SHORT TERM EFFECTS OF GLASS FIBERS ON PROPERTIES OF CONCRETE

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by

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To my Parents,

my Brothers and Sister, and

To my Friends & Colleagues .

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ABSTRACT

Short Term Effects of Glass fibers on properties of Concrete

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Glass fiber reinforced concrete (GFRC) is defined as a concrete composed of cement, aggregates (fine and coarse) and alkali-resistant glass fibers randomly dispersed throughout the composite. The reason for using fibers is attempting to improve the ductility and modifying other properties of concrete.

A comprehensive testing program was developed to study the performance of glass fiber reinforced concrete. The following tests were carried out: slump test, air content, dry unit weight, compressive strength, tensile strength and resistance to freezing and thawing cycles. All tests were conducted on two sets of concrete grades 20MPa and 40MPa. Experiments were carried out with different fiber contents (0.5, 0.75 ,1.0 and 1.5) % V_f[1] for concrete grade 20 MPa, and (0.25, 0.5 and 0.75) % V_f for the 40 MPa concrete mixes. On the other hand, two standard fiber lengths 12mm and 24mm were used for each ratio to determine the effect of fiber length on the properties of concrete. A group of 144 cylinders, 48 cubes, 32 prisms were molded for a total of 16 mixes forming a total of 224 specimens.

The study resulted in finding that the addition of alkali resistant glass fiber reduces the workability and the density, increases the air content, improves the tensile strength and the durability as compared to plain concrete and has negligible effect on the compressive strength.

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(1) V_f : the fiber volume fraction was taken as a percent from the final volume.

RESEARCH SIGNIFICANCE

The primary scope of this research is to describe the effect of presence of glass fibers in concrete, to understand how these fibers can influence the physical and mechanical properties of the concrete matrix, and to determine the characteristics of the fresh and hardened concrete reinforced with glass fibers.

Different ratios and different lengths of glass fiber were added to the concrete mix, to evaluate the influence of the quantity of the fibers as well as the effect of fiber lengths on the properties of concrete in both the fresh and hardened states.

From the obtained results one can compare the performance of fresh concrete and the mechanical properties of hardened concrete with and without glass fibers.

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

Concrete is a widely used construction material composed of cement, aggregates and water. Concrete is a brittle material and has low tensile strength compared to compressive strength. One relatively new technique, which provides concrete with high tensile strength and converts the sudden failure into a gradual ductile failure, has been the development of fiber reinforced concrete (FRC).

Fiber reinforced concrete is defined as concrete made of hydraulic cements with or without aggregate of various sizes and incorporating discontinuous discrete fibers (Mindess *et al.*, 1981). The addition of a random dispersion of fibers to brittle materials offers a convenient and practical means of achieving improvements in engineering properties such as flexural, tensile and impact strengths, as well as it controls cracking and mode of failure by means of post - cracking ductility.

1.2 HISTORICAL BACK GROUND

The use of fibers in brittle matrix materials has a long history going back at least 3500 years when sun baked bricks reinforced with straw were used to build the 57m high hill of Aqar Quf near Baghdad. More recently, asbestos fibers have been used to reinforce cement products for about 100 years, cellulose fibers for at least 50 years, and metal, polypropylene and glass fibers for the past 30 years. Hannant,(1995).

Nowadays, it is evident that asbestos fibers are a health hazard, steel fibers are susceptible to the problem of corrosion at cracks, most polymeric fibers have lower elastic modulus than concrete, therefore they can not increase the strength of the composite material, even the conventional glass fibers (E - glass) are attacked by the alkali in the cement. Because of this, efforts have been made to find a convenient substitute.

This research will focus on the development of glass fibers. In the early 1960s, the Russians Biryukovich et al developed the idea of using glass fibers as a reinforcement for cement and concrete. (Hannant, 1978). As mentioned previously, the early work was based on the conventional borosilicate E glass fibers which are quickly attacked by the alkali in the cement. This stimulated the work of Majumdar and Nurse at the Building Research Establishment (BRE) in the United Kingdom which was directed towards the development of a glass fiber which would resist attack by the highly alkaline ordinary portland cement .(Hannant, 1978). In the late 1960s, that work led to the discovery of a glass formulation containing zirconia which could be formed into fibers and offered the possibility of a durable reinforcing material. That special glass fiber became ***Cem-FIL***, subsequently developed into a commercial reality and was launched 25 years ago. (Cem-FIL News, 1995).

1.3 DEFINITION OF GLASS FIBERS

Concrete reinforced with glass fibers exhibit superior properties to the traditional one. From this point of view there is a growing interest in its usage and production. To know more about this material the followings are discussed:-

1.3.1 Manufacture of Glass Fibers

Chemically, glass fiber is composed predominantly of silica (SiO_2) plus other oxides such as zircon (ZrO_2) and lime stone ($CaCO_3$). The manufacturing process of fiber glass consists of melting the raw materials into a furnace at which the individual filaments (14-20μ) are formed. The variety of filament diameters can be produced by varying the orifices which are located at the base of the drawing furnace and from the drawing conditions. These filaments are then collected together, quenched and usually coated with a protective binder known as sizing. (Margolis, 1986). The collection of 200 or so of filaments is known as strands. The process of manufacturing fiber glass is shown diagrammatically in Figure 1.1. At the end of the process two forms of glass fiber can be produced, these forms are:-

- Continuous or Roving : collections of continuous filaments.
- Discontinuous or Chopped Strands: the continuous filaments passed through a chopping device to produce chopped strands with desired length.

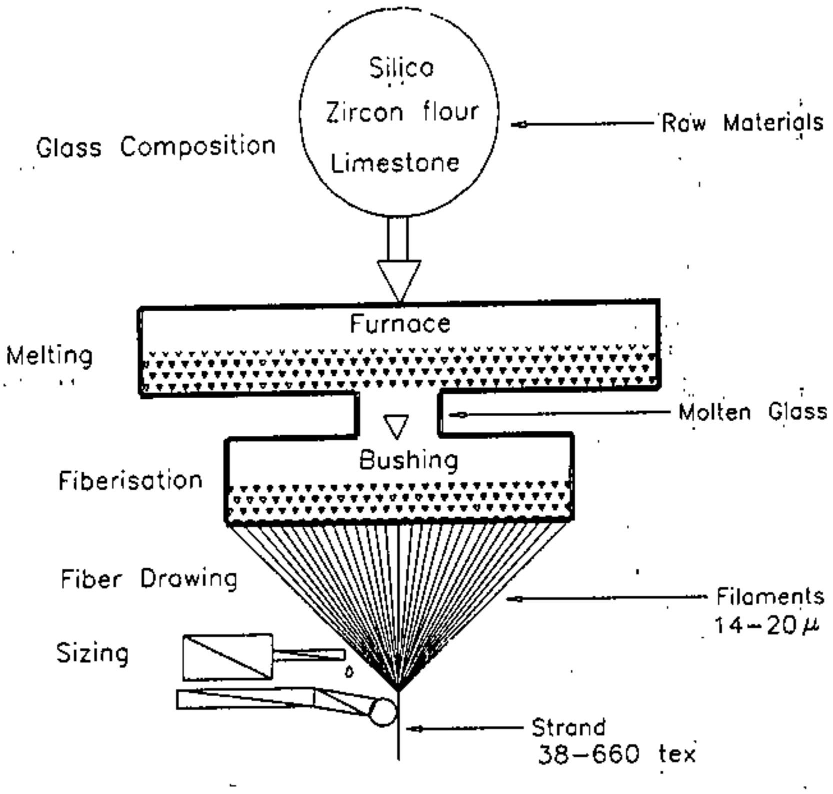

Figure 1.1 : Manufacturing process of glass fiber.

1.3.2 Glass Fiber Properties

The remarkable properties possessed by the AR(1) glass fiber, commercially known as Cem-FIL, make it very attractive to be used in many applications. The general characteristics are summarized as follows, (The Cem-FIL Range, 1995), :

- Cem-FIL has proven resistance to chemical attack in both acid and alkali environments.
- Cem-FIL has a modulus of elasticity 10 times that of most organic fibers and 3 times of the cement matrix.

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(1) AR : Alkali Resistant

- Cem-FIL has a greater specific resistance (tensile strength/volumetric mass) than that of steel (3-4 greater).
- Cem-FIL is naturally incombustible.
- Cem-FIL is insensitive to variations in temperature and humidity and has a low coefficient of linear expansion (dimensional stability).
- Cem-FIL fibers do not rod and have a good resistance to corrosion and insect or biological attack.

1.4 MECHANICAL PROPERTIES OF GLASS FIBER REINFORCED CONCRETE

1.4.1 General

Glass fiber reinforced concrete (GFRC) is considered to be one of the most innovative construction materials available today. This is the belief of the Prestressed Concrete Institute, Chicago ILL, as expressed in one of its publications relating to GFRC.(Prestressed Concrete Institute, 1985). The properties of GFRC is influenced by many factors such as the fiber content, fiber length, the strength of the bond between the fibers and the matrix, the orientation and distribution of fibers where it is believed that continuous aligned fibers result in more effective reinforcement than short random fibers because the full strength of the fiber can be utilized at failure. However the variables that are important for traditional reinforced concrete properties such as : w/c ratio, air content, density, aggregate size, etc. also have significant influence on the properties of fiber reinforced concrete. (ACI Committee 544.1, 1984).

1.4.2 Typical Material Properties

1.4.2.1 Workability

Workability is a property of fresh concrete which indicates its ability to be mixed, handled, transported and placed with a minimum loss of homogeneity. Workability can be determined from the slump test, Vebe test and compacting factor test. Edgington showed that workability of fiber reinforced concrete decreased by increasing the coarse aggregate content, due to this he suggested to use aggregates 3/8 in. (9.53 mm) or less in size, or just sand to improve workability. It is evident that workability goes down by increasing the fiber percentages.(ACI Committee 544.1, 1984)

1.4.2.2 Compressive and Tensile Strengths

Adding fibers to concrete has a minor effect on the compressive strength of concrete. In the other hand, fibers increase the tensile strength and the ductility of concrete significantly depending on the percent of the fiber. This improvement modifies a major weakness in plain concrete.

1.4.2.3 Toughness

Toughness is a measure of the ability of a material to absorb energy and is an indication of the resistance against crack propagation. Toughness is found by taking the area under the load - deflection curve. When the fibers are present, the cracks are bridged and can not extend without stretching and debonding the fibers. As a result, considerable additional energy is necessary before complete fracture of the material occurs. Several investigators have shown that the toughness of fiber reinforced concrete is at least 10 - 40 times higher than that of plain concrete.(ACI Committee 544.1, 1984).

1.4.2.4 Dynamic and Fatigue Strengths

The dynamic strength of concrete reinforced with various types of fibers and subjected to explosive charges and dynamic tensile and compression loads have been measured. The dynamic strengths for various types of loading were 5 to 10 times greater for FRC than for plain concrete. The greater energy requirements to strip or pull out the fibers provides the impact strength and resistance to spalling and fragmentation. It has been shown that the addition of fibers increases fatigue life and decreases the crack width under fatigue loading. (ACI Committee 544.1, 1984).

1.5 APPLICATIONS

The utilization of glass fibers as reinforcement for brittle materials is used throughout the world for many applications. The major field applications include the followings:-

1.5.1 Civil Engineering (cast in situ and precast applications).

Glass fiber concrete by virtue of its superior flexural, tensile, impact and fatigue properties and its ability to be used in thin sections appears to be advantageous as:

- Bridge deck formwork and parapets.
- Highway, street and airfield pavement overlays and construction.
- Industrial floor.
- Concrete pipes and pile tips.

- Repairs and new construction of hydraulic structures.

1.5.2 Architectural Moldings

- Cladding panels: since glass fibers add flexural, tensile, and impact strength, GFRC is perfect for lightweight architectural cladding panels. GFRC cladding panels can be cast as wall units, window wall units, spandrels and mullions. McDougle *et al.*, (1995).
- Capitals and column casing.
- Decorative garden units

1.5.3 Cement or Mortar Applications

- Permanent formwork : since glass reinforced cement (GRC) is a material of consistent quality and controlled thickness, GRC permanent formwork is used to protect steel. GRC provides more protection against carbonation and chloride induced corrosion than the same thickness of a good ordinary concrete. Brown, (1988).
- Glass fiber shotcrete : The advantages of fiber reinforced shotcrete included good strength, durability, and density as well as significantly lower costs compared to latex shotcrete, epoxy or polymer mortars.

