the siliceous aggregate, the strength was (75) percent of the original strength at (430C°).

Furumura et al.[(54)] (1995) used 50mm×100mm concrete cylinders using three compressive strength levels: (21 MPa) (normal strength concrete FR-21), (42 MPa) (intermediate strength concrete FR-42), and (60 MPa) (high strength concrete (FR-60). The heating rate was (1C°/min) and target temperatures were from (100C°) to (700C°) with an increment of (100C°). The time at target temperatures to allow a steady state was two hours. The concrete was made from ordinary Portland cement. They observed that the compressive strength decreased at (100C°), recovered to room temperature strength at (200C°) and then decreased monotonically with increasing temperature beyond (200C°). The modulus of elasticity, in general, decreased gradually with increase of temperature.

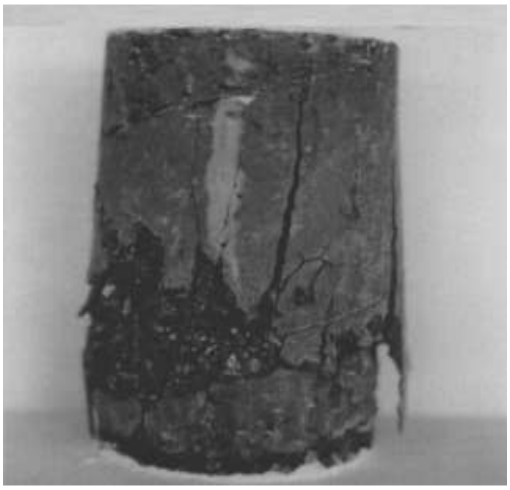
Noumowe et al[(55)] (1996) conducted unstressed residual strength tests to compare the performance of HSC exposed to high temperatures with NSC. The specimens were (160mm×320mm) cylinders and (100mm*100mm *400mm) prisms. A normal strength (38.1 MPa) and high strength (61.1 MPa) were used. The prismatic specimens had enlarged ends and were used to measure tensile strength. Calcareous aggregates were used for both concretes. The specimens were heated at a rate of (461C°/min) to target temperatures of (150, 300, 450, 500, and 600C°), which was maintained for 1 hour.

Uniaxial compressive, splitting tensile, and direct tensile tests were performed to obtain residual compressive strength. Residual tensile strengths for NSC and HSC decreased similarly and almost linearly with increase of temperature. Tensile strengths of HSC at all temperatures were (15) percent higher than those of NSC. Also, the tensile strengths measured by splitting tension experiments were higher than those obtained in direct tension. Mass losses in both concretes were also similar up to (110C°). The highest rate of mass loss occurred in the temperature range of (110C°) to (350C°). The rate of weight loss stabilized at temperatures above (350C°).

Kodur's[(54)] test results show that the addition of polypropylene fibers minimizes spalling concrete under fire conditions. One of the well-accepted theories is that by melting at a relatively low temperature of (170C°), the polypropylene fibers create "channels" for the steam pressure in concrete to escape, thus preventing internal pressurization causing spalling. The study showed that the amount of polypropylene fibers needed to minimize spalling is about (0.1) percent to (0.25) percent (by volume). On the other hand, the fibers increase the tensile strength of concrete (below the melting point of the fibers), which also provides higher resistance to the pore pressure.

The presence of steel fibers increases the ultimate strain and concrete ductility according to the results of Lie and Kodur (1995 a).

Cheng et al. (2004) carried out compression experiments to study the influence of various aggregates and steel fibers at elevated temperature. The effect of steel fibers on spalling is illustrated in Fig (2.3) which shows concrete containing steel fiber after two hours of fire exposure(52).



Al-Hadithi, A. I.(56) studied the flexural; impact and thermal properties of polymer modified concrete. He used sulphat resisting Portland cement, natural sand and course aggregate with maximum size (12mm). The mix proportional was (1:1.5:4) and modified by polymer with various ratio (3, 5, 10). The result of testing compressive strength at (56) days age with (21C°, 200C°, 325C°, 475C°, 625C° and 925C°) temperature are given in table (2.1).

Compressive Strength for Concrete Mixes

Mix	RM		PM3			PM5			PM10		
Temp. C°	Comp. St.	% Decrease over 21C° comp. St.	Comp. St.	% Decrease over 21C° comp. St.	% Increase over Reference comp. St.	Comp St.	% Decrease over 21C° comp. St.	% Increase over Reference comp. St.	Comp. St.	% Decrease over 21C° comp. St.	% Increase over Reference comp. St.
21	25	0	30	0	20	34	0	36	29	0	16
200	16.8	32.8	22.8	24	35.71	26	23.53	54.76	21.33	26.44	26.98
325	17.36	30.56	12.56	58.13	-27.65	18.4	45.88	5.99	13.72	52.69	-20.97
475	16.8	32.8	17	43.33	1.19	18.13	46.68	7.92	8	72.41	-52.38
625	4.6	81.6	3.68	87.73	-20	4.4	87.06	-4.35	4.4	84.83	-4.35
925	2.96	88.16	3.68	87.73	24.32	1.68	95.06	-43.24	2.24	92.28	-24.32

The specimens of polymer modified concrete follow the reference mix with the increasing in temperature degree up to (425c). After that the specimens mix gained a compressive strength greater than the former.

The mix containing (p/c = 10%) suffered from high temperatures (325 – 925) more than the other mixes.

2.6 Concluding Remarks

From the literature review, the following remarks can be drawn:

1. There are different types of fibers that can be used in producing fiber reinforced concrete in different volumes ratios.

2. There is a wide range of types of concrete modified with polymers, because of the different types of polymers and the different ratios of (polymer/cement) used in concretes.

3. Using fibers in concrete or modified concrete with polymer will improve its engineering properties that will significantly increase the tensile strength, flexural strength and the crack development strength.

4. It is recognized that the impact mechanical properties of concrete under temperature will increase with the existing of fibers.

5. Although there are many researches and studies concerning the effect of temperature, the effect of temperature of steel fibers modified concrete had not been studied yet. Hence, this study is considered, locally, new, since we did not find in references any similar research.

6. The increase of temperature leads to decrease of the mechanical properties of concrete.

Chapter Three

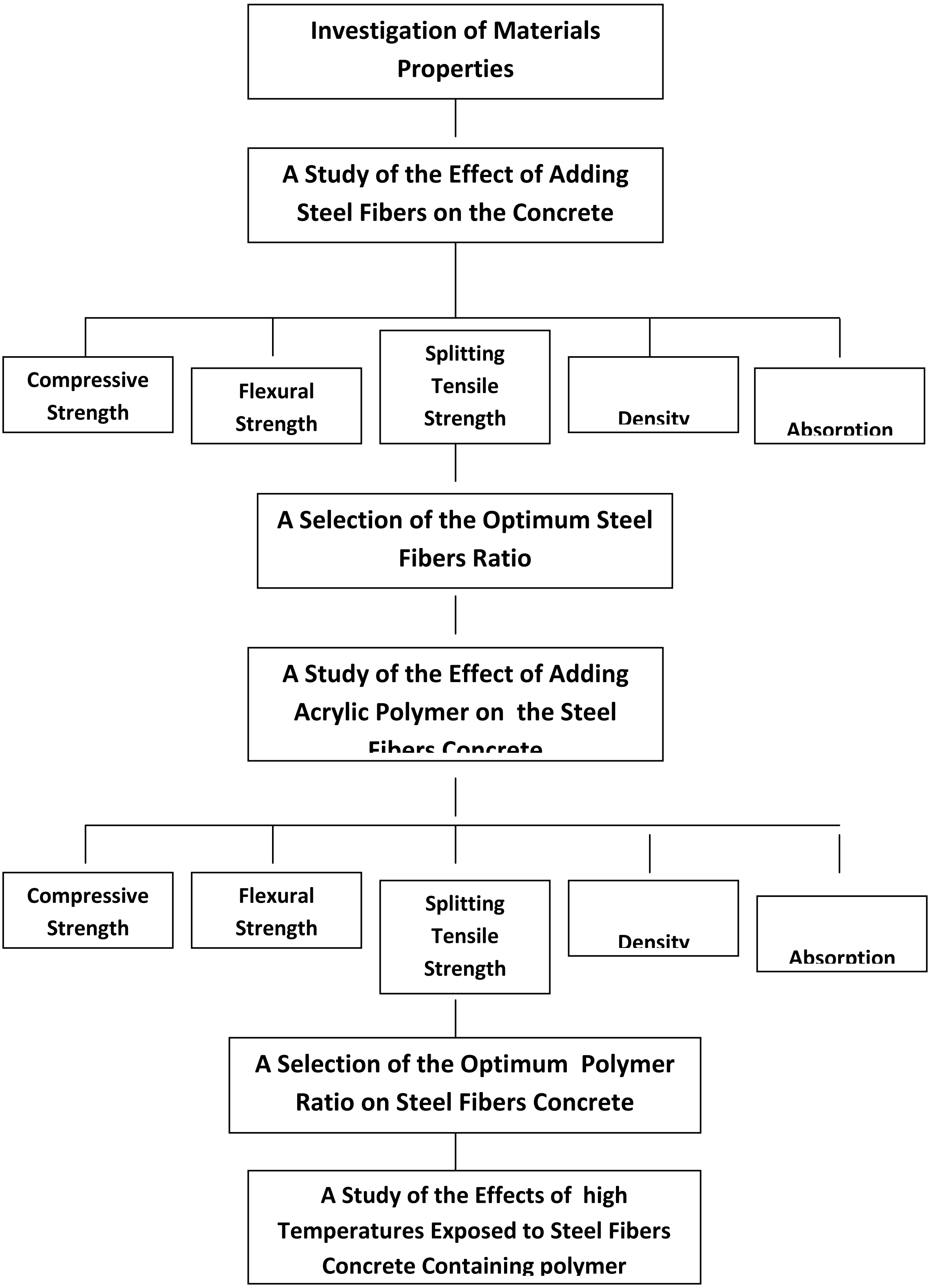
Experimental Works

The aim of this work is to study the mechanical and thermal properties of plain and steel fiber modified polymer concrete. This chapter includes the materials used and its properties, mix proportions, mixing procedure, casting and curing condition, in addition to the testing procedures adopted through out this investigation.

The tests were done in materials and construction laboratory - College of Engineering – AL-Anbar University.

3.1.1- Program Layout:

The experimental program layout is shown in the following figure:


Investigation of Materials Properties
A Study of the Effect of Adding Steel Fibers on the Concrete
Compressive Strength
Flexural Strength
Splitting Tensile Strength
Density
Absorption
A Selection of the Optimum Steel Fibers Ratio
A Study of the Effect of Adding Acrylic Polymer on the Steel Fibers Concrete
Compressive Strength
Flexural Strength
Splitting Tensile Strength
Density
Absorption
A Selection of the Optimum Polymer Ratio on Steel Fibers Concrete
A Study of the Effects of high Temperatures Exposed to Steel Fibers Concrete Containing polymer

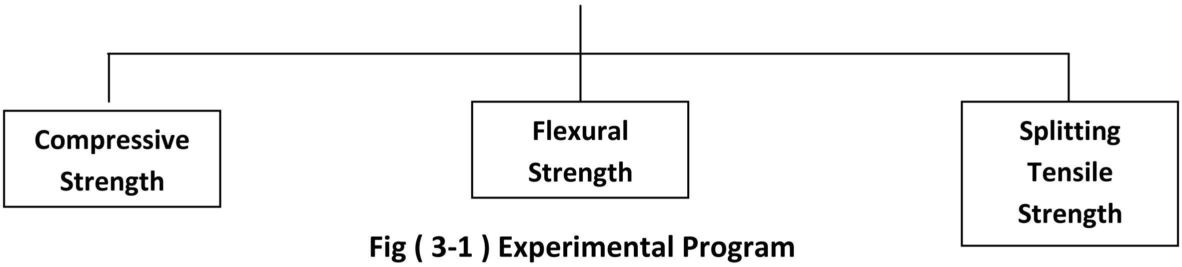


Fig (3-1) Experimental Program

3.2 Materials:

3.2.1 Cement

Cement type I (Trabit AL-Sabi'a cement) is used in this work. It is stored in airtight plastic containers to avoid exposure to different atmospheric conditions. The chemical analysis and physical tests results from the used cement are given in tables (3-1) and (3-2), respectively. They conform to the Iraqi specification No. 5/1984.

Table (3-1) Chemical Analysis of Cement

Compound Composition	Abbreviation	Percentage by Weight	Limits of Iraqi Spec. No 5/1984
Lime	CaO	60.6	-
Silica	SiO_2	22.6	-
Alumina	Al_2O_3	6.1	-
Iron oxide	Fe_2O_3	3.3	-
Sulfate	SO_3	2.7	$\leq$ 2.8%
Magnesia	MgO	3.3	$\leq$ 5.0%
Loss on Ignition	L.O.I	1.88	$\leq$ 4.0%

Lime saturation factor	L.S.F	0.87	0.66-1.02
Insoluble residue	I.R	1.47	≤ 1.5
Main compounds (Bogue's equation) percentage by weight of cement			
Tricalcium silicate (C_3S)		18.57	
Diacalcium silicate (C_2S)		50.79	
Tricacium aluminates (C_3A)		10.58	
Tetracalcium alumona ferrite (C_4AF)		10.63	

Table (3-2) Physical Properties of Cement

Physical properties	**Test Result**	**Limits of Iraqi Spec. No. 5/1984**
Specific surface area Blain method, m^2/kg	379	≥ 230 m^2/kg
Setting time, Vicat's method: Initial setting hrs: min. Final setting hrs: min.	 1.53 8	 ≥ 1 hour ≤ 10 hours
Soundness	0.2%	≤ 0.8%
Compressive strength of mortar, N,mm^2 3- day 7- day	 15.4 23.5	 ≥ 15 N,mm^2 ≥ 23 N,mm^2

3.2.2 Fine Aggregate

Al-Kirbeet region natural sand of (4.75mm) maximum size is used for concrete mixes of this investigation. The grading of fine aggregate is shown in table (3-3). Results indicate that the aggregate and the sulfate content are within the requirement of the Iraqi specification No. 45/1984 [57]. Table (3-4) shows the specific gravity, sulfate content and absorption of fine aggregate.

Table (3-3-) Grading of Fine Aggregate

Sieve Size (mm)	Cumulative Passing (%)	Limits of Iraqi Specification No. 45/1984 for Zone (3)
4.75	100	90-100
2.36	90.4	85-100
1.18	85.6	75-100
0.6	68.8	60-79
0.3	22.4	12-40
0.15	8.15	0-10

Table(3-4) Physical Properties of Fine Aggregate

Physical Properties	Test Result	Limits of Iraqi Specification No. 45/1984
Specific gravity	2.66	-
Sulfate content	0.09%	≤ 0.5%

3.2.3 Coarse Aggregate

The washed coarse aggregates of (12.5mm) maximum size were brought from Al-Nibae'e region. The sieve analysis of this aggregate is given in table (3-5). It conforms to the Iraqi specification No. 45-1984.

Table(3-5) Grading of Coarse Aggregate

Sieve Size (mm)	Accumulate Percentage Passing (%)	Limits of Iraqi Specification No. 45/1984
12.5	100	100
9.5	99	85-100
4.75	20.3	10-30
2.36	4.1	0-10
1.18	0	0-5

3.2.4 Water

Al-Ramadi ordinary drinking water was used in all mixes.

3.2.5 Polymer

Acrylic was used in this work. Its properties are shown in table (3-6). The polymer acrylic was used as a ration by weight of cement of 3%, 7% and 10%.

Table (3-6) Chemical Composition of Acrylic (terra bond)

Specific gravity	1.25 m.005
Service tem	- 30C + 125C
Softening point	> 180C

Drying time	2-3 hours
Shore 'A' hardness	70
Elongation at break	> 550%
Recovery @ 10% elongation	93%
Bond strength to concrete	2.5 N/mm^2
Tear resistance	16 kN/m
Tensile strength	89 N (9.1 kgf)
Water penetration	Nil tested @ 5 bar Pressure (DIN 1048)
Chloride ion diffusion	350 Coulombs
Carbon dioxide diffusion	Nil
Reduction in chloride ion ingress	25%

3.2.6 Steel Fibers

Steel fibers of straight deform type were used with volume fraction of **(0.5%; 1%; 1.5%).**

Table (3-7) The properties of the used steel fibers

Physical Properties	**Test Result**	**Limits of Iraqi Specification No. 45/1984**
Straight Deformed	Density	7860kg/m^3
	Ultimate strength	1500 MPa
	Modulus of elasticity	210^5 MPa
	Passions ratio	0.28

	Length	30mm
	Diameter	0.3mm
	Aspect ratio	100

3.3 Mix Proportions

Table (3-8) shows the mix proportions of materials used in this work.

Table (3-8) Mix proportions of Materials

Symbol	Proportion Cement: Sand: Gravel	Polymer-Cement Ratio %	Steel Fiber Content (Vol.%)	W/C Ratio
R	1: 1.86: 2.5	0	0	0.48
F1	=	0	0.5	0.48
F2	=	0	1	0.48
F3	=	0	1.5	0.48
M1	=	3	1	0.45
M2	=	7	1	0.41
M3	=	10	1	0.38

3.4 Concrete Mixing Procedure

A mechanical mixer of ($0.1m^3$) capacity was used. The interior surface of the mixer was cleaned and moistened before placing the materials. Aggregations were added before adding the cement.

After adding the cement, the materials were well mixed for about (1.5) minutes to attain uniform mix. The required tap water with polymer was then added. Mix and mixing should be continued until all particles are fully coated with (polymer-cement paste) matrix, moreover, the total mix should have a uniform or a homogenous color.

3.5 Casting, Compaction and Curing

The models were lightly coated with mineral oil before use, concrete casting was carried out in three layers. Each layer was compacted by using a vibrating table for (15-30) seconds until no air bubbled emerged from the surface of concrete, and concrete is leveled off smoothly to the top of the laboratory for (24) hrs, after that the specimens remolded carefully and marked. Specimens immersed in water until the age of test. Folic and Randonjanin [58] method `was used for curing the polymer modified concrete specimens by curing for (7, 14, 28) days in water until test. The ages of test were (14, 28 and 90) days for control, properties and thermal tests. Plate (3-1) shows samples of concrete specimens used in this work.

Plate (3-1) Concrete Specimens

3.6 Testing of Hardened Concrete

3.6.1 Compressive Strength Test

For compressive strength tests (100, 100, 100mm), concrete cubes were tested according to B.S. 1881, part (16) [59]. A (1000KN) capacity, ELE digital testing, as shown in plate (3-2) , was used for the compressive test with a stress rate of (15 MPa) per minute. The average of compressive strength cubes was taken for each testing age (7, 14 and 28 days).

Plate (3-2) ELE Compressive testing machine

3.6.2 Splitting Tensile Strength Test

The splitting strength was conducted on cylinders of (100mm diameter and 200mm height). The average of three test specimens was taken.

The splitting tensile strength test was carried out according to ATSM C496-86 [(60)], using the compression testing machine (1000 KN) capacity ELE digital testing machine at stress rate of about (6 MPa) per minute. Two bearing strips of nominal (3mm) thick plywood, approximately (25mm) wide and length equal to specimen which was placed between the bearing blocks tile failure. The average of the three specimens was taken to calculate the splitting tensile strength. The splitting tensile strength was calculated as follows:

Ft = 2P / π dL ………………………………………….. (3-1)

Where:

Ft = splitting tensile strength (N/mm^2)

P = maximum applied load, (N)

L = length, (mm)

d = Diameter, (mm)

3.6.3 Flexural Strength Test

The flexural strength was conducted on prisms of (100, 100, 500mm). the test was carried out using two points load according to (ASTM C293-86)[61]

Flexural strength was determined using (50KN) capacity (ELE) machine, as shown in plate (3-3). The average modulus of rupture of three prisms was obtained for each testing age (7, 14, 28) days.

$$Fr = PL / bd^2 \quad \text{……………………………………………}(3\text{-}1)$$

Where:

Fr = modulus of rupture, (N/mm^2)

P = maximum applied load indicated by testing machine, (N)

L = distance between supports and equal to (450mm)

b = Average width of specimen, (mm)

d = Average depth of specimen, (mm)

Plate (3-3) ELE Flexural Testing machine

3.6.4 Density Test

Density was found by weighting the specimens and dividing the weight by the measured volume of the specimens.

3.6.5 Water Absorption Test

The specimens were dried at a temperature of (100C̊) for one day and their weights were taken. Then, they were kept in water at ambient temperature for (24 hr) and their weights were taken and the percentages of the water absorption were calculated by using the following equation.

Water Absorption (%) = $\frac{W1-W2}{W2}$ **……………………….(3-2)**

Where:

W1 = weight of specimens after dried by oven.

W2 = weight of saturated surface dry specimen.

3.7 Effect of Temperature on Concrete Tests:

Temperature degrees of test were (100C̊, 300C̊, 500C̊ and 700C̊).

For each temperature we used: (100, 100, 100mm) cubes for compressive strength, (100, 200mm) cylinders for splitting tensile strength and (100, 100, 500mm) prisms for flexural strength. The specimens were heated without load and tested hot with (28) days age.

Table (3-9) Mix proportions of Materials

Symbol	Proportional Gravel	Polymer/Cement Ratio %	Steel Fiber Content (%) by Volume	W/C Ratio
R	1: 1.86: 2.5	0	0	0.48
M2	=	7	1	0.41

Plate (3-4) The Oven used for heating specimens

Chapter Four

Analysis and Discussion of Results

4.1- Introduction

This chapter deals with the presentation and discussion of the results obtained from compressive; tensile and flexural strength. In addition, the study of effects of temperature and density are presented in this chapter.

4.2- Compressive Strength

The results of compressive strength for various types of concrete specimens at age (7, 14 and 28 days) are given in table (1.4). The relationship between compressive strength at different ages and various ratio of steel fiber and various (p/c) ratio is shown in figures (4.1) to (4.4), respectively. It can be noticed that the compressive strength increases with the increase of steel fibers, after (1%) there will be a decrease in compressive strength of reference mix. The reason of this is the fiber after which (1%) had formed bulks and segregate on mix. This led to form stiff bond about these bulks.

When polymer is added to mix, we see that the compressive strength increases with the increase of polymer but after (p/c = 7%) the compressive strength decreases but still higher than that the compressive strength of reference mix. This increase in compressive strength may be due to three facts.

The first is that (PMC) has less w/c ratios, which gives higher strength. The second is that the use of polymer leads to form continuous three dimensional networks of polymer molecules throughout concrete which increases the binder system due to good bond characteristic of polymer. The last is the partial filling of pores with polymer which reduces the porosity, and hence increases the strength[62] .

The payment compressive strength was obtained when the mixing containing (1%) steel fibers by volume and (7%) polymer.

4.3 Splitting Tensile Strength

`The results of splitting tensile strength for various types of concrete specimens at age (7, 14, 28 days) are given in table (4.2). The relationship between splitting tensile strength and various ratios of steel fiber and various (p/c) ratio polymer is shown in figures (4.5) to (4.8). We can see that the addition of steel fiber leads to increase of remarkable splitting tensile strength but it decreases after ($V_f = 1\%$) steel fiber but it is still higher than the splitting of reference. The increase is due to the fact that the presence of steel fibers arrests cracks progression. The tensile strength is increased with the increase of the polymer unit (p/c = 7%) after it. The tensile strength decreases but it is still higher than reference mix. This increase may be due to the reduction in w/c ratio. Also we can note that the plain concrete cylinders fail suddenly and split into two separate parts, while the mode of failure in cylinders with steel fibers with and without polymer is cracked at failure without separation.

The maximum splitting tensile strength is obtained at mixing containing (1%) steel fiber by volume and (p/c = 7%).

4.4 Flexural Strength

The result of flexural strength for various types of concrete specimens at age (7, 14, 28 days) is given in table (4-3).

The relationship between flexural strength and various ratios of steel fiber and various (p/c) ratio of polymer is shown in figures (4-8) to (4-10). We can note that the addition of steel fiber leads to remarkable increase in flexural strength until (1%), after that the flexural strength decreased. The increase is due to the same reasons mentioned for the compressive strength and splitting tensile strength. When adding polymer to concrete specimens with (1%) steel fiber, the flexural strength also increase until ratio (7%). After (7%), the flexural strength will decrease but it is still greater than reference mix. We note that the specimens containing steel fiber show higher degree of ductility before failure and steel fiber does not start to pull out from fractures surface until the maximum load is reached.

The maximum flexural strength is obtained when we mix contents (1%) steel fiber by volume and (7%) polymer.

4.5- Density

Table (4-4) shows the increase in density for different types of concrete mixes at age (28) days. It can be noted that the density increases with age. This increase is mainly due to the concrete hydration products and continuous polymer film formation.

Figure (4-11) shows the relationship between density and various rations of steel fiber and figure (4-12) shows the relationship between density and various ratios of polymer with (1%) steel fiber.

From figure (4-13), it can be concluded that the density increases with the increase of steel fibers because the high density of steel. From figure (4-14), we can see that the density increases with the increase of polymer, this increase is due to the reduction in (w/c) ratio and the increase in compaction and degrees voids.

4.5.1 Compressive Strength-Density Relationship

The relationship between density and compressive strength for concrete specimens (plain, containing steel fiber and steel fiber with polymer) is plotted in figures (4-13) and (4-18).

4.5.2- Tensile Strength-Density Relationship

The relationship between density and tensile strength for concrete specimens (plain, containing steel fiber and steel fiber with polymer) is plotted in figures (4-19) to (4-21).

4.5.3 Flexural Strength-Density Relationship

The relationship between density and flexural strength for concrete specimens (plain, containing steel fiber and steel fiber with polymer) is plotted in figures (4-22) to (4-24).

4.5.4 The Relationship between Compressive Strength and Splitting Tensile Strength

The relationship between compressive and tensile strength is plotted in figures (4-25) to (4-27) for concrete specimens (plain, containing steel fiber and steel fiber with polymer).

From figure (4-25), the equation of the best-fit curve for the result is:

Ft = 0.73 Fcu +1.85

R^2 = 0.874

Where

Ft = Tensile Strength (MPa)

Fcu = Compressive Strength (MPa)

R = Correlation coefficient

From figure (4-26), the equation of the best-fit curve for the result is:

Ft = 1.46 Fcu +3.4033

R^2 = 0.9269

Where

Ft = Tensile Strength (MPa)

Fcu = Compressive Strength (MPa)

R = Correlation coefficient

From figure (4-27), the equation of the best-fit curve for the result is:

Ft = 2.06 Fcu +3

R^2 = 0.9544

Where

Ft = Tensile Strength (MPa)

Fcu = Compressive Strength (MPa)

R = Correlation coefficient

4.5.5 Relationship Between Compressive and Flexural Strength

The relationship between compressive and flexural strength is plotted in figures (4-28) and (4-30) for concrete specimens (plain, containing steel fibers and steel fibers with polymer).

From figure (4-28), the equation of the best-fit curve for the result is:

Fr = 0.9 Fcu +3.83

R^2 = 0.9996

Where

Fr = Flexural Strength (MPa)

Fcu = Compressive Strength (MPa)

R = Correlation coefficient

From figure (4-29), the equation of the best-fit curve for the result is:

Fr = 1.43 Fcu +5.2367

R^2 = 0.9707

Where

Fr = Flexural Strength (MPa)

Fcu = Compressive Strength (MPa)

R = Correlation coefficient

From figure (4-30), the equation of the best-fit curve for the result is:

Fr = 2.315 Fcu +4.56

R^2 = 0.995

Where

Fr = Flexural Strength (MPa)

Fcu = Compressive Strength (MPa)

R = Correlation coefficient

4.6 Water Absorption

The results of water absorption tests for concrete specimens (plan, containing steel fibers and steel fibers with polymer) are represented in table (4-5) and plotted in figures (4-31) and (4-32). It can be noted that the increase in (p/c) ratio decreases the water absorption. This decrease may be due to the reduction in (w/c) ratio and the pores can be filled with polymers. Also we can see that the addition of steel fibers leads to decrease in water absorption. This may be attributed to the ability of steel fibers to arrest micro cracks, and the steel fibers can cut the pure and reduce the volume of these pores.

The best reduction in water absorption in case of adding steel fibers only was (24.47%) at (1.5%) by volume steel fiber.

The best reduction in water absorption in case of adding steel fiber and polymer was (33.5%) at (1%) by volume steel fibers and (p/c = 7%).