- Asbestos cement replacement : - Corrugated sheet.
  - Partition fire boards.
  - Pipes and accessories.
  - Roof slates and flat roof tiles.

1.6 PREVIOUS STUDIES

Although GFRC are used in many applications but there is relatively little published work on the physical properties of glass fiber concrete. March and Clark, (Hannant, 1978) investigated the effect of fiber contents on workability and the flexural strength of reinforced concrete using AR glass fibers and 10 mm maximum sized aggregate. The conclusion they reached that increasing the volume percentages decreases the slump rapidly while it increases the ultimate strength.

Meanwhile, the research efforts have been concentrated on the development of GRC which is made from ordinary resistant glass fiber combined with a matrix consisting of ordinary Portland cement with or without silica sand. It is evident that GRC has remarkable properties in flexural, impact, tensile strengths, toughness and in controlling crack growth. On the other hand, exposing GRC products for long time under natural weathering leads to embrittlement and loss of flexural and impact strengths. The loss of strength and ductility was due to chemical reactions and physical changes. The chemical factor is that the AR glass fibers are subjected to some alkali attack in moist cement and lose some of their tensile strength. The physical cause of GRC aging results from the tendency of the cement hydration products, especially calcium hydroxides, to fill up spaces between and around the filaments of glass fibers and bind the filaments. This causes excessive bonding and local concentration of stresses under load at the surface fiber, resulting in embrittlement. Parviz *et al.*, (1993). Many solutions have been suggested to eliminate the chemical attack, such as the use of low alkaline cement. Recently a new type of cement has been developed in Japan, calcium silicates C_4A_3S-CS-slag type, to improve the durability of GRC. Akihama *et al.*, (1987). Other solution lies in fiber modification and this is achieved in two ways:

1- Improving the actual glass composition by adding 10% of rare earth oxides to the basic AR glass composition. Such development has been commercialized by Asahi with the introduction of their "AR Fiber - Super". Proctor, (1990).

2- Surface treatments based on the inclusion of chemical inhibitor in the fiber size which is slowly released around the fiber and reduces the rate of alkali/glass reaction and hence improves the strength of the fibers, Proctor *et al.*, (1985), the treated fibers are known as ***Cem-FIL 2***.

CHAPTER TWO

EXPERIMENTAL PROGRAM

2.1 GENERAL

The main objective of adding fibers is attempting to modify the properties of concrete. A comprehensive experimental program was carried out to determine the main characteristics and the mechanical properties of fibrous concrete such as compressive strength, splitting tensile strength, air dry unit weight, durability, air content and workability.

To accomplish this aim 16 concrete mixes have been made for two grades of concrete strength namely 20 MPa and 40 MPa. Different ratios and different lengths of glass fibers were added to the mix and tested in both the fresh and hardened states.

2.2 MATERIALS USED

Cement, aggregates, water, admixtures and other conventional materials used for fiber reinforced concrete should conform to the same Jordanian recognized specifications used for conventional concrete .(ACI Committee 544.3, 1984)

2.2.1 Cement

The cement used in this investigation is the commercially available Ordinary Portland Cement (OPC) - Petra Brand, commonly known as Al Janoube cement. The chemical composition and the physical characteristics for this type of cement satisfy the relevant Jordanian Standard Specification (JSS) No.30. (JSS/30, 1983). These specifications and the results obtained from Royal Scientific Society (RSS) are illustrated in Tables 2.1 and 2.2.

Table 2.1 : Chemical composition of ordinary portland cement.

Chemical Component	**Percent, %**	
	Jordanian Specification	**RSS Results**
SiO_2	*	21.35
Al_2O_3	*	5.83
Fe_2O_3	*	2.92
SO_3	≤ 3.5%	2.59
MgO	≤ 5%	1.98
C_3A	*	10.51
CL	≤ 0.1 %	0.02
Loss on Ignition	≤ 5%	1.13
Insoluble Residue	≤ 5%	0.31

* : not available

Table 2.2 : Physical characteristics of ordinary portland cement.

Specific Gravity	3.15	*
Initial Setting Time, minutes	≥ 60	162
Final Setting Time, minutes	*	215
Fineness, m^2/Kg	*	310
Compressive Strength @ 2 days	≥ 10 N/mm^2	22 N/mm^2
Compressive Strength @ 28 days	≥ 42.5 N/mm^2	52.18 N/mm^2

* : not available

2.2.2 *Aggregates*

The aggregates used were crushed natural wadi materials which consist of coarse, medium and fine sizes, locally known as Foulyeh, Addassia, wadi sand respectively. In order to determine the properties of aggregates the following tests were carried out, and the tests results are summarized in Table 2.3 :

- Grain Size Distribution, according to ASTM C 136 - 94, " Sieve Analysis of Fine and Coarse Aggregates".
- Specific Gravity and Water Absorption according to ASTM C 127 & 128 - 94, " Specific Gravity and Absorption of Coarse & Fine Aggregates".
- Abrasion Resistance, according to ASTM C 131 - 94, " Resistance to Degradation of Small-Size Coarse Aggregate By Abrasion and Impact in Los Angeles Machine".

Table 2.3 : The properties measured for all the sizes of aggregate.

Aggregate Size		**Coarse Aggregate**	**Medium Aggregate**	**Fine Aggregate**
Sieve Opening		**Percentage Passing by Weight, %**		
1"	25 mm	100	100	100
3/4"	19 mm	85.1	100	100
1/2"	12.5 mm	14.7	89.6	99.2
3/8"	9.53 mm	0.96	48.2	98.6
No. 4	4.75 mm	0.73	2.9	88.9
No. 8	2.36 mm	0.3	2	78.1
No. 16	1.18 mm	0.3	0.75	70.9
No. 30	600 μm	0.3	0.75	60.3
No. 50	300 μm	0.3	0.75	34.6
No. 100	150 μm	0.3	0.75	15.3
No. 200	75 μm	0.3	0.75	11.2
Specific Gravity				
- Oven Dry Gs		2.570	2.562	2.544
- Saturated Surface		2.622	2.622	2.600
- Apparent Gsa		2.712	2.725	2.700
Water Absorption, %		2.04	2.33	2.2
Los Angeles Abrasion				
- Grading Type		B		
- Percent Loss, %		22.9		

2.2.3 *Water*

Mixing water should be clean and free from deleterious matter. In this investigation ordinary tap water from the municipal supply system was used for mixing.

2.2.4 *Admixture*

The admixture used is commercially known as ***Melment L10***. Chemically ***Melment L10*** is a sulphonated melamine based polycondensation product. These products comply with ASTM C 494, Types A and F; that means that ***Melment L10*** is a water reducing superplasticizer admixture. It is absorbed on the surface of the binding agents and of the fine aggregate particles, where it forms a lubricating film thus reducing the inner friction of the heterogeneous fresh mix. In addition it has a strong dispersing effect which influence the hydration processes of the clinker phases and therefore the early hardening of the cement paste.(SKW TROSTBERG, 1990). Table 2.4 shows some properties of ***Melment L10***.

Table 2.4 : Melment L10 characteristics

Appearance	Colorless to slightly yellow, transparent to slightly liquid.
Density/Unit Weight	$1.110 \div 1.118$ gm/cm^3
pH Value	9 - 12
Viscosity	3 -5 $mm^2.s^{-1}$

The benefits gained from using Melment L10 are summarized as follows :-

- High early and final strength can be obtained by reducing the w/c ratio.
- The consistency of concrete is improved.

- Good resistance to freezing and thawing is attained.
- Low permeability to water can be provided.
- Concretes with ***Melment*** is resistant to aggressive chemicals attack.

In this work *Melment L10* was used to obtain a high early and final strength, hence it was added to the mixes of 40 MPa grade.

2.2.5 Reinforcement Fibers

The fiber used in this study was the alkali resistant glass fiber, a United Kingdom product commercially known as ***Cem-FIL***. These fibers are manufactured from a specially formulated glass composition within a critical region of the Na_2O-CaO-ZrO_2-SiO_2 system. ***Cem-FIL*** exhibits a high degree of acid and alkali chemical resistance. It was specifically developed to enable these fibers to resist the very high alkalinity produced by the hydration of Ordinary Portland Cement.(The Cem-FIL Range, 1995)

The glass fibers are available in two forms, the ***Cem-FIL Rovings*** which are continuous fibers while the other is discontinuous and known as ***Cem-FIL AR Chopped Strands***. The latest was used in this research with standard lengths of 12mm and 24mm (Figure 2.1). Evidence to date has shown that these fibers cause no long term health hazard, although some temporary skin irritation may be experienced. (Cem-FIL Composites, 1995).

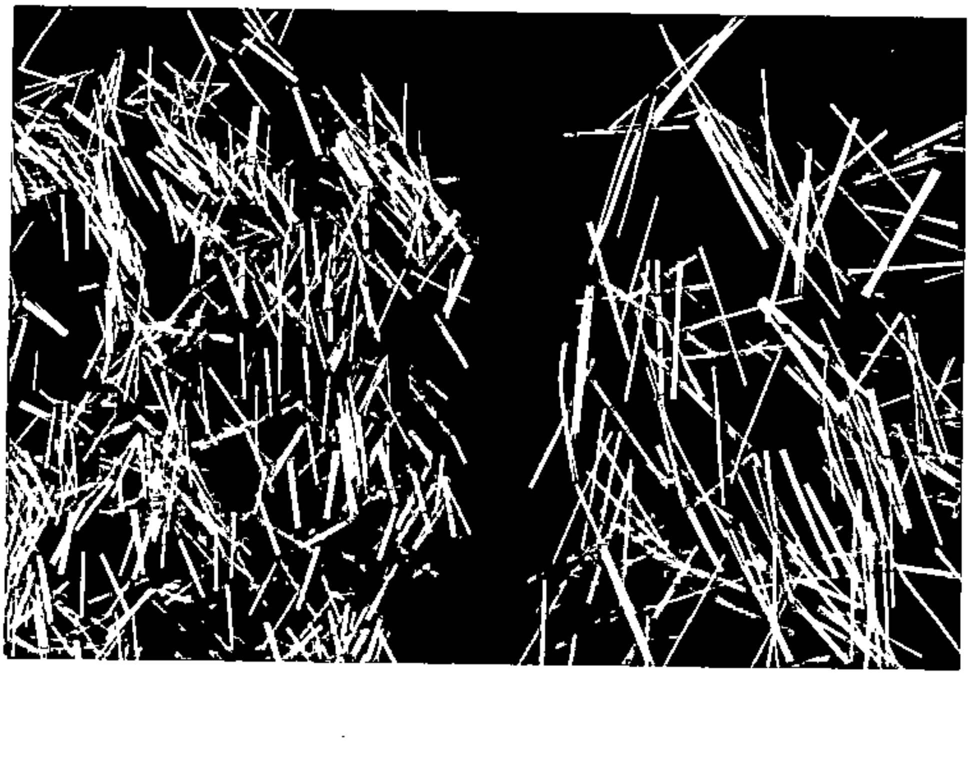

Figure 2.1 : Glass fiber type Cem- FIL AR chopped strands with standard lengths 12mm and 24mm.

Glass fibers have remarkable properties which are shown below in Table 2.5, (The Cem-FIL Range, 1995):

Table 2.5 : Cem-FIL AR chopped strands properties.

Single Filament Tensile Strength	3500 MPa
Strand Tensile Strength	1700 MPa
Young's Modulus of Elasticity	72000 MPa
Specific Gravity	2.68
Strain at breaking point (strand)	2.4 %
Softening Temperature	860 °C
Filament Diameter	20 μ
Water uptake	< 0.1 %
Strand Tex	83 gm/Km
Loss on Ignition	1.7 %

2.4 MIX PROPORTIONS

The concrete mixes were designed to have a 28 days compressive strength of 20 MPa and 40 MPa. Mix proportioning was based on finding the absolute volumes of the ingredients. The grading of aggregates used in the concrete mixes satisfies the grading limits specified by the Ministry of Public Works and Housing (MPW&H).(Jordanian Standard Specification, 1987). The grading limits of MPW&H and the combined grading (31% coarse , 31% medium and 38% fine) are shown below in Table 2.6 and Figure 2.2. The maximum aggregate size used was 20mm.