4.7 Effect of Temperature on Concrete

Human safety in the event of fire is one of the considerations in the design of residential, public and industrial buildings. Concrete has good service record in this respect. Unlike wood and plastics, concrete is incombustible and does not emit toxic fumes on exposure to high temperature, unlike steel when subjected to temperatures of the order of (700 C̊) to (800 C̊) [(63).]

The specimens were heated unstressed for each temperature degree and they stayed inside furnace for about (60) minutes and then tested hot. The results of compressive, tensile and flexural strength for two types mix, the first mix was the reference mix and the second was specimens containing (1%) by volume steel fiber with (p/c = 7%) polymer are given in tables (4-6) and (4-7). The relationship between compressive , tensile and flexural strength with different temperatures is plotted in figures (4-33) to (4-36).

The best results for compressive, tensile and flexural strength were obtained with (1%) steel fiber and (7%) polymer at each temperature.

The degrees in mechanical properties of steel fiber reinforced concrete modified polymer were less than mechanical properties in reference for all temperatures. For example, at (700C̊̊), compressive strength decreased about (80.12%) for reference concrete, while it decreased (71%) for steel fiber reinforced concrete modified polymer, flexural strength decreased about (91.4%) for reference concrete, while it decreased (85.5%) for steel fiber reinforced concrete modified polymer.

The superior performance of steel fiber reinforced concrete at higher temperature degree may be due to:

- continuous steel-dimensional network of polymer molecule throughout concrete which increases the binder system due to good characteristics of polymer.
- good bond surface between matrix and steel fiber because the performance of surface fiber.

Table (4-1) Compressive Strength of Reference and Various Types of Concrete Specimens Cured at Different Ages with its Percentage Increases over Deference Concrete.

Symbol	7 days		14 days		28 days	
	Compressive strength (MPa)	% increase	Compressive strength (MPa)	% increase	Compressive strength (MPa)	% increase
R	25.83	0	32	0	35.2	0
F1	30.61	18.5	36.1	12.8	40.2	14.2
F2	35	35.5	42.5	32.8	49.5	40.6
F3	28.41	9.9	35	9.3	39.6	12.5
M1	41.7	61.4	46	43.75	60	70.45
M2	42	62.6	50	56.25	65.7	86.64
M3	40	54.85	43.5	35.9	51	44.8

Table (4-2) Splitting Tensile Strength of Reference and Various Types of Concrete Specimens at Different Ages with its Percentage Increases over Deference Concrete.

symbol	7 days		14 days		28 days	
	Tensile strength (MPa)	**% increase**	**Tensile strength (MPa)**	**% increase**	**Tensile strength (MPa)**	**% increase**
R	2.74	0	2.99	0	4.2	0
F1	4.4	60.6	5.28	76.5	6.3	50
F2	5.1	86.13	5.85	95.6	8.02	91
F3	4.61	68.24	5.46	82.6	6.31	50.2
M1	5.35	95.25	6.72	124.75	9	114.3
M2	5.32	94.16	6.6	120.7	9.44	124.7
M3	5.19	89.4	5.86	96	8.5	102.4

Table (4-3) Flexural Strength of Reference and Various Types of Concrete Specimens Cured at Different Ages with its Percentage Increase over Deference Concrete.

Symbol	7 days		14 days		28 days	
	Flexural strength (MPa)	**% increase**	**Flexural strength (MPa)**	**% increase**	**Flexural strength (MPa)**	**% increase**
R	4.72	0	5.65	0	6.52	0
F1	5.92	25.4	6.41	13.45	8.1	24.2
F2	6.81	44.27	7.81	38.23	9.67	48.3
F3	6.53	38.34	7.1	25.66	8.82	35.3
M1	5.4	14.4	7.15	26.5	10.56	62
M2	6.97	47.7	9	59.3	11.6	78
M3	7.65	62	8.26	46.2	11.2	72

Table (4-4) Density Strength of Reference and Various Types of Concrete Specimens Cured at Different Ages.

symbol	Density (kg/m^3) 7 days	Density (kg/m^3) 14 days	Density (kg/m^3) 28 days
R	2410	2437	2455
F1	2445	2461	2480
F2	2469	2475	2488
F3	2475	2483	2493
M1	2466	2475	2505
M2	2465	2467	2515
M3	2467	2469	2519

Table (4-5) Water Absorption (%) of Reference and Various Types of Concrete Specimens at (28) Days.

symbol	Steel Fiber (%) volume	p/c Ratio	Water Absorption (%)
R	0	0	1.43
F1	0.5	0	1.28
F2	1	0	1.12
F3	1.5	0	1.08
M1	1	3	1.03
M2	1	7	1.02
M3	1	10	1.95

Table (4-6) Compressive, Tensile and Flexural Strength for Specimens of Reference Concrete at (28) Days.

Temperature C̊	Compressive Strength	Decrease (%)	Tensile Strength	Decrease (%)	Flexural Strength	Decrease (%)

Room Temperature	35.2	0	4.2	0	6.52	0
100	35	0.57	3.07	26.9	5.51	15.5
300	33.1	5.96	2.3	45.2	2.67	59
500	22.5	36	2.07	50.7	1.9	83.12
700	70	80.12	1.51	64	0.65	91.4

Table (4-7) Compressive, Tensile and Flexural Strength for Specimens with (p/c = 7%) and (1%) Steel Fibers.

Temperature C̊	**Compressive Strength**	**Decrease (%)**	**Tensile Strength**	**Decrease (%)**	**Flexural Strength**	**Decrease (%)**
Room Temperature	65.7	0	9.44	0	11.6	0
100	63.7	3	6.13	28.7	10.32	11
300	51	22.37	5.35	43.32	7.87	32.15
500	38.2	41.85	4.12	56.35	4.1	56
700	19	71	2.3	75.63	1.6	85.5

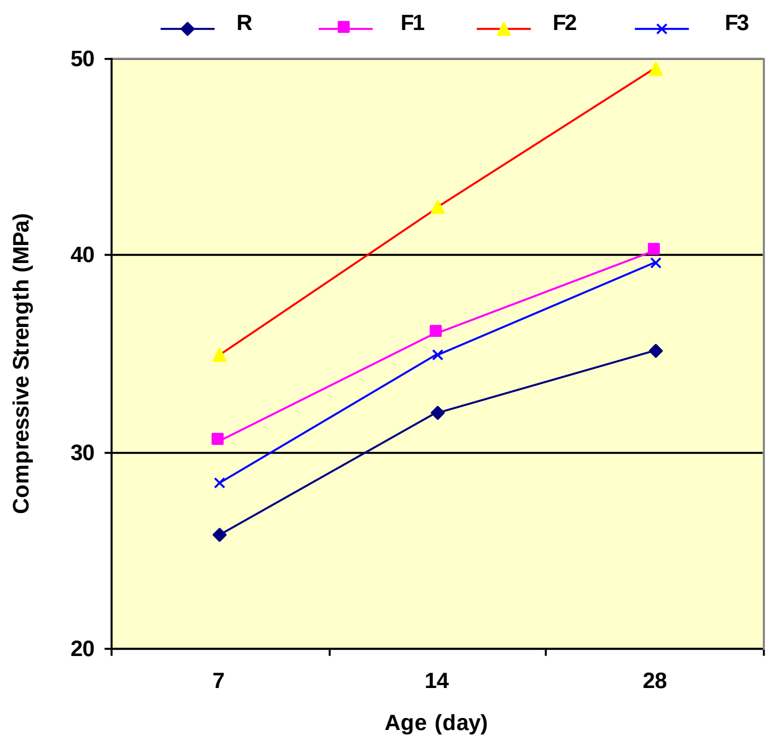


figure (4.1) The Development of Compressive Strength with age for various ratio steel fibers

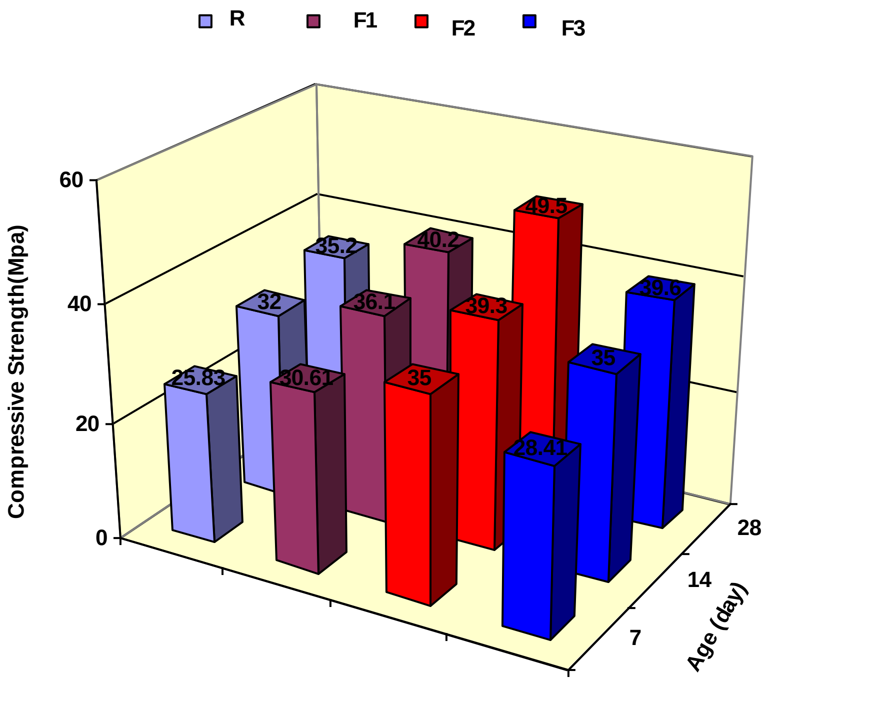


figure (4-2) The Development of Compressive Strength with age for various ratio steel fibers

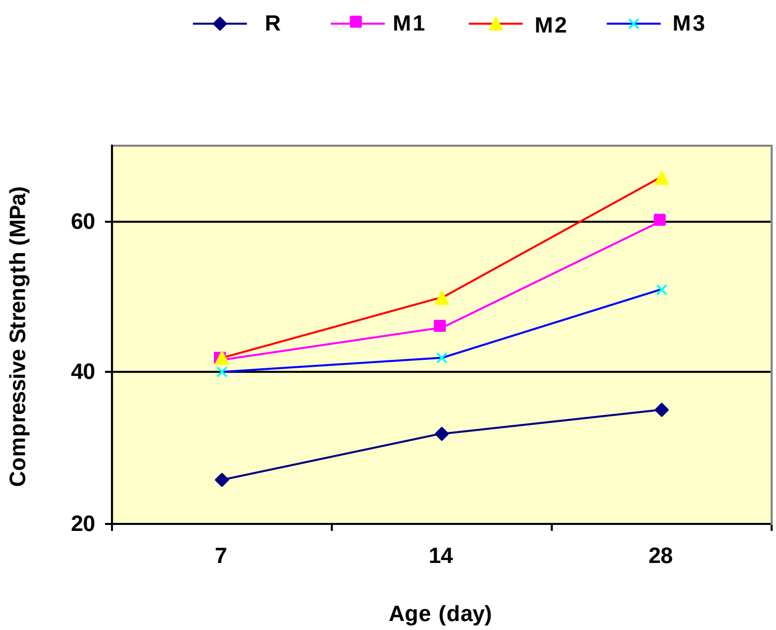


Figure (4-3) The Development of Compressive Strength with age for (1%) steel fibers containing various p/c ratios

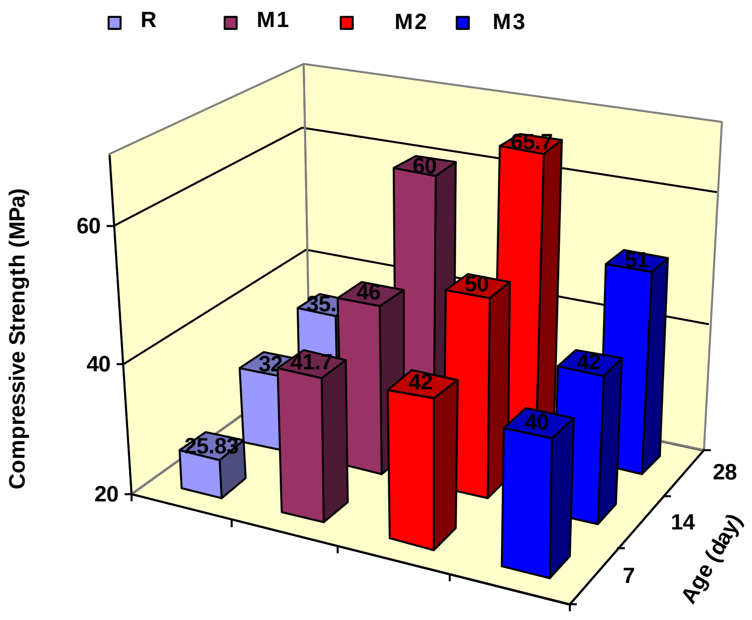


Figure (4-4) The Development of Compressive Strength with age for (1%) steel fiber containig various p/c ratio

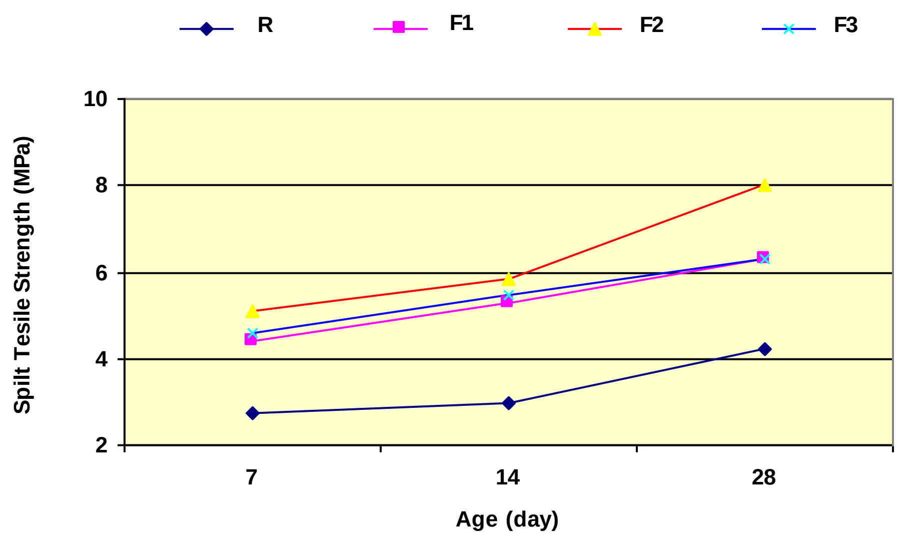


figure (4-5) The Development of Split Tensile Strength with age for various ratios of steel fibers