Table 2.6 : The Combined grading of aggregates and the grading limits.

Sieve Opening	Combined Grading	MPW&H Grading Limits
1"	100	90 - 100
3/4"	95.4	70 - 100
1/2"	70.0	-
3/8"	52.7	50 - 75
No. 4	35.0	35 - 60
No. 8	30.4	27 - 45
No. 16	27.3	20 - 35
No. 30	23.2	12 - 25
No. 50	13.5	5 - 15
NO. 100	5.0	1 - 5
No. 200	4.6	0 - 5

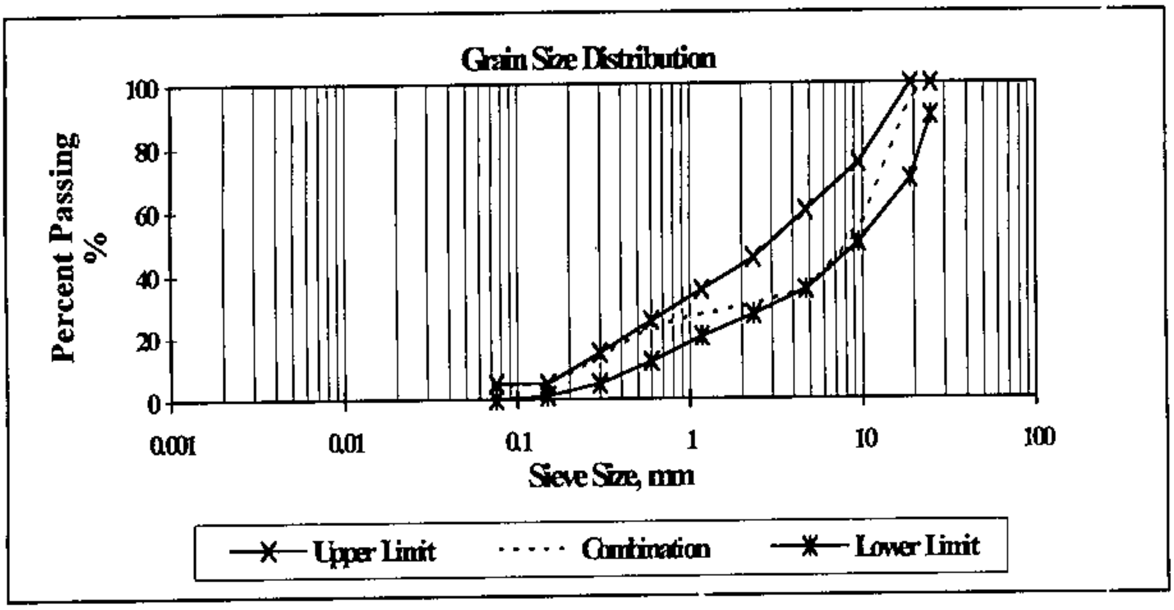

Figure 2.2 : The Aggregates grading combinations and the MPW&H specifications.

The mix proportions for the two grades of concrete mixes (20 and 40 MPa) are summarized in Table 2.7.

Table 2.7: The mix proportions for all the mixes.

Ingredients	20 MPa	40 MPa
W/C	0.78	0.337(1)
Cement, Kg/m^3	256.4	392.2
Net water, liter/m^3	200	140
Total water, liter/m^3	239.14	180.1
Coarse aggregate, Kg/m^3	553.9	566.8
Medium aggregate, Kg/m^3	553.9	566.8
Fine aggregate, kg/m^3	678.9	694.9
Melment L10, Kg/m^3	-	9.81(2)
Fiber Percentages, %V_f(3)	0.5, 0.75, 1.0 and 1.5 %	0.25, 0.5 and 0.75%

2.5 MIXING PROCEDURE

The quantities of raw materials have been weighed using a heavy duty balance with a capacity up to 20 Kg (1 gm sensitivity) . Mixing was made using

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(1) Including the Melment water.

(2) 2.5% by weight of cement.

(3) Fiber volume fraction was taken as a percent of the final volume.

Electric Revolving Drum mixer with a total capacity of 0.04m^3.

The absorbed water was added to the dry aggregates, mixed and left for 10 minutes so as to be saturated.

Cement was added to the ingredients and the mixing operation was continued for 3.5 minutes during which the total amount of water was added gradually. The last step in mixing was the addition of fibers. In feeding ***Cem-FIL AR chopped Strands*** to the mixer the following precautions should be considered so as to obtain a good dispersion and little fiber damage as well as to prevent fiber clumping :-

- The fiber should be added to a fluid mix, so the addition is delayed to the last step.
- The fibers should be fed into the mixer by sprinkling them during mixing and avoid throwing them in handfuls (Figure 2.3) .
- Since over-mixing will damage the fibers, it is recommended to add the fibers to the mix in less than 1.5 minutes (Cem-FIL GRC, 1995).

The same procedure was followed for the high strength concrete except that the Melment was added before adding the fibers. The total number of specimens molded after the completion of mixing were three cubes , nine cylinders and two prisms (Figure 2.4).

Figure 2.3 : Fiber addition techniques

Figure 2.4 : The total Number of specimens obtained for each mix proportion.

2.6 CASTING AND CURING

Since there is no standard specification for casting and curing of fibrous concrete, the specimens were prepared in accordance with ASTM C 192-81 "Making and Curing Concrete Test Specimens in the Laboratory".

Glass fiber reinforced concrete (GFRC) was cast in 150 mm cube molds, 150×300 mm cylinders and 75×75×255 mm prisms. Casting was done by placing GFRC into molds with required number of layers of approximately equal volume. Each layer was consolidated with the required number of blows using a suitable consolidation tool (Table 2.8). The sides were tapped lightly using the mallet and the top surface was finished by means of trowel.

Demoulding was carried out after 24 hours and the specimens were stored in water curing tanks at 23°C until the day of testing.

Table 2.8 : Number of layers, Number of roddings and the rodding tool used in molding test specimens.

Specimen Type	Number of Layers	Number of strokes/Layer	Rodding Tool
Cubes(1)	3	35	25 mm square steel
Cylinders	3	25	16 mm tamping rod
Prisms	2	25	16 mm tamping rod

A group of 144 cylinders, 48 cubes and 32 prisms were molded for the total mixes forming a total of 224 specimens.

2.7 MEASUREMENT OF PROPERTIES

The glass fiber reinforced concrete has been tested in both the fresh and hardened states. The fresh state tests consist of workability and air content. The hardened state tests were the air dry unit weight, compressive strength, splitting tensile strength and durability.

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(1) The cubes were molded according to the BS 1881: Part 108 : 1983 " Method for Making test cubes from concrete".

2.7.1 Fresh State

2.7.1.1 Workability

Workability was measured by the slump test which is covered under the specification of ASTM C 143-78 “Slump of Portland Cement Concrete”.

2.7.1.2 Air Content

Air content of fresh concrete was determined using Controls C170 air entrainment meter (Figure 2.5). The air content in this type of meter ranges from 0 to 7 %. The test was carried out according to ASTM C 231-82 “Air Content of Freshly mixed Concrete By the Pressure Method”.

The operational principle of this meter consist of introducing water above a sample of concrete of known volume ($0.005m^3$) to a definite elevation, and the application of a predetermined air pressure called the standard operating pressure ($1\ Kg/cm^2$) over the water.

The reduction in the water level is indicative of the reduction in volume of the air contained in the concrete sample. A graduated scale is provided from which the reduction of water level is read directly in terms of percent air content (A_1).

The air content determined included the entrained air and the air held within the pores of the aggregate particles. (Controls testing equipment, 1993) . Due to this, the same procedure mentioned earlier is carried out on a combined sample of all sizes of aggregates to determine the air held within the aggregate particles. The result obtained is known as the aggregate correction factor (G). The corrected air content of the concrete is obtained by using the following formula :

$$A_s = A_1 - G$$

where : - A_s : air content of the tested sample.

- A_1 : apparent air content of the tested sample.
- G : aggregate correction factor.

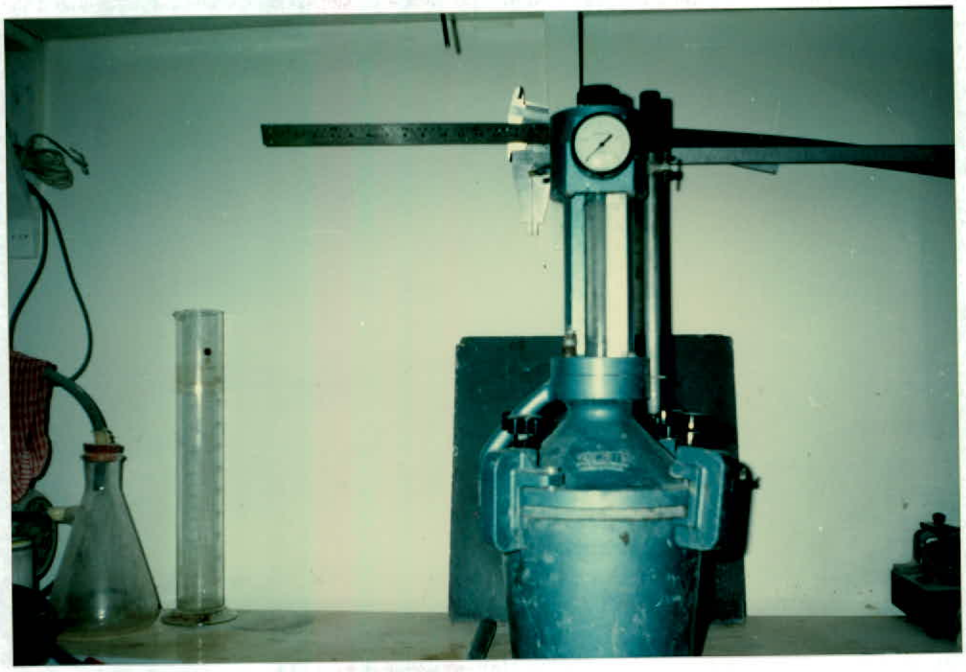

Figure 2.5 : Pressure - type air content meter, type A

2.7.2 Hardened State

2.7.2.1 Compressive Strength

Compressive strength test was performed in accordance with the British standards BS. 1881: Part 116 : 1970 "Method for Determination of Compressive Strength of Concrete Cubes". Cube specimens of 150×150×150 mm were tested under compression at the age of 28 days. Three specimens for each mix proportion were tested. The test was conducted by using compression machine type Controls with a capacity up to 200 ton (880 Kg/cm^2) (Figure 2.6).

2.7.2.2 Air Dry Unit Weight

The same cubes used for compression were used also to determine the air dry unit weight. The cubes were taken out from the curing tank 24 hours before the testing date at the age of 28 days. The specimens were left to dry in air under the room temperature. At the testing date the dimensions of the specimens were measured to the nearest 0.1 mm and also weighed to the nearest 1 gm. The air dry unit weight is determined by dividing the weight of the specimen by its volume:

$$\gamma = W/V$$

where : - γ : Dry unit weight, g/cm^3
- W : Weight of the specimen, g
- V : Volume of the specimen, cm^3

Figure 2.6 : The Compression testing machine, Controls Type.

2.7.2.3 Tensile Strength

The splitting tensile strength test is used to determine the first crack tensile strength, but should not be used for additional determinations due to the unknown stress distribution after the first crack . (ACI Committee 544.2, 1984).

Three cylindrical specimens of 150×300 mm were tested at 7,14 and 28 days to determine the splitting tensile strength. The test was conducted in accordance with ASTM C 469-71 “Splitting Tensile Strength of Cylindrical Concrete Specimens”.

The cylinders were placed with its axis horizontal between two bearing plywood strips of 3.2mm nominal thickness, free of imperfections, approximately 25mm wide, and of a length equal to or slightly longer than that of the specimen. The load was applied continuously using ELE testing machine with a capacity up to 2000 KN. until splitting occurs (Figure 2.7).

Knowing the maximum load and the dimensions of the specimen, the splitting tensile strength is calculated as follows :

$$T = 2P/\pi LD$$

where - T = splitting tensile strength, N/mm^2.

- P = maximum applied load indicated by the testing machine, KN.
- L = length of the specimen, mm.
- D = diameter of the specimen, mm.

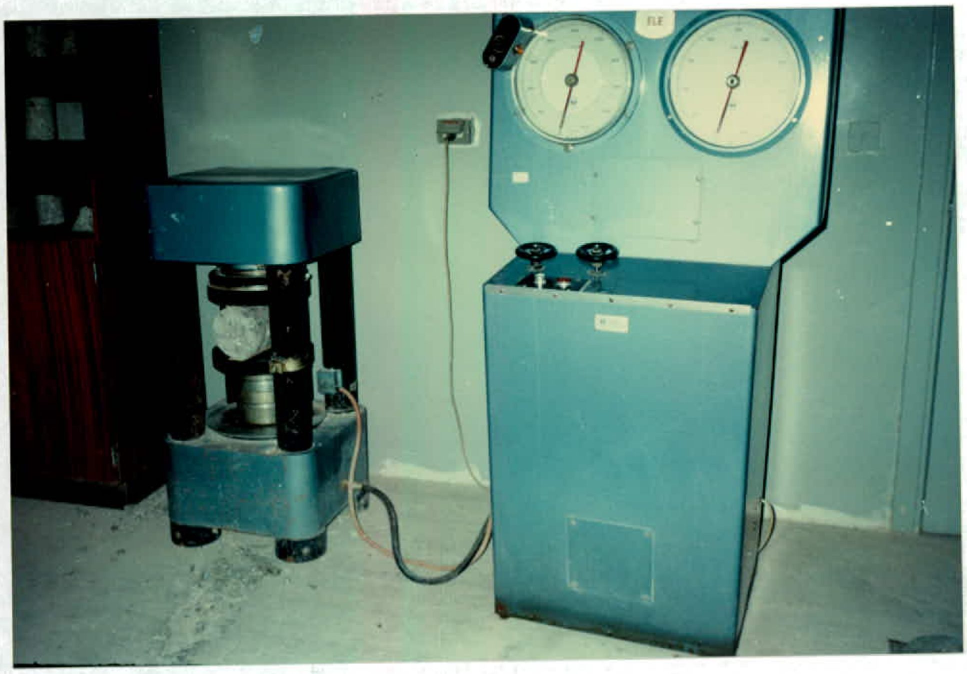

Figure 2.7 : ELE testing machine for determination of splitting tensile strength.

2.7.2.4 Durability Test

The durability of concrete was measured by its resistance to freezing - thawing cycles. For each mix, two prismatic specimens of 75×75×255 mm were tested at the age of 14 days. The tests were performed according to ASTM C 666-84 "Resistance of Concrete to Rapid Freezing and Thawing", procedure A was adopted where freezing and thawing take place in water.

The specimens were placed in the apparatus (Figure 2.8) where each specimen should be surrounded by approximately 3 mm of water at all times while it is being subjected to freezing and thawing cycles.(Humboldt MFG., 1985). The freezing/thawing cycles consist of alternately lowering the temperature of the specimens from 4.4 to -17.8°C and raising it from -17.8 to 4.4°C. This operation is entirely automatic. It takes 2 1/2 hours for each cycle with 2 hours for freezing and 1/2 hour for thawing. After a specified number of cycles, the specimens brought to the thaw temperature to determine the weight, length and transit time, from which the change in weight, length change and ultrasonic pulse velocity are calculated. The test was terminated after 300 cycles.

2.7.2.4.1 Change in Weight

The weighing operation was done by using an electric balance with a capacity up 13 Kg and 1 g sensitivity. At 0 cycles, the weight of the specimens was determined (W_0). To find the weight loss, the specimens were weighed after n cycles and compared to the initial weight.

$$\textbf{\textit{Weight Change}} = \frac{w_1 - w_0}{w_0} \times 100\%$$

where:
- W_0 = Weight at 0 cycles, Kg.
- W_1 = Weight at n cycles, Kg.

2.7.2.4.2 *Length Change*

The length of specimens was determined by using length comparator (Figure 2.9). To estimate the length change, the length comparator at 0 and n cycles was determined.

$$L_c = \frac{(L_2 - L_1)}{L_g} \times 100\%$$

- L_c = length change of the test specimen after c cycles of freezing and thawing, %.
- L_1 = length comparator reading at 0 cycles.
- L_2 = length comparator reading at n cycles.
- L_g = the effective gage length between the inner most ends of the gage studs, 247 mm.

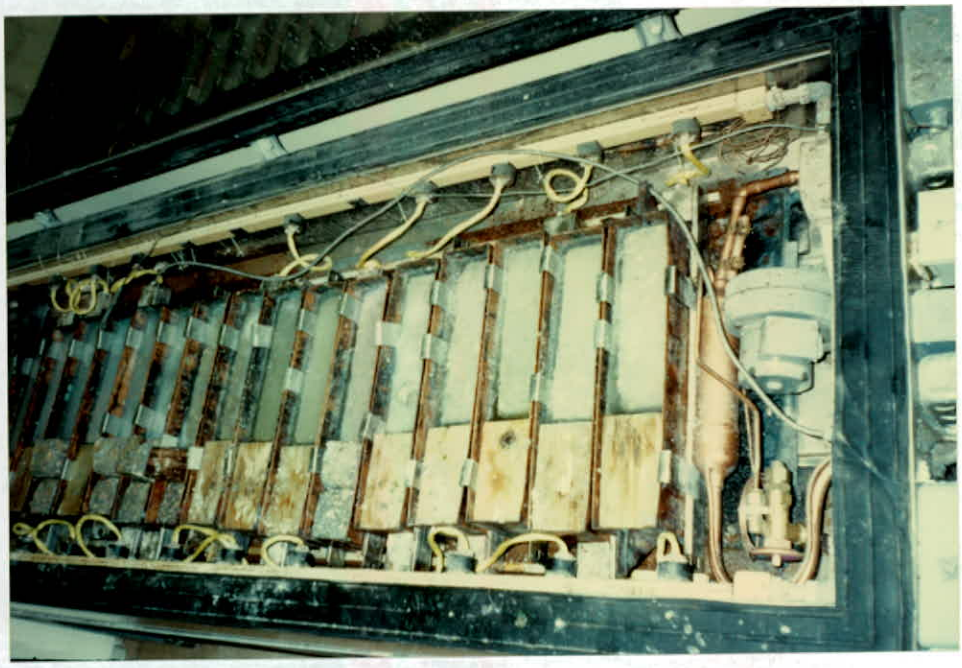

Figure 2.8 : Rapid freeze - thaw apparatus, Model H - 3185.

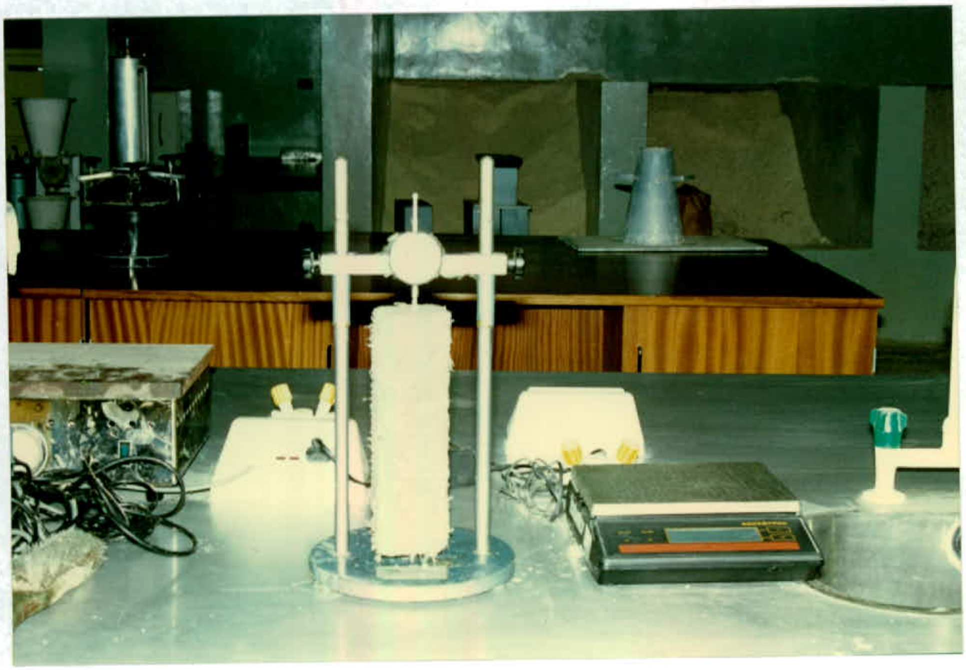

Figure 2.9 : Length measurement comparator.

2.7.2.4.3 Velocity of Ultrasonic Pulses in Concrete.

The pulse velocity test was conducted according to the British standards BS. 1881 : Part 203 : 1986 " Recommendations for measurement of velocity of Ultrasonic Pulses in Concrete". The test was carried out using Portable ultrasonic non - destructive digital indicating tester, Pundit type (Figure 2.10) .

To make measurements of pulse velocity the transducer and the receiver were placed on opposite faces of the specimen, this arrangement is known as direct transmission. The transit time, time taken for an ultrasonic pulse to travel from the transmitting transducer to the receiving one passing through the interposed concrete, is recorded to the nearest 0.1μs, the pulse velocity (v) is estimated from dividing the path length by the transit time

$$v = \frac{l}{t}$$

where:

- v : ultrasonic pulse velocity, Km/s.
- l : path length, mm
- t : transit time, μs

The velocity was measured at different cycles. At the end of the test the durability factor (DF) was evaluated as the square of the ratio between the pulse velocity after 300 freeze - thaw cycles to the initial pulse velocity (0 cycles).

$$DF = \left(\frac{v_{300}}{v_0}\right)^2 \times 100\%$$

where:

- DF = durability factor, %
- v_{300} = pulse velocity after 300 cycles.
- v_0 = initial pulse velocity at o cycles.

This durability coefficient based on pulse velocity measurements is similar to the usual durability factor based on dynamic modulus of elasticity measurements, according to Neville, the dynamic modulus of elasticity is a function of the square of pulse velocity, density and Poisson's ratio of concrete. Pigeon *et al.*, (1981).

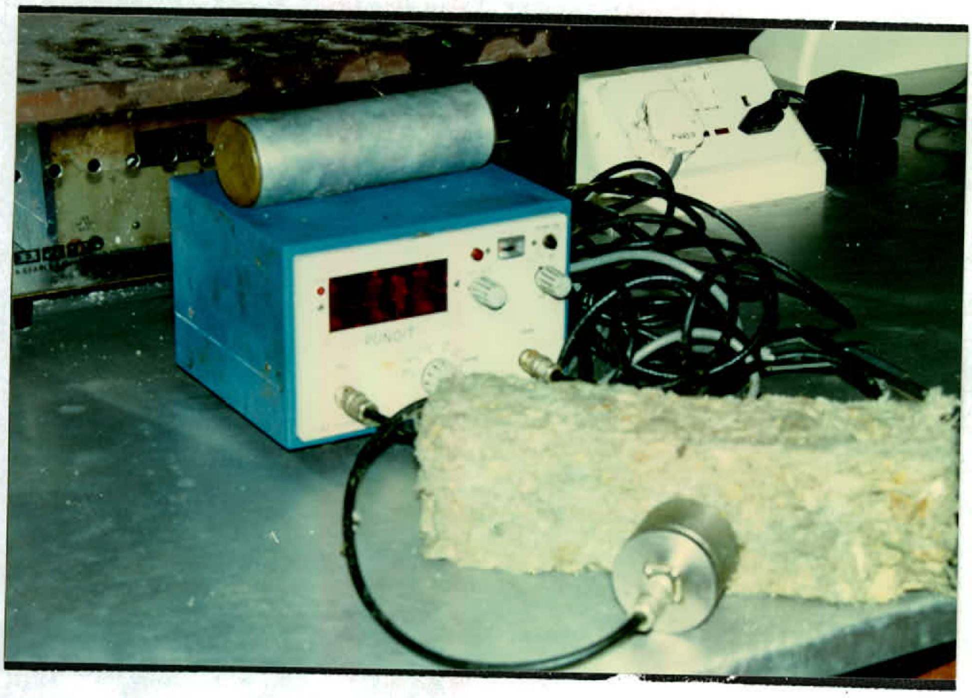

Figure 2.10 : Portable ultrasonic non - destructive digital indicating tester, Pundit type.