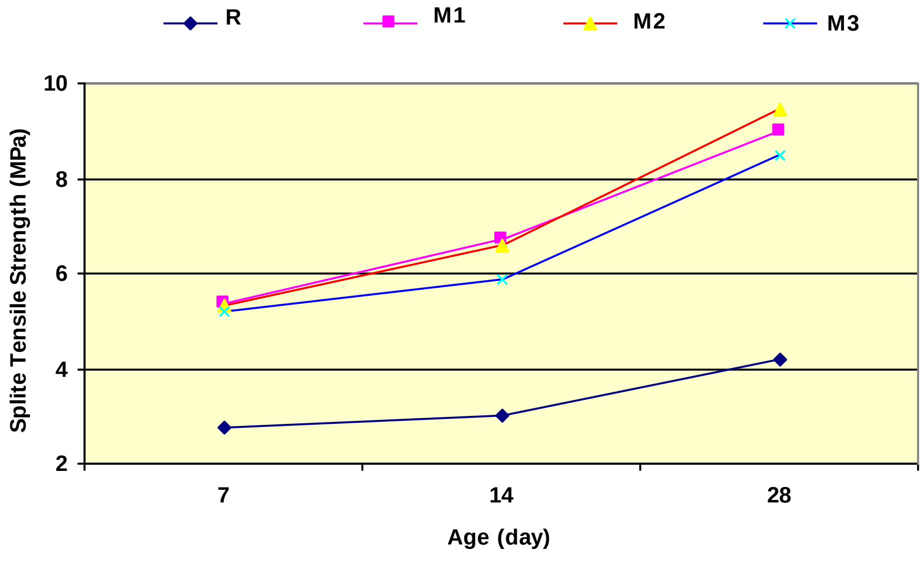


Figure (4-6) The Development of Split Tensile Strength with age for (1%) steel fibers containing various p/c ratio

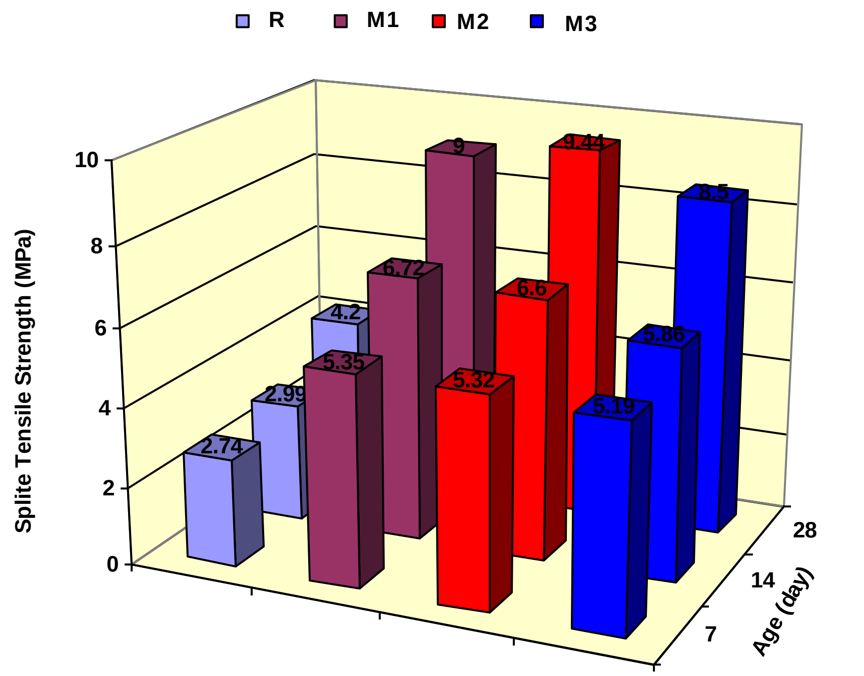
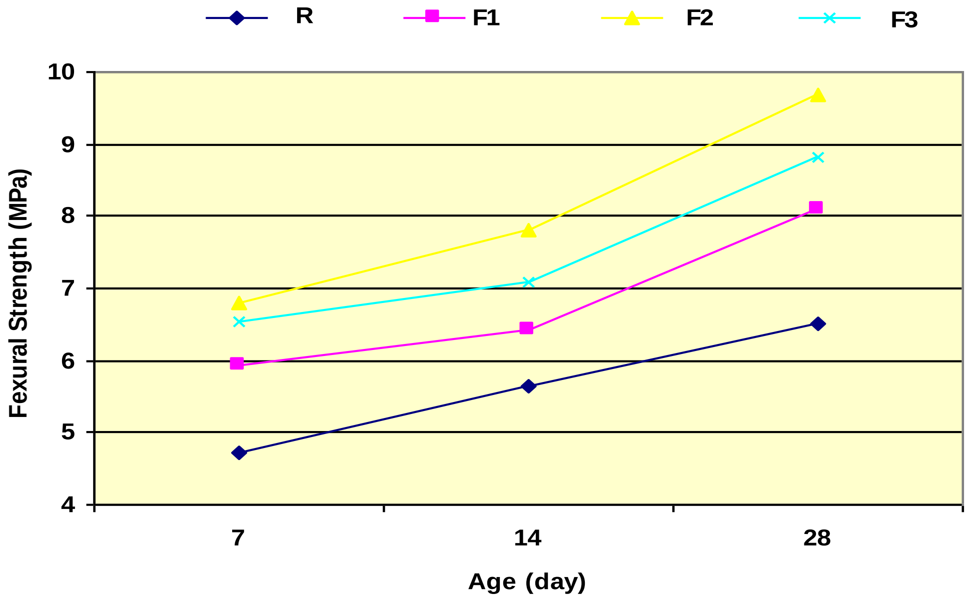
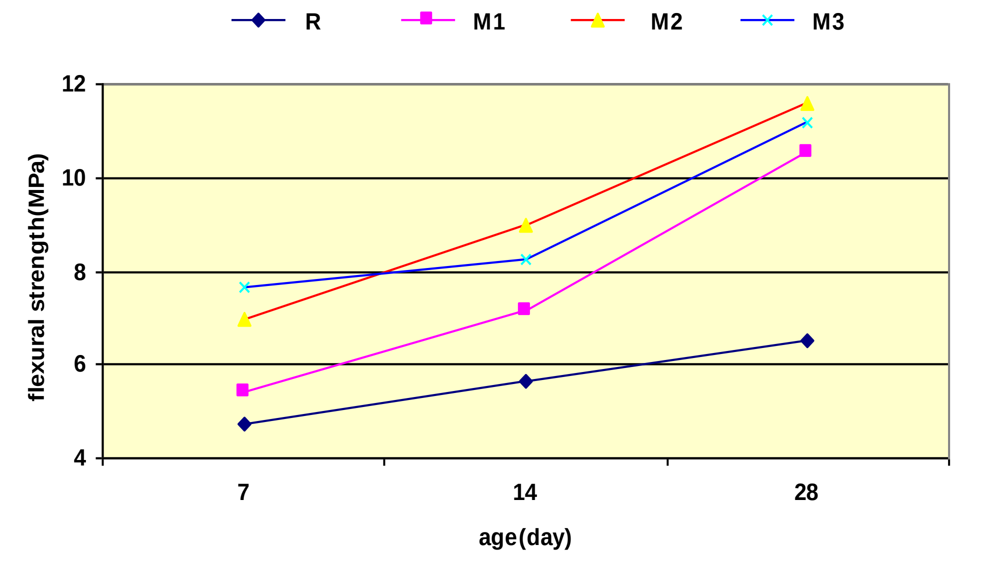


Figure (4-7) The Development of Split Tensile Strength with age for (1%) steel fibers containing various p/c ratio



figure(4.8) The Development of Flexural Strength with age for various ratio of Steel Fibers



figure(4.9) The Development of Flexural Strength with age for (1%) Steel Fibers containing various p/c ratios

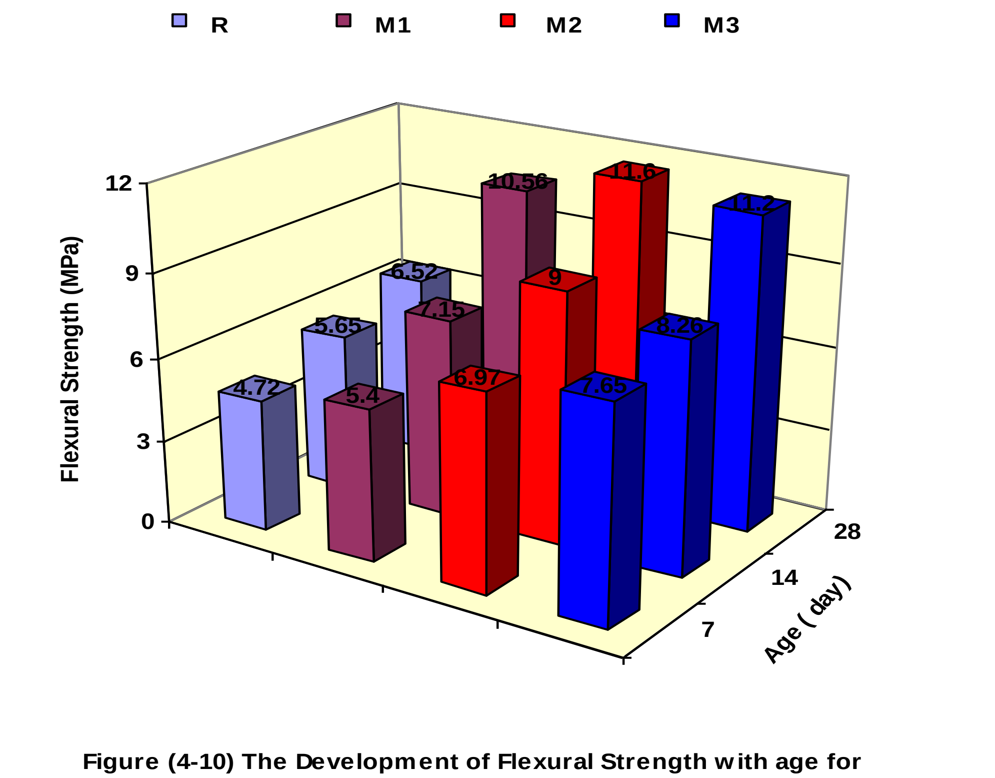


Figure (4-10) The Development of Flexural Strength with age for (1%) Steel Fibers containing various p/c ratio

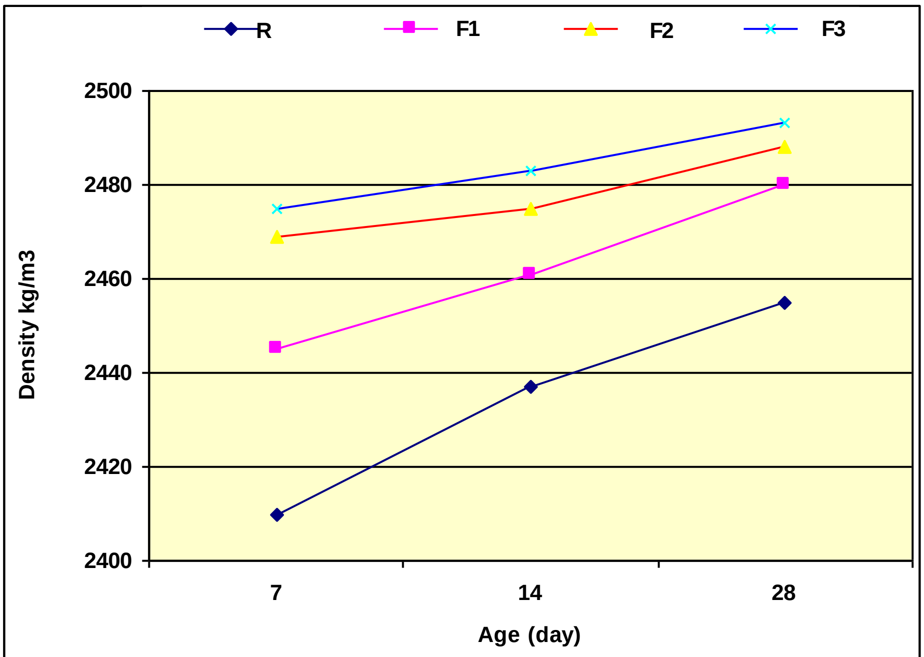


Figure (4.11) The Relationship between Density and Age for various ratio of Steel Fibers