CHAPTER THREE

TEST RESULTS AND ANALYSIS

3.1 INTRODUCTION

The aim of this research as repeatedly mentioned is to determine the effect of adding alkali resistant glass fibers (*AR Cem-FIL*) on the properties of concrete. For better understanding of this effect, mixes with different fiber volume fractions and different fiber lengths were mixed for two sets of concrete grades namely 20 MPa and 40 MPa. The results, for control mixes as well as for mixes incorporating AR glass fibers, obtained from the experimental program which included : slump, air content, unit weight, compressive strength, tensile strength and durability are summarized and analyzed in the next sections.

3.2 FRESH STATE

3.2.1 Workability

Table 3.1 shows the slump values and degree of workability for the two grades of concrete (20 & 40 MPa) with different fiber concentrations and fiber lengths. It is evident from the data obtained that there is a considerable loss of workability in concrete incorporating fibers and the workability of the concrete reinforced with alkali resistant glass fibers was generally low to very low.

Figure 3.1 illustrates the effect of fiber lengths and fiber percentages on slump value from which it is obvious that increasing the fiber content the slump value decreases rapidly and the mixes tend to be not workable and not easy to handle, also that the 12 mm fibers gave a higher slump than the 24 mm fibers. The low values of slump can be attributed to the fact that :-

- Fibers tend to have relatively large surface areas (Mindess *et al.*, 1981), so that the same amount of water used results in a somewhat decreased workability.
- Glass fiber bundles are porous themselves, Majumdar,(1975) so they absorb water between filaments making up each individual fiber .

The slump obtained for all mixes was true slump except for the control mix for grade 20 MPa where the slump was collapse type (Figures 3.2 to 3.4). The rate of loss of workability in concrete grade 40 MPa was greater than that of concrete grade 20 MPa since a stiff consistence mix was obtained at 1.5%V_f in the latter while it is obtained at 0.75% V_f in the former.

Table 3.1 : The Slump values and the degree of workability for the two grades of concrete strength 20 MPa and 40 MPa

Concrete Grade : 20 MPa				Concrete Grade : 40 MPa			
Fiber Length mm	Fiber Percent %	Slump Value mm	Degree of Workability	Fiber Length mm	Fiber Percent %	Slump Value mm	Degree of Workability
-	0	150	High	-	0	70	Medium
12	0.5	60	Medium	12	0.25	10	Very Low
12	0.75	40	Low	12	0.5	5	Very Low
12	1.0	10	Very Low	12	0.75	3	Very Low
12	1.5	5	Very Low				
24	0.5	30	Low	24	0.25	3	Very Low
24	0.75	15	Low	24	0.5	2	Very Low
24	1.0	12	Very Low	24	0.75	0	Very Low
24	1.5	0	Very Low				

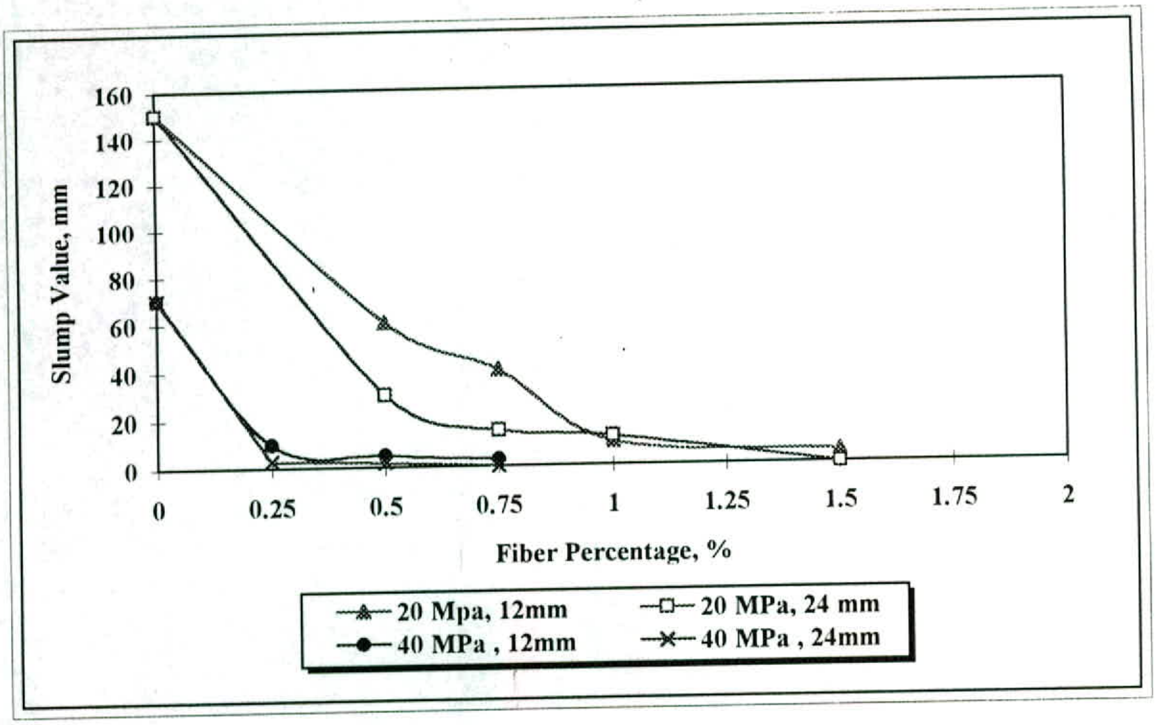

Figure 3.1 : The influence of fiber percentages on slump of concrete with different fiber lengths (12mm & 24 mm) for the two grades of concrete strengths.

Figure 3.2 : The slump for control mix of concrete grade 20 MPa, collapse slump

Figure 3.3 : The slump for concrete grade 20 MPa with glass fiber ratio of 0.75%V_f and fiber length of 12mm

Figure 3.4 : The slump for concrete grade 20 MPa with glass fiber ratio of 1.5%V_f and fiber length of 24mm

3.2.2 Air Content

Table 3.2 shows the results of air content test for the two classes of concrete strengths from which it is noticed that more air was entrapped in concrete mixes containing fibers than in control mixes.

Table 3.2 : Air content for control mixes as well as for mixes incorporating fibers.

Concrete Grade : 20 MPa			Concrete Grade : 40 MPa		
Fiber Ratio %	Fiber Length mm	Air Content %	Fiber Ratio %	Fiber Length mm	Air Content %
0	-	1.7	0	-	2.0
0.5	12	2.2	0.25	12	2.2
0.75	12	1.9	0.5	12	2.2
1.0	12	2.4	0.75	12	2.4
1.5	12	2.6			
0.5	24	1.9	0.25	24	2.3
0.75	24	1.6	0.5	24	2.2
1.0	24	2.5	0.75	24	2.5
1.5	24	2.9			

The effect of different fiber ratios and different fiber lengths on air content is illustrated in Figures 3.5 and 3.6. Since there is a variability in the results a regression analysis was performed. A linear model was adopted in the regression analysis since the R-squared value (also called the coefficient of determination, and is often used to judge the adequacy of a regression model, the R^2 value lies between 0 and 1) is reliable and its value is shown in the above mentioned figures.

It is obvious from the graphs that the air content increases by increasing the fiber ratio and that the concrete mixes incorporating 12mm fibers have lower air content than the 24mm fibers.

These phenomena can be explained as :-

- Long fibers with high volume fractions tend to interlock in some fashion to form a mat from which it is very difficult to dislodge them and more bubbles are entrapped.
- Using 20mm maximum aggregate size will affect the fiber distribution. Mixes contain large aggregate size tend to have a low fraction of mortar due to which the fibers can not move freely and this will lead to bunching and greater interaction of fibers between large aggregate particles. (Hannant, 1978).

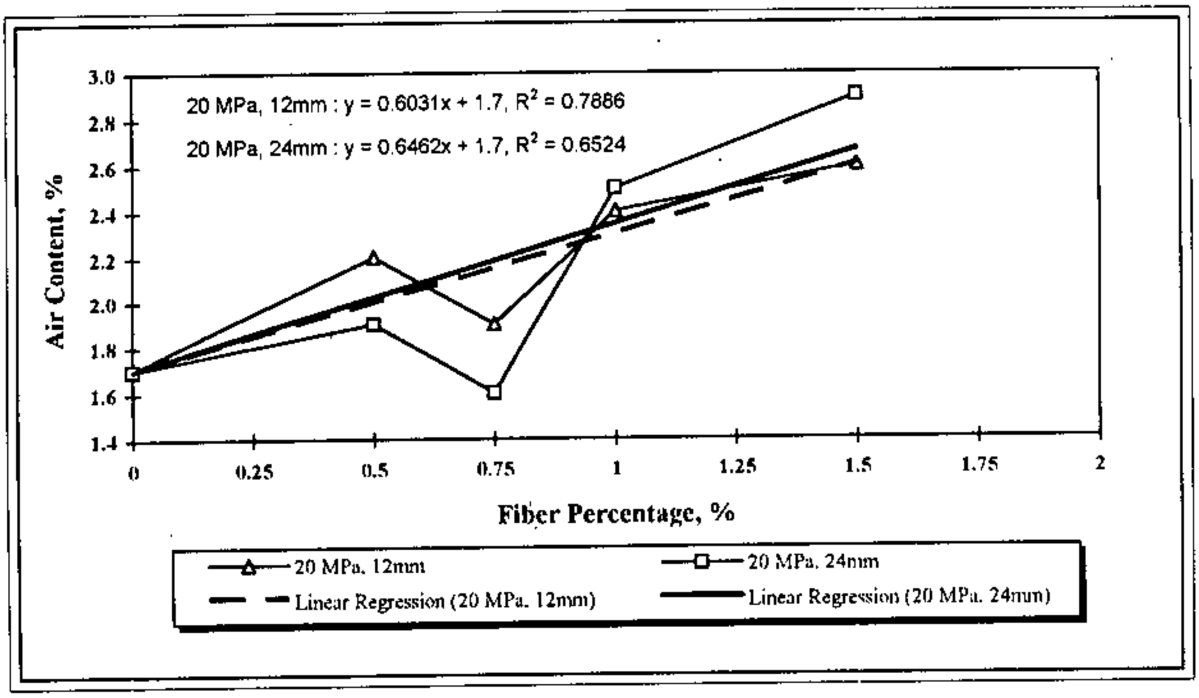

Figure 3.5 : The relationship between the air content and the fiber volume fraction for the two fiber lengths (12 & 24mm) for concrete grade 20 MPa. The experimental data and the regression curves.

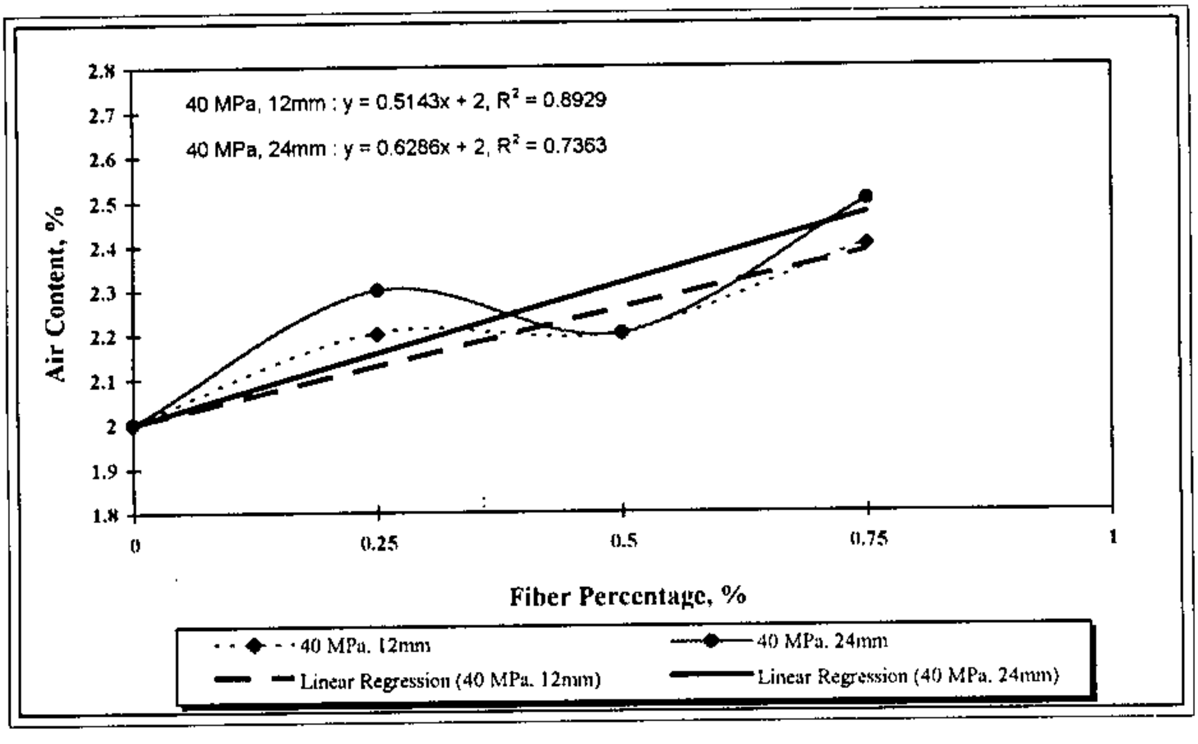

Figure 3.6 : The relationship between the air content and the fiber volume fraction for the two fiber lengths (12 & 24mm) for concrete grade 40 MPa. The experimental data and the regression curves.