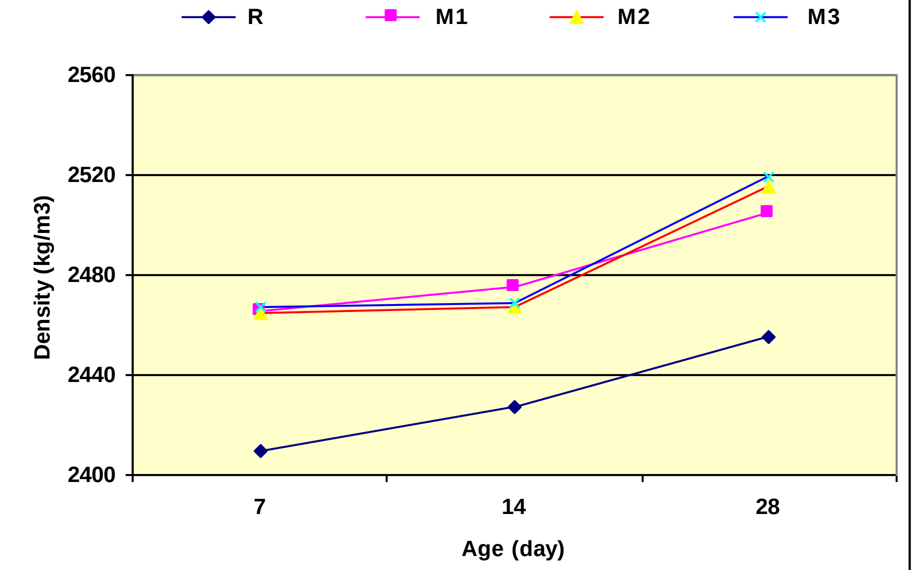
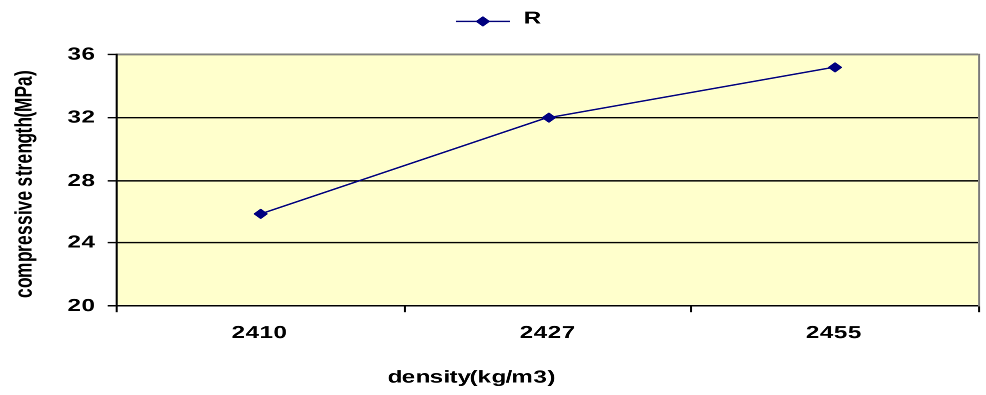
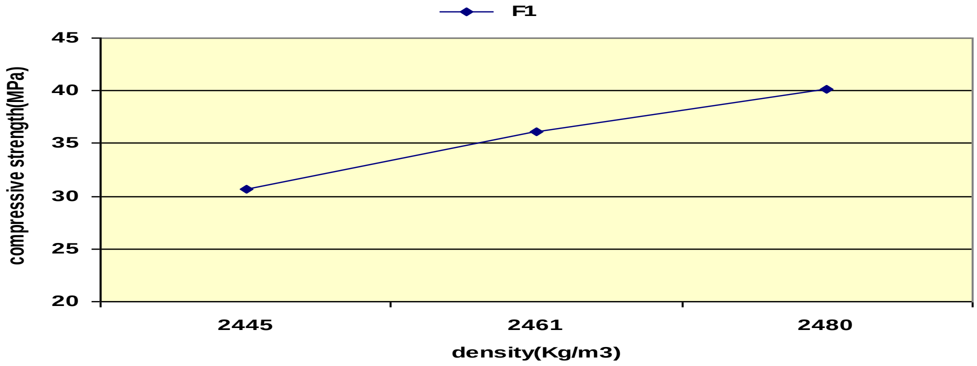


Figure (4-12) The Relationship between Density and Age for (1%) Steel Fibers with various p/c ratio



figure(4.13) The Relationship between Density and Compressive Strength for Reference Concrete



figure(4.14) The Relationship between Density and Compressive Strength for concrete with (0.5%) Steel Fibers

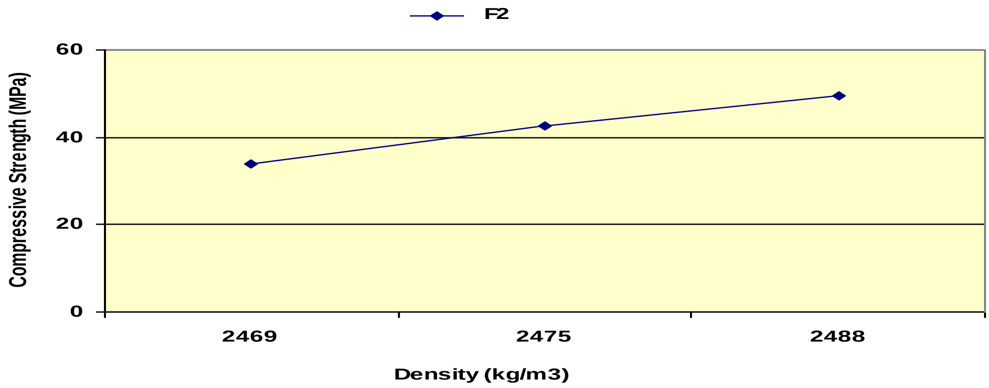


figure (4-15) The Relationship between Density and Compressive strength for (1%) Steel Fiber

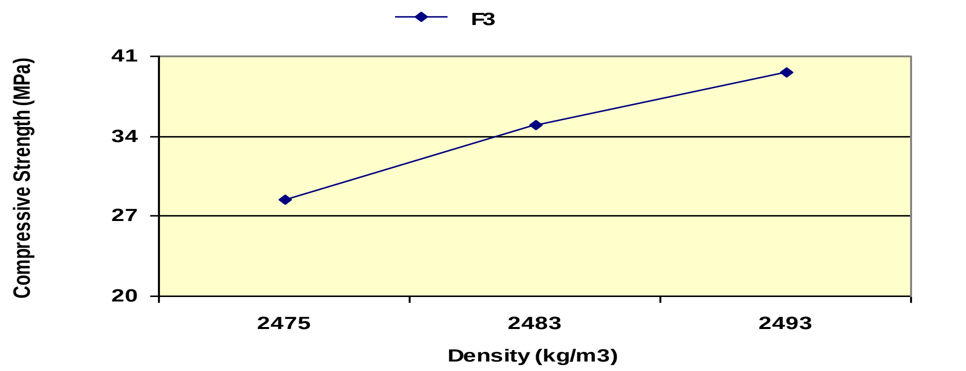


figure (4-16) The Relationship between Density and Compressive Strength for (1.5%) Steel Fiber

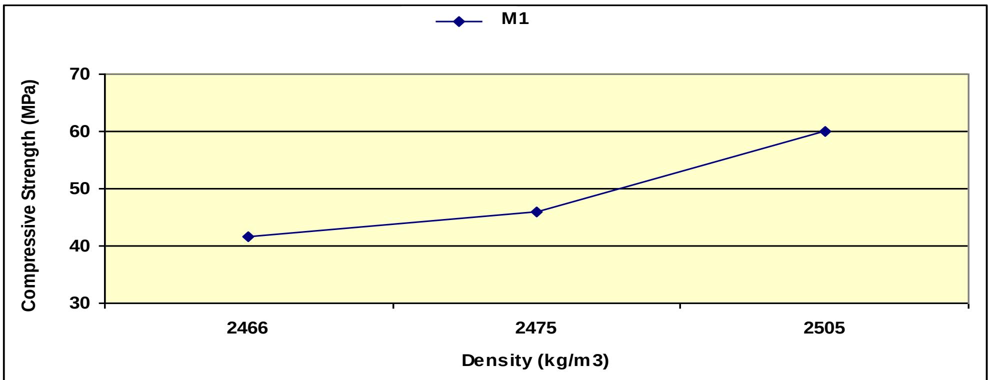


figure (4-17) The Relationship between Density and Compressive Strength for (1%) Steel Fiber with (3% p/c)

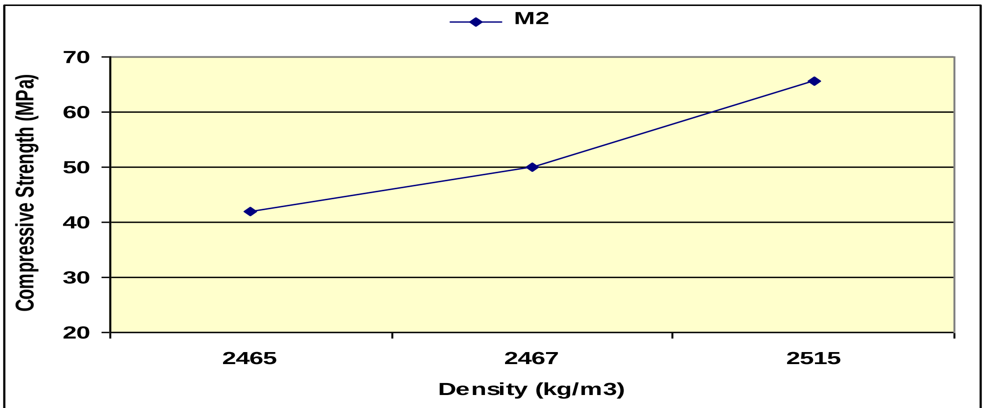


figure (4-18) The Relationship between Density and Compressive Strength for (1%) Steel Fiber with (7% p/c)

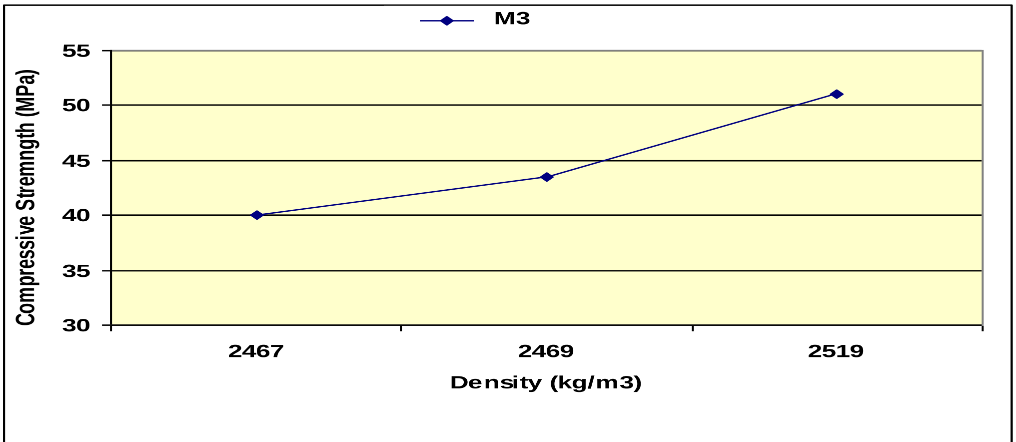
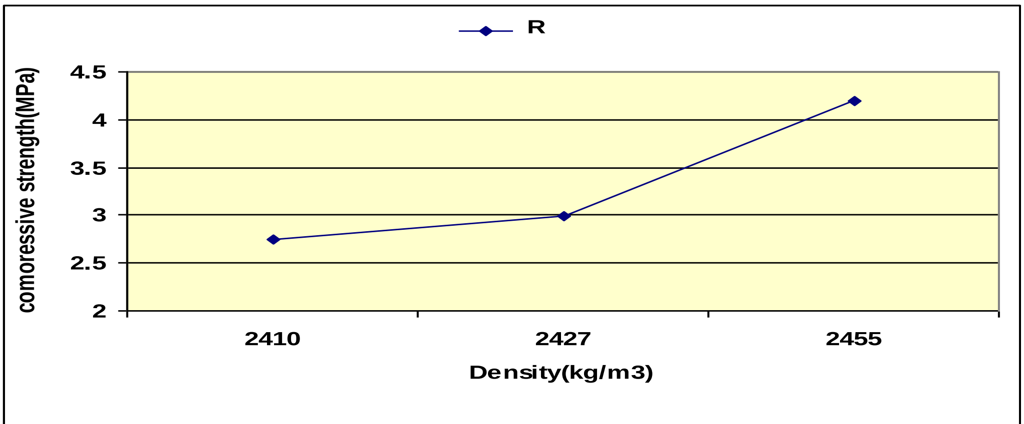


figure (4-19) The Relationship between Density and Compressive Strength for (1%) Steel Fiber with (10% p/c)



figure(4.20) The Relationship between Density and Tensile Strength for Reference Concrete

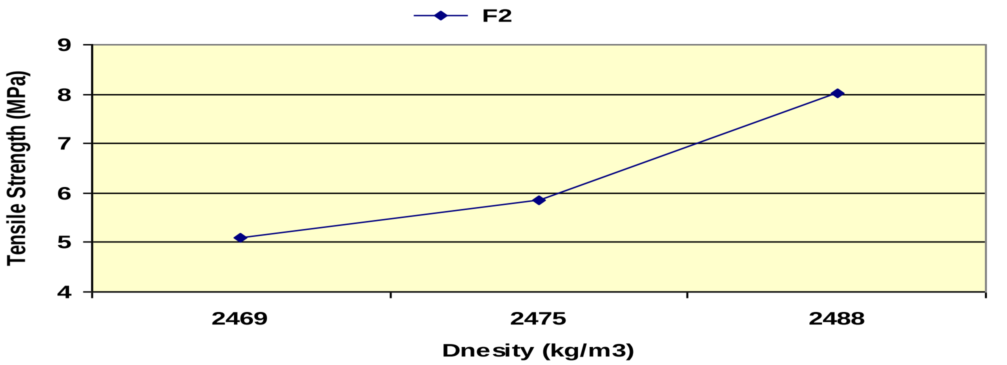


figure (4.21) The Relationship between Density and Tensile Strength for (1%) Steel Fiber

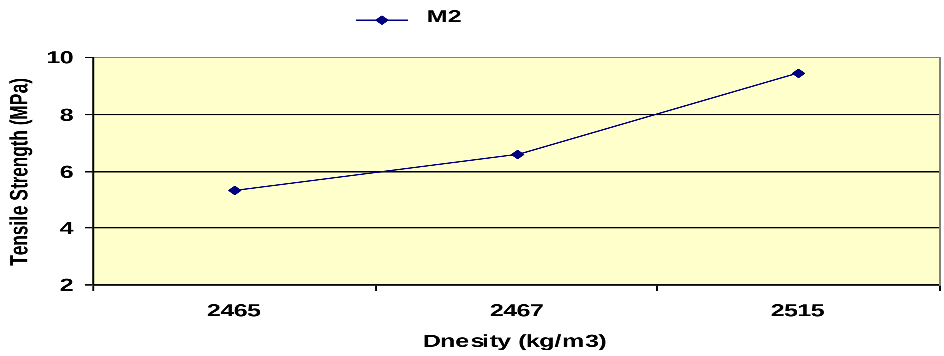


figure (4-22) The Relationship between Density and Tensile Strength for (1%) Steel Fiber with (7% p/c)

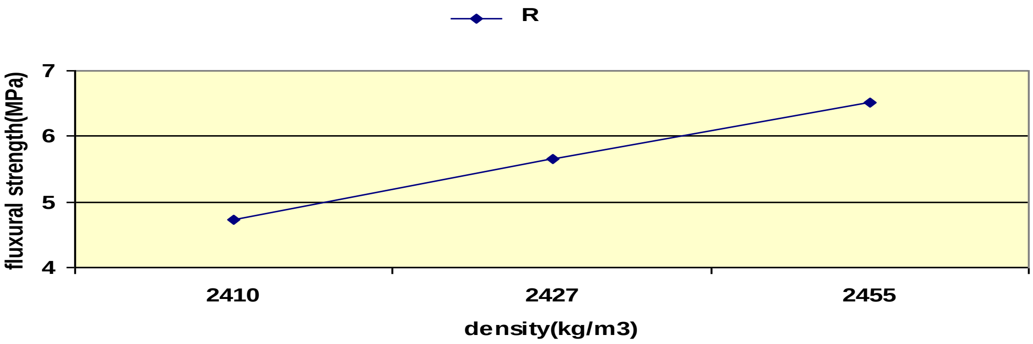


Figure (4.23) The Relationship between Density and Flexural Strength for Concrete Reference

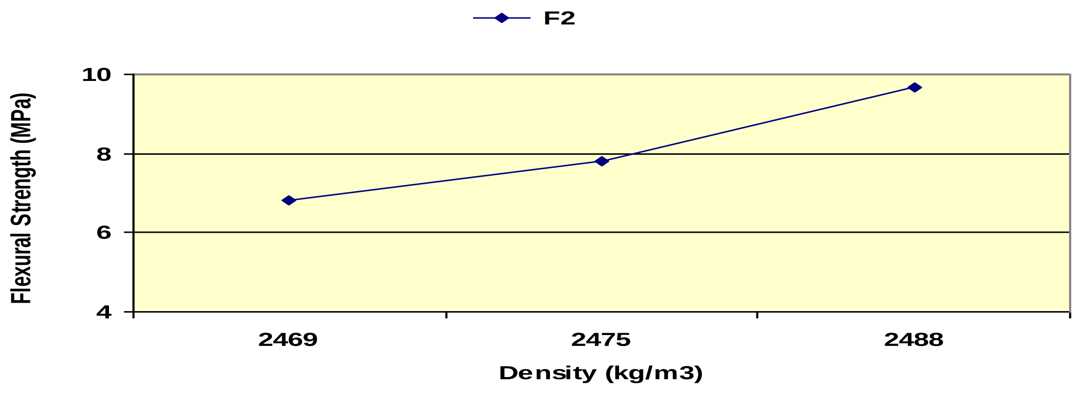


figure (4-24) The Relationship between Density and Flexural Strength for (1%) Steel Fiber

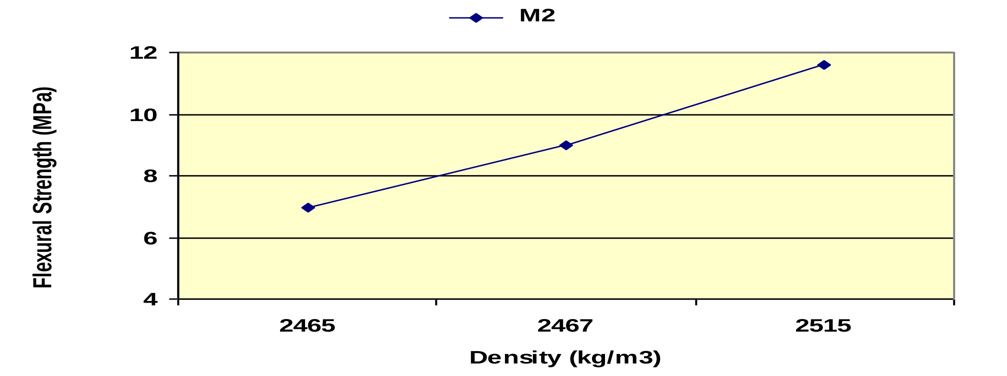


Figure (4-25) The Relationship between Density and Flexural Strength for (1%) Steel Fiber and (7% p/c)

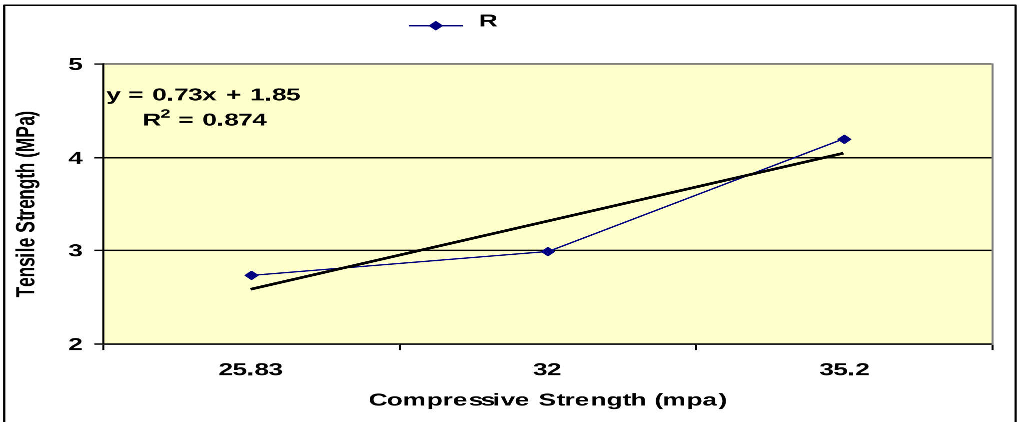


Figure (4.26) The Relationship between Compressive and Tensile Strength for Concrete Reference

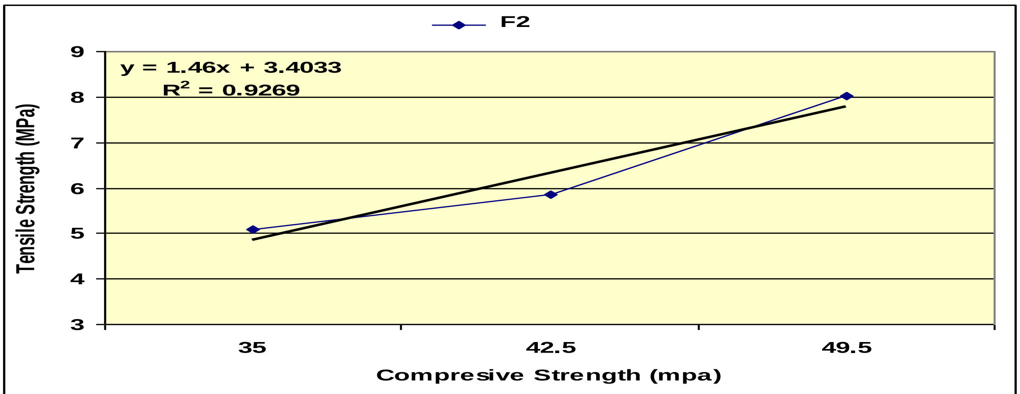


Figure (4.27) The Relationship between Compressive and Tensile Strength for (1%) Steel Fiber

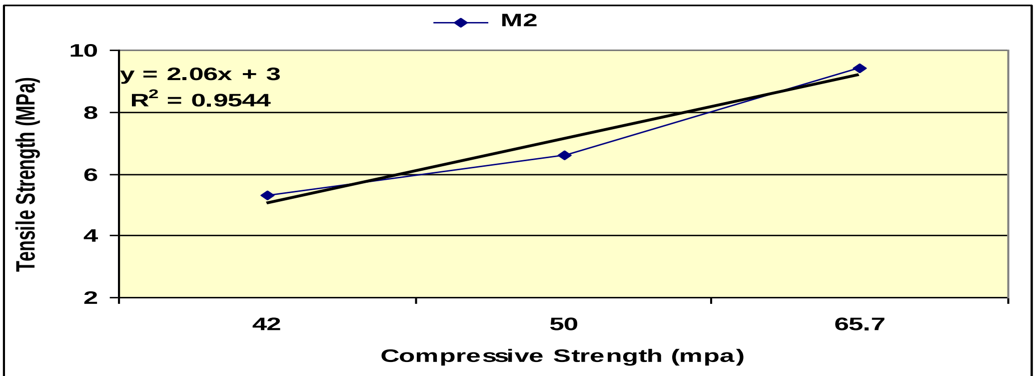


Figure (4.28) The Relationship between Compressive and Tensile Strength with (1%) Steel Fiber and (7% p/c)

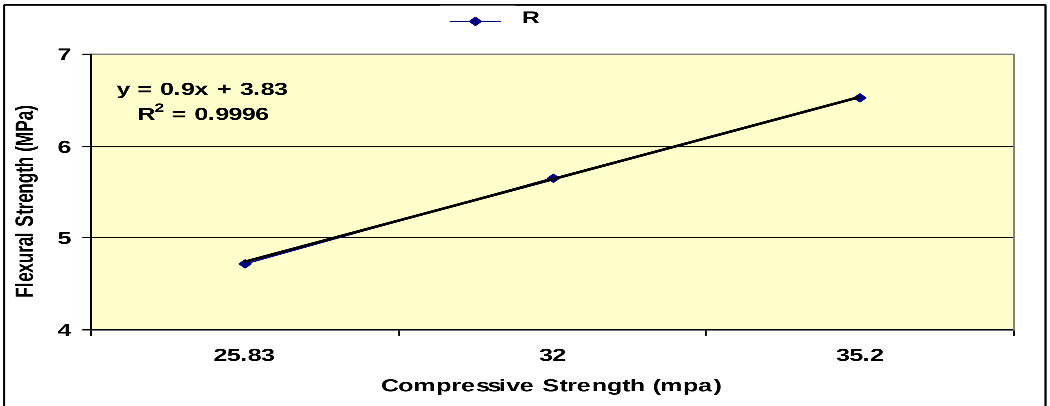


Figure (4.29) the relatioship betwen compressive and flexural strength for reference concrete

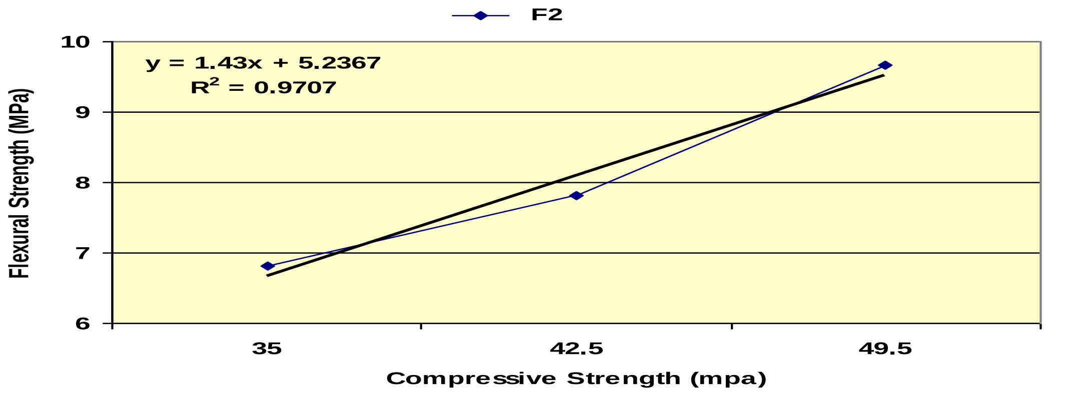


Figure (4.30) The Relationship between Compressive and Flexural Strength for (1%) Steel Fiber

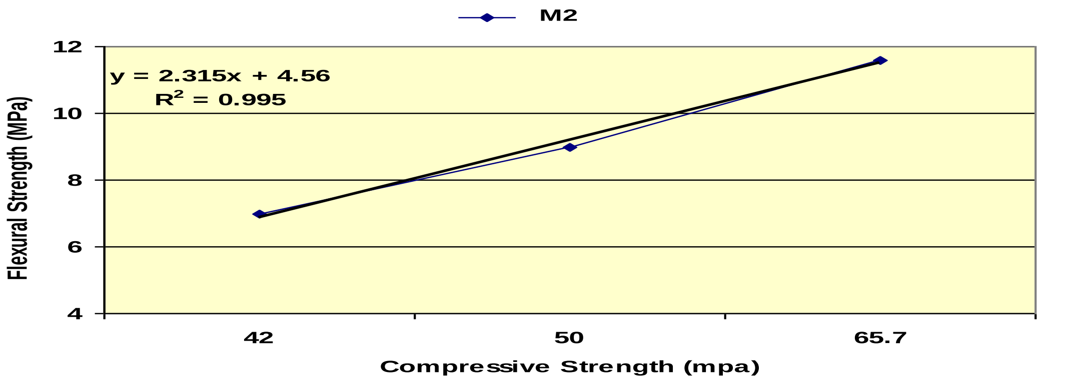


Figure (4.31) The Relationship between Compressive and Flexural Strength for (1%) Steel Fiber with (7% p/c)