3.3 HARDENED STATE

3.3.1 Dry Unit Weight.

The dry unit weight results are presented in Table 3.3. It is clear that there is a considerable loss in density for the mixes reinforced with ***AR Cem-FIL*** fibers. Figures 3.7 and 3.8 show the relationship between the unit weight and the AR glass fiber percentage for the two standard lengths and their linear regression curves. It is obvious that the higher glass fiber volume fraction the lower the unit weight. Increasing the fiber length would reduce the density. This is true since air content increases with greater fiber ratio and with longer fiber as shown in the preceding section. On the other hand, the behavior of 24mm fiber length in concrete grade 40 MPa was different, since its density was greater than for the 12mm fiber length even though the air content was higher, the rate of change is negligible. The scatter in results is due to the fact that increasing the fiber ratio and fiber length, segregation and non homogenous mixes were produced resulting in less accurate data.(Figure 3.9)

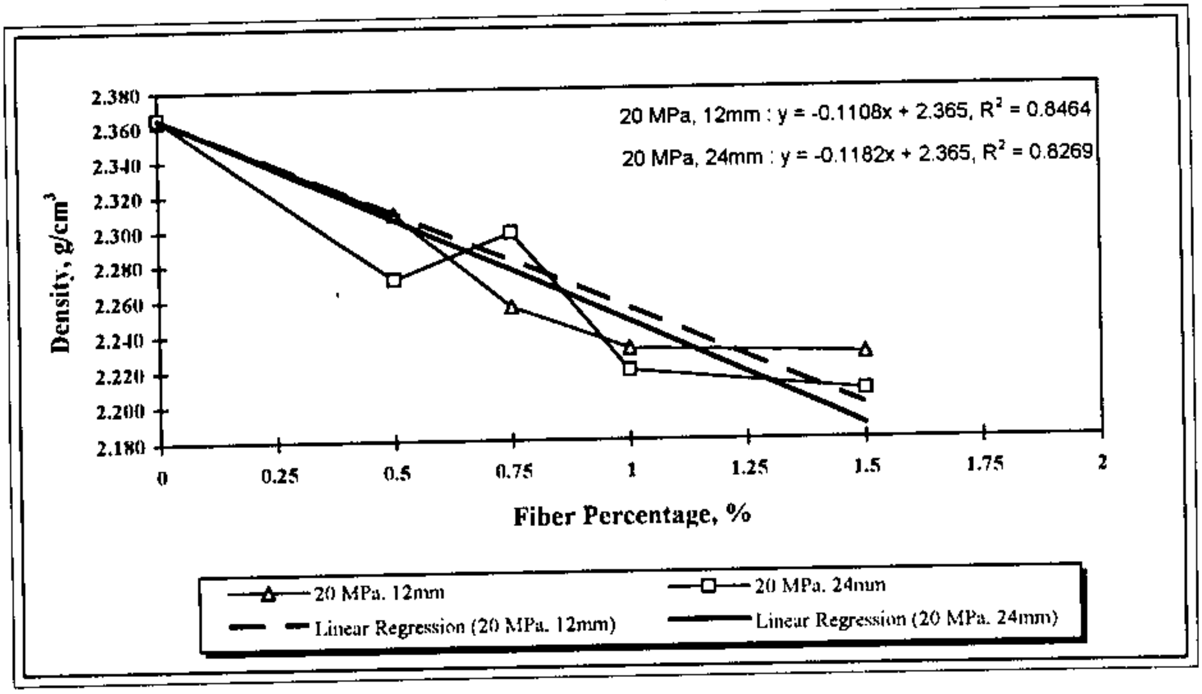

Figure 3.7 : The influence of the fiber length and the fiber concentration on the density of concrete for all mixes of 20 MPa concrete grade and the regression curves.

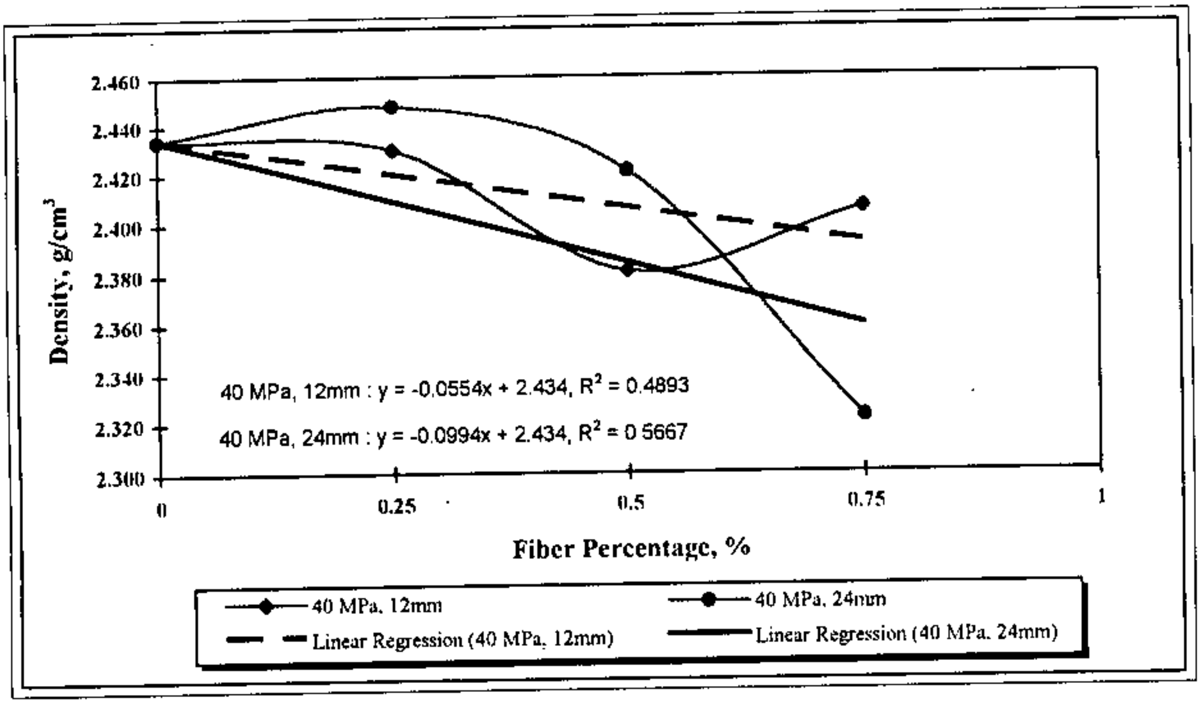

Figure 3.8 : The influence of the fiber length and the fiber concentration on the density of concrete for all mixes of 40 MPa concrete grade and the regression curves.

Table 3.3 : The results of air unit weight tested at 28 days for all mixes

Concrete Grade : 20 MPa			Concrete Grade : 40 MPa		
Fiber Ratio %	Fiber Length mm	Dry Density g/cm^3	Fiber Ratio %	Fiber Length mm	Dry Density g/cm^3
0	-	2.365	0	-	2.434
0.5	12	2.309	0.25	12	2.430
0.75	12	2.255	0.5	12	2.381
1.0	12	2.231	0.75	12	2.406
1.5	12	2.228			
0.5	24	2.271	0.25	24	2.448
0.75	24	2.298	0.5	24	2.421
1.0	24	2.219	0.75	24	2.322
1.5	24	2.207			

Figure 3.9 : The non homogeneity obtained by increasing the fiber ratio and fiber length. This mix contains 0.75%V_f and 24mm fiber length for concrete grade 40MPa.

3.3.2 *Compressive strength*

The results for the compressive strength and the rate of variation (rate of increase or decrease from the control mix as a percent) for both grades are summarized in Table 3.4. The data indicate that the addition of fibers had no positive effect on the compressive strength of concrete, on the contrary the compressive strength for control mixes was higher than mixes incorporating fibers. An exception to this was the mixes containing 12mm fiber at 0.25 and 0.5%V_f in grade 40 MPa. This may be related to the contribution of ***Melment L-10*** which increases the compressive strength by reducing the water/cement ratio at unchanged consistency.

Table 3.4 : Compressive strength @ 28 days and the rate of variation for all the fiber concentrations and the two used fiber lengths.

Concrete Grade 20 MPa				Concrete Grade 40 MPa			
Fiber Ratio %V_f	Fiber Length mm	Compressive Strength MPa	Rate of Variation %	Fiber Ratio %V_f	Fiber Length mm	Compressive Strength MPa	Rate of Variation %
0	-	22.2	-	0	-	50.7	-
0.5	12	20.3	-8.6	0.25	12	51.8	2.2
0.75	12	18.7	-15.8	0.5	12	52.2	3
1.0	12	21.0	-5.4	0.75	12	47.4	-6.5
1.5	12	17.0	-23.4				
0.5	24	17.8	-19.8	0.25	24	48.5	-4.3
0.75	24	20.4	-8.1	0.5	24	46.3	-8.6
1.0	24	19.8	-10.8	0.75	24	40.2	-20.7
1.5	24	17.5	-21.1				

Figures 3.10 and 3.11 show the influence of fiber volume fraction and the effect of fiber length on the compressive strength. For concrete grade of 20 MPa a linear regression 'analysis was adopted from which it is clear that the compressive strength was reduced by increasing the fiber ratios for the two standard fiber lengths. On the other hand, it indicates that the 12mm fiber length has a higher compressive strength than the 24mm but the differences between the two are very small. Meanwhile, a polynomial regression model was adopted for concrete grade of 40 MPa since the R^2 value obtained by this model is higher than the R^2 value resulted from the linear regression.(For 12mm fiber length the R^2 was 0.1603 from linear regression compared to 0.9251 obtained from the polynomial model).

The drop in the compressive strength of glass fiber reinforced concrete may be attributed to the following reasons :

- As the fiber percentage and length are increased, the probability of these fibers nesting together and leaving large voids in the concrete is greater.
- It is believed that glass fibers will suffer severe damage and loss of strength since, during mixing and compacting a considerable abrasion and impact forces are generated by the movement of aggregates. Zonsveld, (1975).

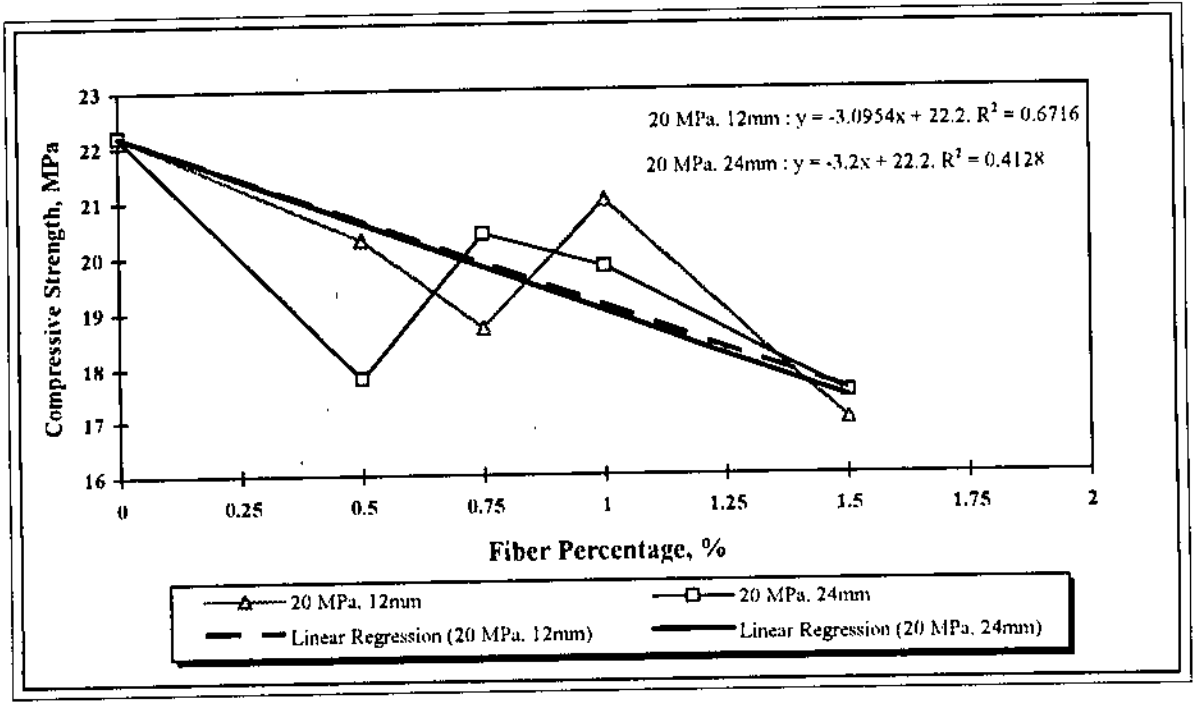

Figure 3.10 : The effect of different fiber lengths and different fiber ratios on the compressive strength of concrete grade 20 MPa and the regression curves.

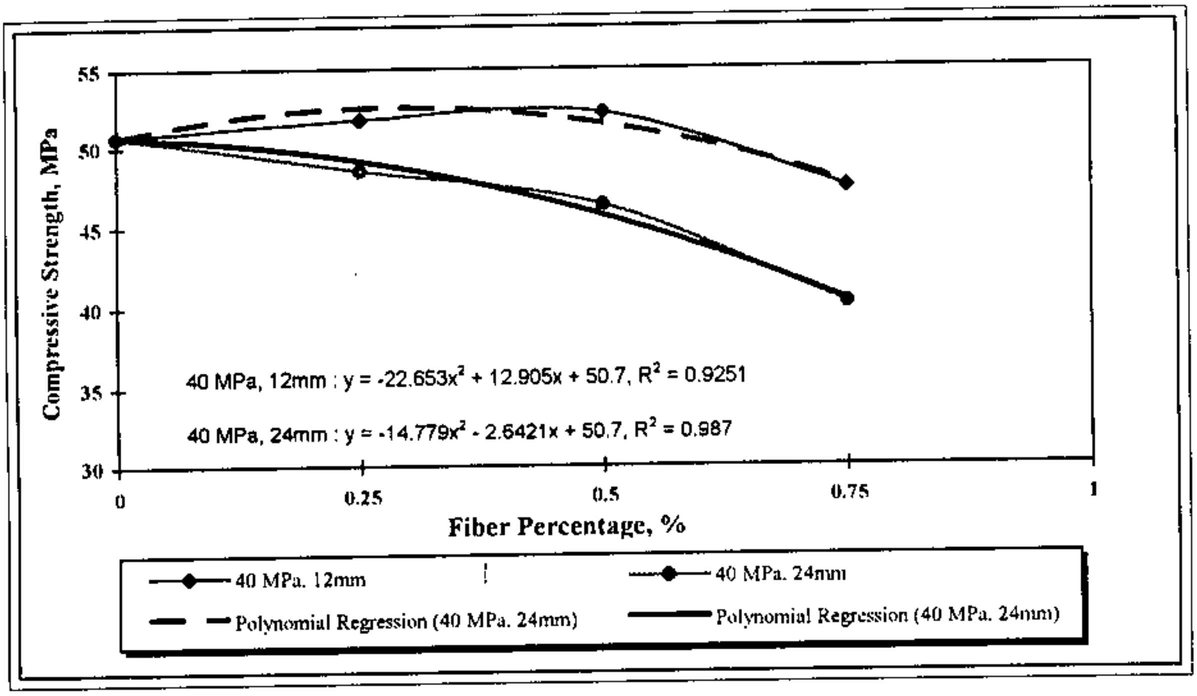

Figure 3.11 : The effect of different fiber lengths and different fiber ratios on the compressive strength of concrete grade 40 MPa and the regression curves.

3.3.3 *Tensile Strength*

The results for the tensile strength at the age of 7, 14 and 28 days for the control mixes as well as for the mixes reinforced with fibers are shown in Table 3.5. Figures 3.12 to 3.15 indicate the relationship between the fiber volume fraction and the tensile strength with the polynomial regression curves. It is evident, as with conventional concrete, glass fiber reinforced concrete exhibits a gain of strength with time, this leads to the fact that bond improves with age.

Table 3.5 : The tensile strength tested at 7,14 and 28 days for all the mixes.

Concrete Grade : 20 MPa					Concrete Grade : 40 MPa				
Fiber Ratio %V_f	Fiber Length mm	Tensile Strength MPa			Fiber Ratio %V_f	Fiber Length mm	Tensile Strength MPa		
		@ 7 days	@ 14	@ 28 days			@ 7 days	@ 14 days	@ 28 days
0	-	0.98	1.62	2.04	0	-	3.89	4.24	4.35
0.5	12	1.55	1.84	2.44	0.25	12	3.84	4.12	4.34
0.75	12	1.48	1.73	2.19	0.5	12	3.71	4.28	4.51
1.0	12	1.60	1.65	2.27	0.75	12	3.91	4.00	4.32
1.5	12	1.43	1.77	2.18					
0.5	24	1.67	1.83	2.49	0.25	24	3.78	4.16	4.72
0.75	24	1.37	1.68	2.17	0.5	24	3.94	4.49	4.68
1.0	24	1.85	1.89	2.16	0.75	24	3.40	3.48	3.96
1.5	24	1.43	1.88	1.83					

The regression curves point out that there is an increase in tensile strength with increasing glass fiber ratio up to a limit beyond which fiber addition does not improve the strength. These ratio are summarized below:

Concrete Grade, MPa	*Fiber Length, mm*	*Effective Ratio, %V_f*
20	12	0.75 - 1.0
20	24	0.75
40	12	0.25 - 0.5
40	24	0.25

The apparent loss in the tensile strength of the matrix beyond a certain percentage (%V_f) can be contributed to the increase in its porosity and the fact that fibers are susceptible to damage by the movement of aggregates.

The effect of fiber length on the tensile strength for the different volume fractions is illustrated in the Figures 3.16 to 3.22. It is clear that 24mm fiber length produces a stronger product than the 12mm, an exception to this behavior was noticed in concrete mix (grade 40 MPa) containing 0.75%V_f where the reverse was true. In general, the increase in the tensile strength of concrete incorporating fibers can be associated to the fact that the glass modulus of elasticity and the strand tensile strength are greater than the matrix (Table 3.6).

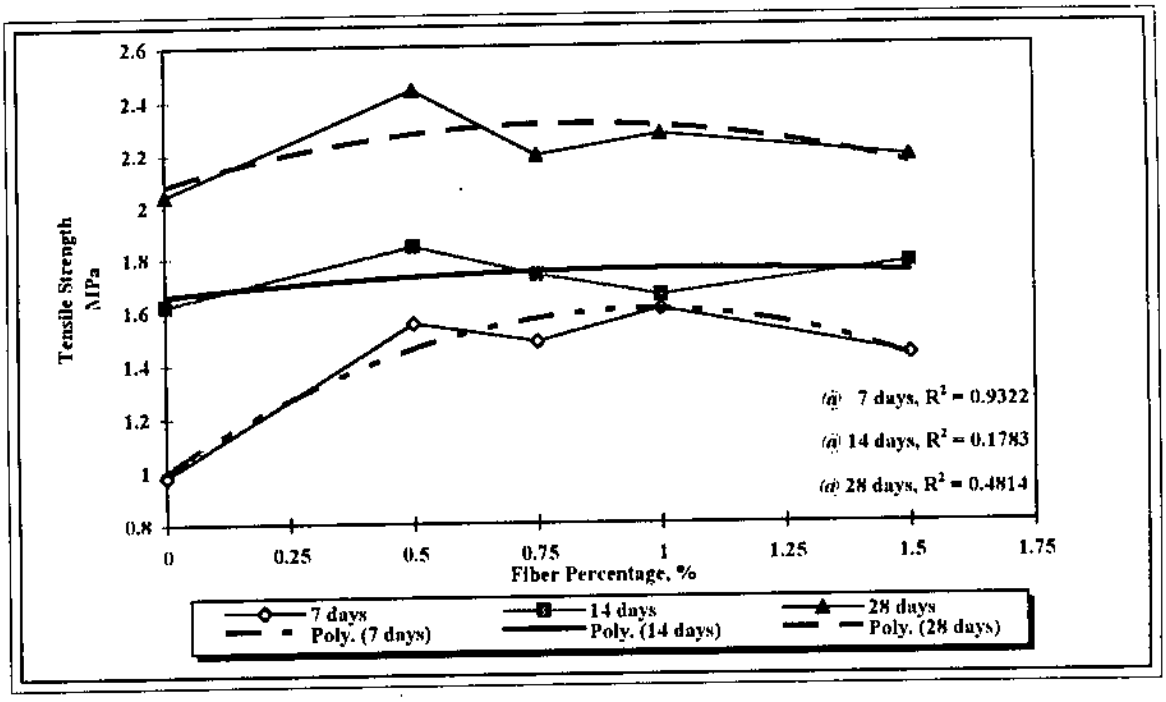

Figure 3.12 : The influence of fiber volume fraction on the tensile strength tested at 7,14 and 28 days for concrete grade 20 MPa and fiber length 12mm with the polynomial regression curves.

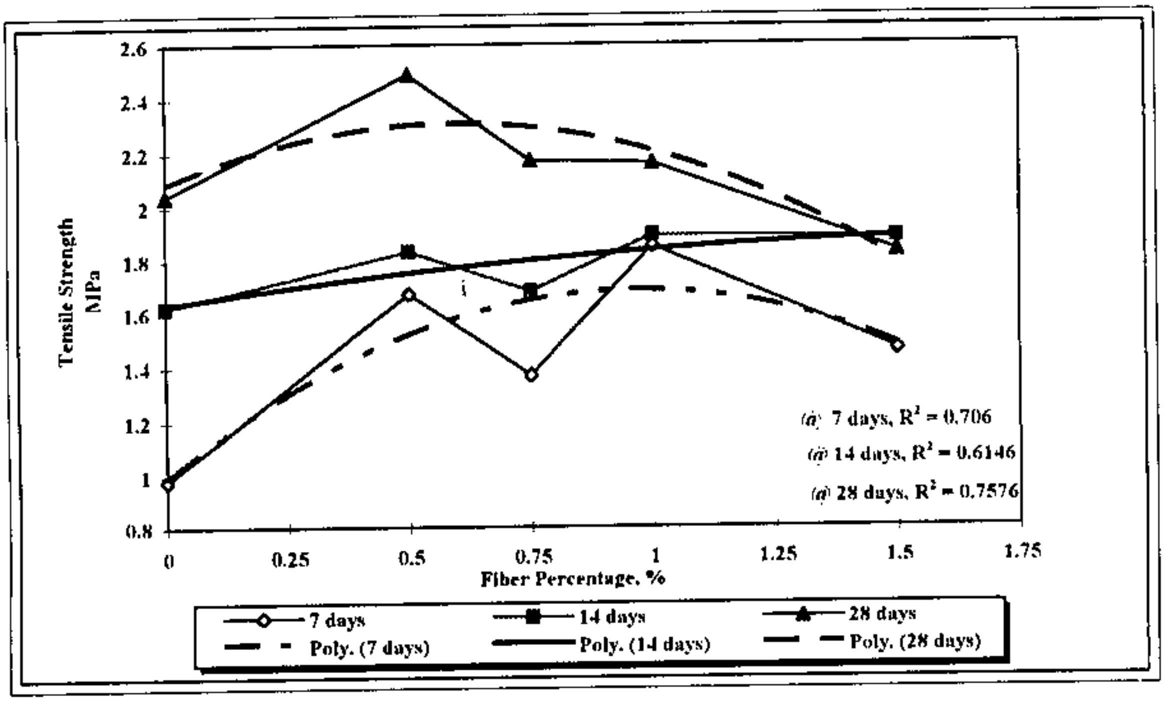

Figure 3.13 : The influence of fiber volume fraction on the tensile strength tested at 7,14 and 28 days for concrete grade 20 MPa and fiber length 24mm with the polynomial regression curves.