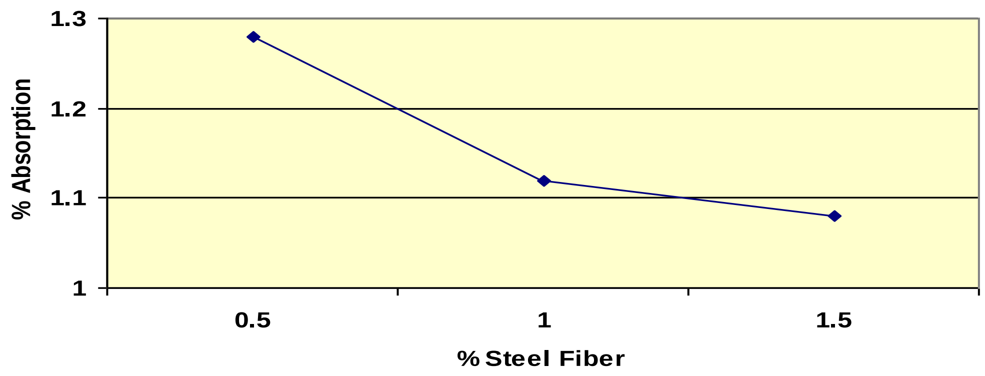


Figure (4.32) The Relationship between various Steel Fiber Ratios and Absorption

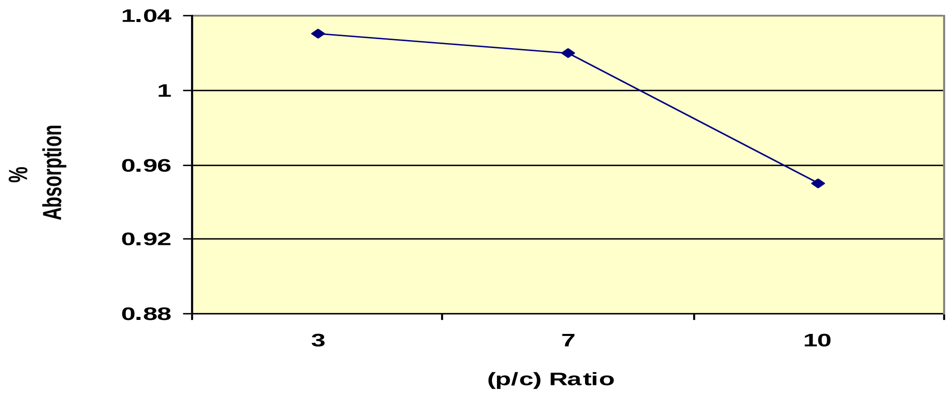


Figure (4.33) The Relationship between Absorption and various (p/c) Ratios

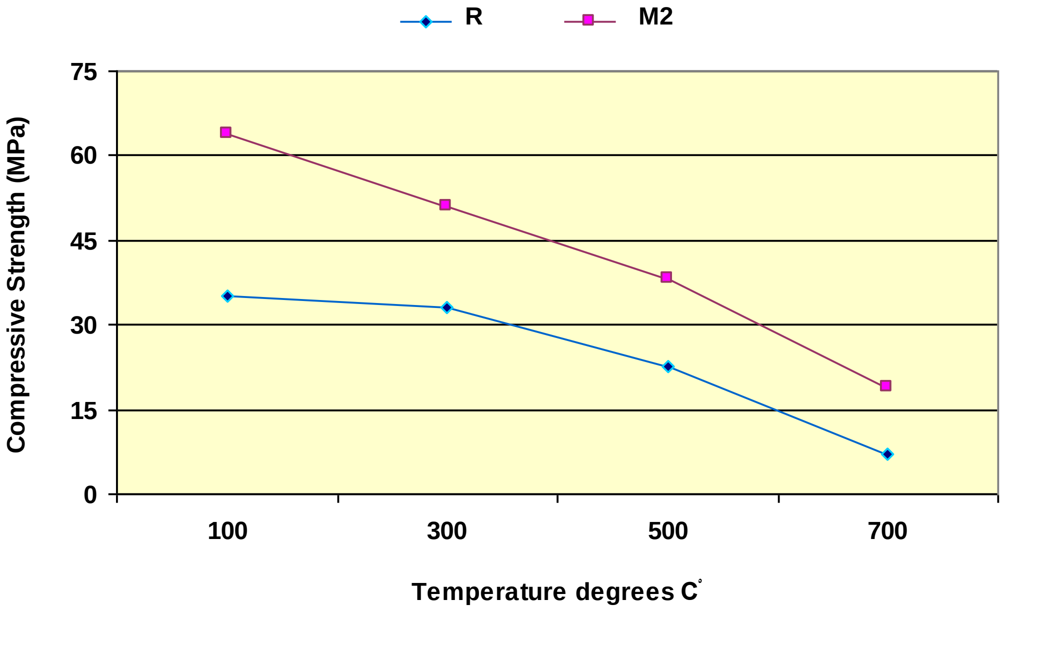


Figure (4.34) The Relationship between Compressive Strength and various Temperature Degrees

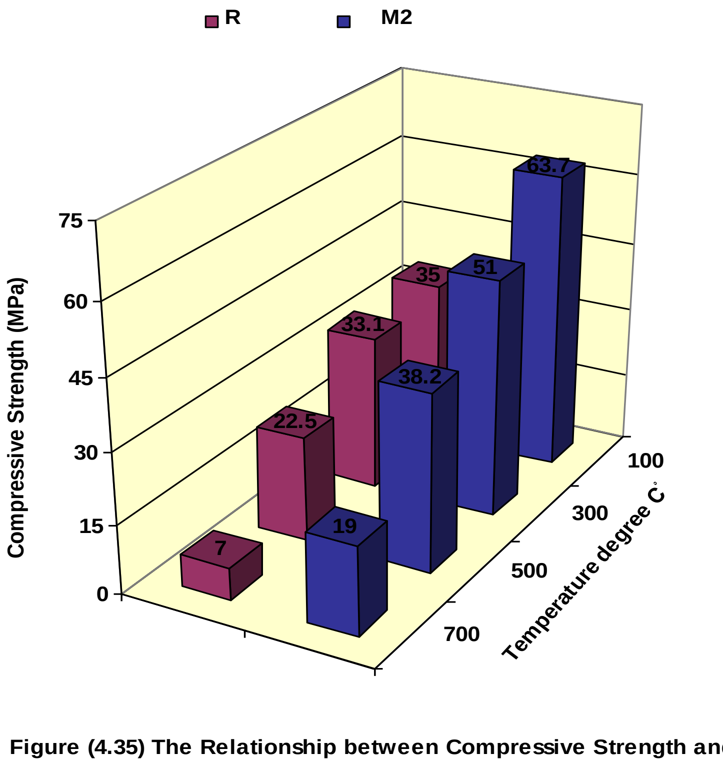


Figure (4.35) The Relationship between Compressive Strength and various Temperature Degrees

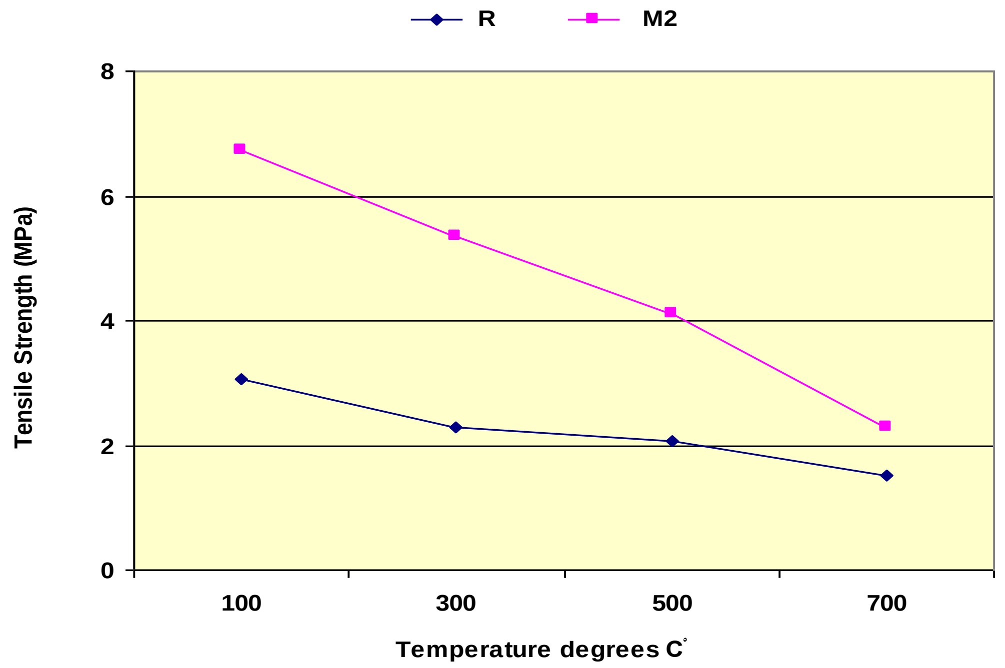


Figure (4.36) The Relationship between Tensile Strength and various Temperature Degrees

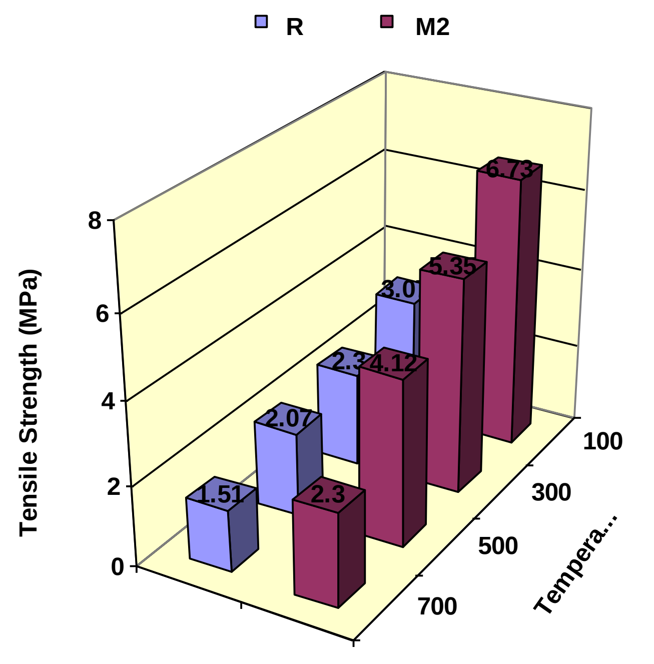


Figure (4.37) The Relationship between Tensile Strength and various Temperature Degrees

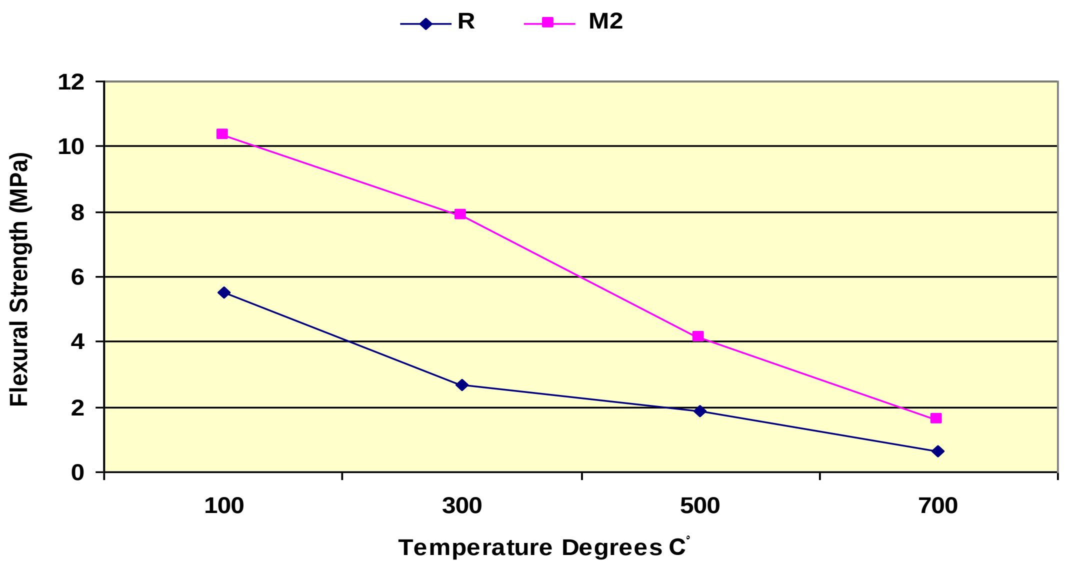


Figure (4.38) The Relationship between Flexural Strength and various Temperature Degrees

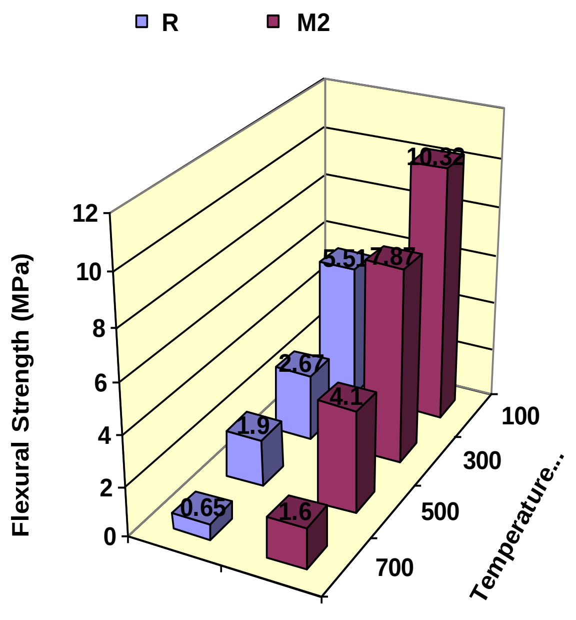


Figure (4.39) The Relationship between Flexural Strength and various Temperature Degrees

Plate (4-1) Specimens before testing

R R

R F1

F1 F1

Plate (4-2) The mode of failure of specimens after testing

F2

F2

F3

F3

M1

M2

Plate (4-2) Continued

M3 M2 under 500 C̊

M2 under 700 C̊ M2 under 700 C̊

M2 under 700 C̊

Plate (4-2) Continued

Chapter Five

Conclusions And Recommendations

5.1- Conclusions

Based on the exclusive research work, the following conclusions can be drawn:

1. The mechanical properties of steel fiber concrete had shown a clear increase in general over control specimens.

- The increase in (28) days compressive strength was (14.2%, 40.6% and 12.5%) over control specimens when using (0.5%, 1%, 1.5%) by volume steel fibers.

- The increase in (28) days splitting tensile strength was (50%, 91%, 50.2%) over control specimens when using (0.5%, 1%, 1.5%) by volume steel fibers.

- The increase in (28) day flexural strength was (24.2%, 48.3%, 35.3%) over control specimens when using (0.5%, 1%, 1.5%) by volume steel fibers.

- The increase in mechanical properties may be attributed to the fact that the presence of steel fibers arrests cracks progression and strengthens the matrix.

2. The mechanical properties of steel fibers concrete containing polymer had shown a clear increase in general over control specimens and over steel fiber concrete without polymer.

- The increase in (28) days compressive strength was (70.45%, 86.64%, 44.8%) over control specimens and (29.85%, 46%, 42%) over steel fiber specimens when using (3%, 7%, 10%) p/c.

- The increase in (28) days splitting tensile strength was (114.3%, 124.7%, 102.4%) over control specimens and (23%, 33.7%, 11.4%) over steel fiber specimens when using (3%, 7%, 10%) p/c.

- The increase in (28) days flexural strength was (62%, 78%, 71%) over control specimens and (13.7%, 29.7%, 23.7%) over steel fiber specimens when using (3%, 7%, 10%) p/c.

- The increase in mechanical properties may be attributed to the effects of lower (w/c) ratio, continuous polymer network formed within the concrete body, the improved bond between hydration products and polymer network, and the filling of pores with polymer.

3. The mechanical properties of (1%) steel fiber concrete containing (p/c = 7%) under various temperatures had shown a clear increase in general over reference specimens.

- The increase in (28) days compressive strength was (82%, 54%, 69.8%) over control specimens at (100 C̊, 300 C̊, 700 C̊)

- The increase in (28) days tensile strength was (119.2%, 132.6%, 99%, 52.3%) over control specimens at (100 C̊, 300 C̊, 700 C̊)

- The increase in (28) days flexural strength was (87.3%, 194.7%, 115.8%, 146%) over control specimens at (100 C̊, 300 C̊, 700 C̊)

4. The addition of steel fibers and polymer slightly increases the concrete density. The maximum density for steel fiber concrete at (28) days was (2493 kg/m^3)

5. The addition of steel fibers and polymer reduces water absorption. The best percent of steel fiber concrete was (1.5%) where

absorption was (1.08%), the best percent of (p/c) was (10%) where absorption was (0.95%).

5.2- Recommendation

The following recommendations are suggested for further researches.

1. Using of other types of fibers in concrete to study the effect of these fibers on mechanical properties.

2. Using of other types of polymers in concrete to study the effect of these polymers on mechanical and thermal properties.

3. Investigating the long-term properties of polymer modified concrete with and without fibers.

4. Investigating the other thermal properties of steel fiber concrete containing polymer.

5. Other degrees of temperature above (700C°) can be applied to steel fibers concrete containing polymer to study the effect of this degree on concrete.

References

1. Arnon Bentur, "Cementitious Materials-Nine Millennia and a New Century: past, present and future" American society of civil

Engineers", journal of materials in civil engineering /January/ 2002. pp. 2-22.

2. I.M Kamal, M.J. Essa and S.A. Niema "Phenol-Formaldehyde Modified Cement Concrete" Basrah University, Basrah-Iraq. Pp. 1-12.

3. Nawy E., "High Performance Concrete" 1st edition, 1996, 764p. cited (AL-Ghassani. Qusai. K.H. "Impact Resistance of Plain and Steel Fiber Reinforced Polymer Modified Concrete"). M. Sc thesis. Civil Engineering Dep., College of Engineering, Unv. Of Al-Mustansiriya. Baghdad. Iraq. 2004

4. Jackson, N. and Dhir, Ravindra. K., "Civil Engineering materials". Macmillan Press LTD. London. 5th Ed. 1996. cited (AL-Hadithi A.K. I smail " Flexural Impact and Thermal Properties of Polymer Modified Concrete") Dr. thesis Building and construction department. The university of Al-technology. Bahgdad. Iraq. March 2005.

5. AL-Khalaf, M. and Yousif, H., "Compatibility of No-Fines Concrete", the International journal of cement composites and lightweight concrete, 8 (1), February, 1986, pp. 45-50.

6. Rong, Li; et al, “Proc. of the First East Asia Symposium on Polymers in Concrete (I-EASPIC)”. Chuncheon, Koria , 1994: 293-300. Cited (Letif, Alaa’ A. , “A Study on the Properties of Polymer-Modified Concrete”. M.Sc. thesis. Civil Eng. Dept., College of Eng. Univ. of Basrah, Basrah, Iraq. Dec.,1998.

7. Fowler, D. W., “Polymers in Concrete”. Handbook of structural concrete, McGrow-Hill, New York, 1983: 8.1-8.32. Cited (Letif, Alaa’

A. , “A study on the Properties of Polymer-Modified Concrete”. M.Sc. thesis. Civil Eng. Dept., College of Eng. Univ. of Basrah, Basrah, Iraq. Dec.,1998.

8. Ohama Y. "Polymer Based Admixture". Journal, cement and concrete composites 20 (1998), college of Engineering, Ninon University Koriyama. Fukushima-ken, Japan. 1998. pp. 189-212.

9. Knott, A. Michael, B. and Nez, G. "Practical Design of Structures in Acrylic Concrete". Report from website.

10. Johnston, C. "Fiber Reinforced Concrete". Significance of tests and properties of concrete and concrete-making materials, ASTM STP 169C, 1994, pp. 547-561.

11. Christopher K.Y. Leung, "Optimal Steel Fiber Strength For Reinforced Cementitious materials". Journal of materials in civil engineering, May. 1999. pp. 116-122.

12. J.A.O. Barros, and J.A. Figueiras "Flexural Behavior of SFRC: Testing and Modeling". Journal of materials in civil engineering. November. 1999. pp. 331-338.

13. Banthia, N., Trottier, J. –F., Pigeon, M., and krishnadev, M. R. (1992). "Deformed Steel Fiber Pull-out: Material Characteristics and Metallurgical Processes" High Performance Cement Composites, H. W. Reinhardt and A. E. Naaman, eds., E & FN Spon, London, 456-466.

14. Michael S. Mamlouk and John. P. Zaniewski "Materials for Civil and Construction Engineering". P. 3.

15. Ohama, Y., "Recent Progress in Concrete Polymer Composites", Advanced Cement Based Materials, New York, 1997, p. 31-40.

16. Mindess, S. and Young, J.F., “Concrete”. Printice-Hall, INC. New Jersey. 1981.

17. Fukuchi,T. and Ohama,Y.,"Manfacturing High-Strength Concrete". Int. Symposium, SP-58, ACI, Detriot, 1978:215-224.

18. A. Blaga and J.J. Beaudion, "Polymer Modified Concrete" Division of Building Research, national research council, Canada, Canadian building digest 241, Ottawa, 1985, cited ("A Seel m.m" effect of polymer(S.B.R) on sulfate resistance of concrete, M.S.C thesis. Civil engineering. University of Al-Anbar. March 2005.

19. Shetty , M.S. ."Concrete Technology Theory and Practice". S.Chand & Company. India. 3rd.Ed.1988.

20. Vipulanandan, C. and Paul, E., “Performance of Epoxy and Polyester Polymer Concrete.” ACI Materials J., May-June 1990: 241-251.

21. Rebeiz, K. S. and Craft, A. P. “Polymer Concrete Using Coal Fly Ash”. Journal of Energy Engineering, 3(128), December, 2002,pp: 62-73.

22. Mebakia, S. and Vipulanadan, C. "Mechanical Properties and Water Diffusion in Polyester Polymer Concrete", Journal of engineering mechanics, ASCE, 121 (12), December, 1999. pp. 1359-1365.

23. ACI Committee 548 , " Guide for the Use of Polymers in Concrete", ACI Manual Of Concrete Practice Part 5-1990 . (ACI 548.1R-86), American Concrete Institute, Detroit, ACI Publication, 1990.

24. Beeldens, A. ; Germert,D. V. ; Ohama,Y. and Czarnecki, L. ; "From Microstructure to Macrostructure: an Integrated Model of Structure Formation in Polymer Modified Concrete", 4th Asia Symposium of Polymers in Concrete, Korea, May 1-3, 2003. (Internet report).

25. Letif, Alaa' A.,"A Study on The Properties of Polymer-Modified Concrete". M.Sc. thesis. Civil Eng. University of Basrah. Dec. 1998.

26. Haddad, U., David, W., and Paul, "Factors Affecting the Curing and Strength of Polymer Concrete." ACI Journal, Proceedings, V. 80, No. 5, 1983: 396-402.

27. Hau, Wu; Brooman, Eric. "Study of Use of Ultrasound Technology to Prepare Polymer Impregnation Concrete.

28. Najim K.B. "Effect of Admixture Type on Compressive Strength and modulus of Elastisity of Rubber-Tire-Waste Concrete", Anbar Journal for Engineering Sciences; Al-Anbar University, Engineering College, Vol. (1), 2007. p.p. 88-104.

29. Al-Hadithi, A. I., "Properties and Behaviour of No-Fines Polymer Concrete" , M.Sc. Thesis, Dept. of Civil Eng., University of Al-Anbar,Al-Anbar, Iraq, September, 2000. 75p.

30. ACI Committee 213R-87, "Guide for Structural Lightweight Aggregate Concrete", ACI Manual of Concrete Practice, Part 1:Materials and General Properties of Concrete, Detroit, Michigan, 1994, 27p.

31. Khalaf F.S. "Analysis of Physical Domes Made of Ferrocement Acrylic", M.Sc. thesis; civil department, Al-Anbar University, 2007.

32. Hollaway, L., "Glass Reinforced Plastic in Construction" A book of Surry and Glasgow University, Press, (England), 1978.

33. Stachiw, D. "Acrylic Plastic View Ports". A book by Marine Technology Society".

34. Haddad, U., David, W., and Paul, “Factors Affecting the Curing and Strength of Polymer Concrete.” ACI Journal, Proceedings, V. 80, No. 5, 1983: 396-402.

35. Ramark Vishnan.V. "Recent Advancements in Concrete Fiber Composites". International Synuosium of Innovate World of Concrete (ACI-IWC-93) part 3, 1993, pp. 163-190.

36. D.J. Hannant "Fiber Cement and Fiber Concrete".

37. Najim. K.B "Evaluation of Dynamic Properties of High Performance Steel Fiber Concrete By using Non-Destructive Tests", Iraqi journal of civil engineering, Al-Anbar University; Engineering College, seventh year, seventh issue. March, 2007. p. 53-70.

38. Al-Azawi, T.K. "Impact Resistance of Reinforced Concrete Slabs", Ph.D. Thesis, Sheffield University, Nov., 1984.

39. Al-Jugifi K.B.N. "Using High performance Steel Fiber Concrete to Improve the Impact Strength property", M.Sc. thesis. Civil Engineering. Military College of Engineering. Nov. 2002.

40. Mahmoud. Kh.M. "The effect of Edition of Steel Fibers on Compressive and Tensile Strength of Structural Lightweight Concrete made of Broken Bricks". Iraqi journal of Civil Engineering, Al-Anbar University; Engineering College, seventh year, 2007.

41. Ohama, Y. kan, S., and miyara, M., "Flexural Behavior of Steel Fiber Reinforced Polymer Modified Concrete", Transaction of the Japan Concrete Institute, Vol. 4, Dec. 1982. pp. 147-152.

42. Ohama, Y., miyara, M. and Kan. S., "Drying Shrinkage of Steel Fiber Reinforced Polymer Modified Concrete", Transaction of the Japan Concrete Institute, Vol. 4, Dec. 1982. pp. 153-158.

43. Fukuch, T., Ohama, Y., and Hashimoto, H., "Properties of Steel Fiber Reinforced Polymer Modified Concrete", the twenty first, Japan Congress on Materials Research, the society of Materials Science, Japan, 1978, p.p. 163-165.

44. Ohama, Y., miyara, M. and Endo. M., "Properties of Steel Fiber and Polyethylene Fiber Hybrid Reinforced Polymer Modified Concrete", the Twenty Eight Japan Congress on Materials Research, the Society of Materials Science, Japan, 1985, p.p. 151-155.

45. Sorousshian, P., Aouadi, F., and Nagi, M., "Latex-Modified Carbon Fiber Reinforced Mortar", ACI. Materials Journal., Title no. 88-M2, January-February, 1991, pp. 11-17.

46. Ohama, Y., Kan, S., and Sugahara, T., "Physical properties of Steel Fiber Reinforced Polymer-Modified Mortar", the Twenty Fifth, Japan Congress on Materials Research, the Society of Materials Science, Japan, 1982, p.p. 239-242.

47. Al-Gassani. Q.K.H. "Impact Resistance of Plain and Steel Fiber Reinforced Polymer Modified Concrete". M.Sc. thesis; Civil Department, Al-Anbar University, 2007.

48. Harada, T.J., Yamane, S., and Fumura, F., "Strength Elasticity and Thermal Properties of Concrete Subjected to Elevated Temperatures", ACI Special Publication, SP-34, Vol. 1, 1972, pp. 377-4O6.

49. Furumura, F., Harada, T.J., and Yamane, " Strength Elasticity and Thermal Properties of Concrete Subjected to Elevated Temperatures", ACI Special Publication, SP-34, Vol. 1, 1972, pp. 377-4O6.

50. Malhotra, H. L., "The Effect of Temperature on the Compressive Strength of Concrete", Magazine of Concrete Research, Vol. 8, No. 23, August, 1956, pp. 85-94.

51. Abrams, Melvin S., "Compressive Strength of Concrete at temperature to 871C̊ ", Temperature and Concrete, SP-25, American Concrete Institute, Detroit, 1971, pp. 33-58.

52. Crowley, M.S. (1956). “Initial thermal expansion characteristics of insulating refractory concretes”, Bulletin of the American Ceramic Society, 35(12), 465-468.

53. Acker, P. (2001). “Micromechanical Analysis of Creep and Shrinkage Mechanisms”, Creep, Shrinkage and Durability Mechanics of Concrete and Other Quasi-Brittle Materials, Proc. of the 6th International Conference Concreep6, Elsevier, Oxford, UK, 15-25.

54. Jaesung Lee, "Experimental Studies and Theoretical AL-Modeling of Concrete Subjected to High Temperature", A thesis submitted to the Faculty of the Graduate school of the University of Colorado in partial fulfillment of the requirement for the degree of Doctor of

Philosophy. Department of Civil, Environmental, and Architectural Engineering, UMI Number: 3239424, 2006.

55. ENV 1992-1-2, (1995). “Design of concrete structures-Part 1-2: General rules structural fire design”, European Committee for Standardization, Brussels.

56. AL-Hadithi A.K.I. "Flexural Impact and Thermal Properties of Polymer Modified Concrete". Dr; thesis Building and construction department, University of Al-technology; March 2005.

57. المواصفات العراقية القياسية رقم (45)لسنة 1948 (ركام المصادر الطبيعية المستعملة في الخرسانة والبناء).

58. kuhlmanan, A, "Application of Styrene-Butadiene Latex-Modified Concrete " Concrete International,Dec,1987,pp.48-53.

59. B.S. 1881, part 116. "Method for Determination of Compressive Strength of Concrete Cubes", British Standards Institution, 1989, p.3.

60. ASTM C496-86, "Standard Tests Method for Splitting Tensile Strength of Cylindrical Concrete Specimens", Annual Book of ASTM Standard, Vol. 04.02, 1984, pp. 259-262.

61. ASTM C293-86, "Standard Test Method for Flexural Strength of Concrete Using Simple Beam with Two Points Loading", Annual Book of ASTM Standard, Vol. 04.02, 1989, pp. 194-196.

62. Letif, Alaa' A.,"A Study on The Properties of Polymer-Modified Concrete". M.Sc. thesis. Civil Eng. University of Basrah. Dec. 1998.

63. Al-Alwani, Assma K. Ch., “Flexural Rigidity of Reinforced Local Porcelinite Lightweight Aggregate Concrete Beams”, M.Sc. Thesis,

Dept. of Civil Eng., Univ. of Al-Anbar, Al-Anbar, Iraq, September, 2002, p. 133