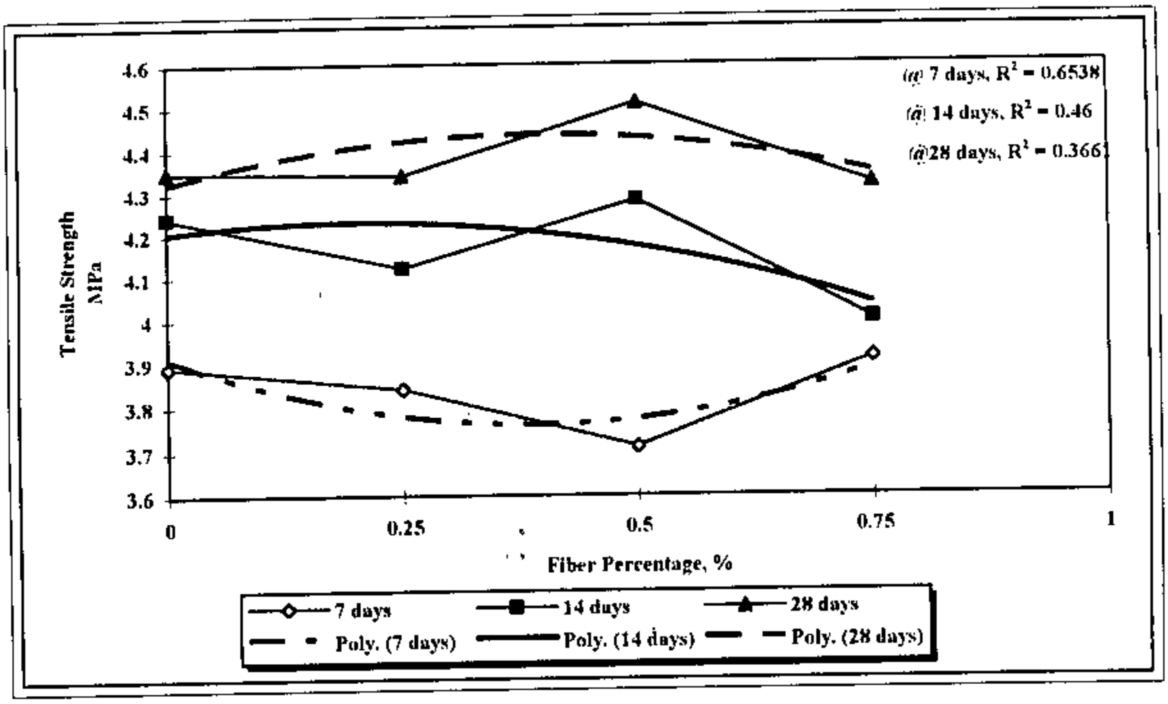

Figure 3.14 : The influence of fiber volume fraction on the tensile strength tested at 7,14 and 28 days for concrete grade 40 MPa and fiber length 12mm with the polynomial regression curves.

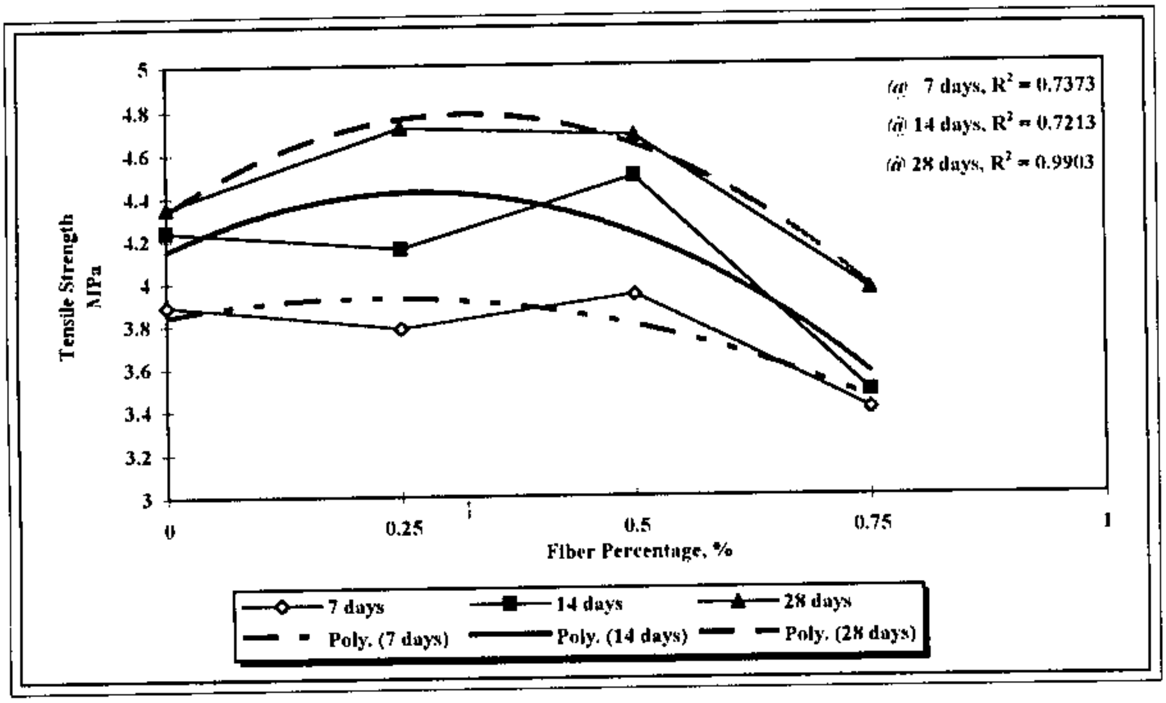

Figure 3.15 : The influence of fiber volume fraction on the tensile strength tested at 7,14 and 28 days for concrete grade 40 MPa and fiber length 24mm with the polynomial regression curves.

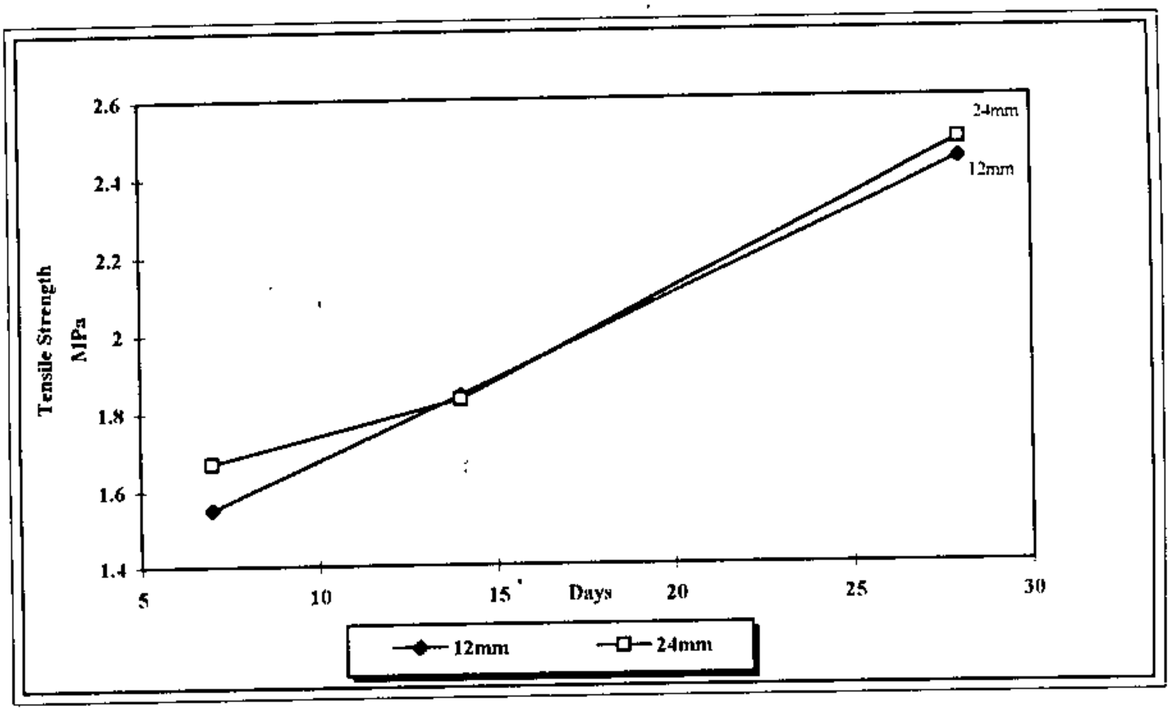

Figure 3.16 : The effect of fiber length on the tensile strength tested at 7,14 and 28 days for concrete grade 20 MPa and fiber ratio 0.5%V_f.

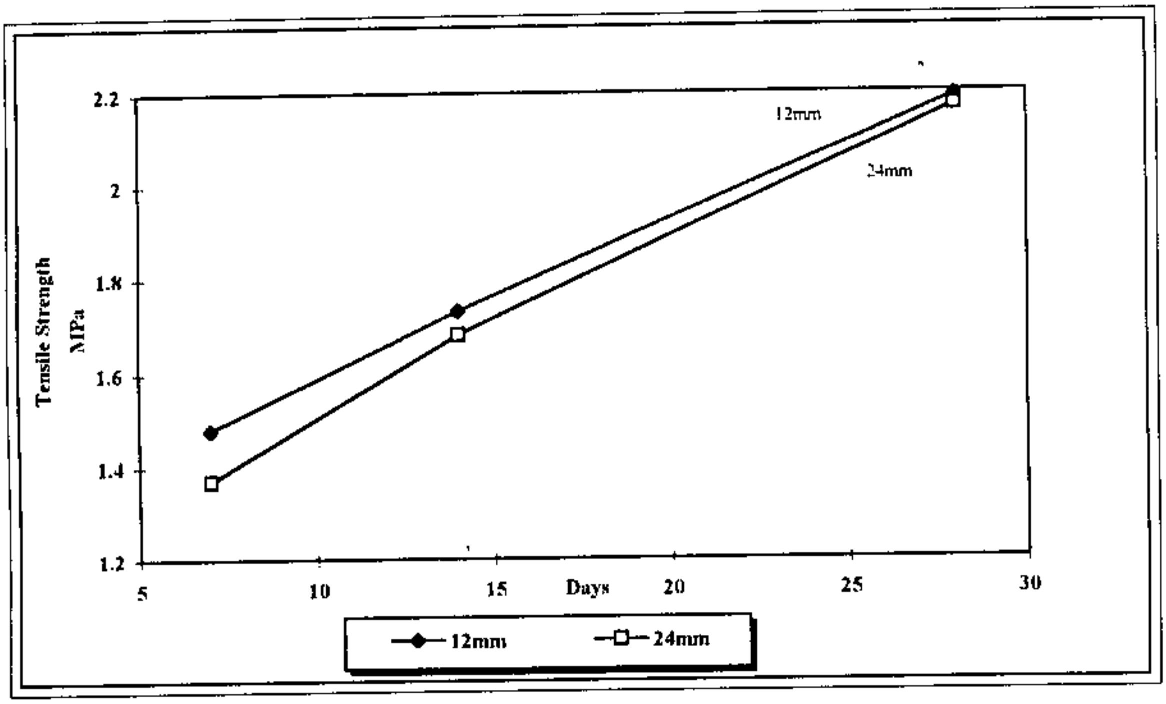

Figure 3.17 : The effect of fiber length on the tensile strength tested at 7,14 and 28 days for concrete grade 20 MPa and fiber ratio 0.75%V_f.

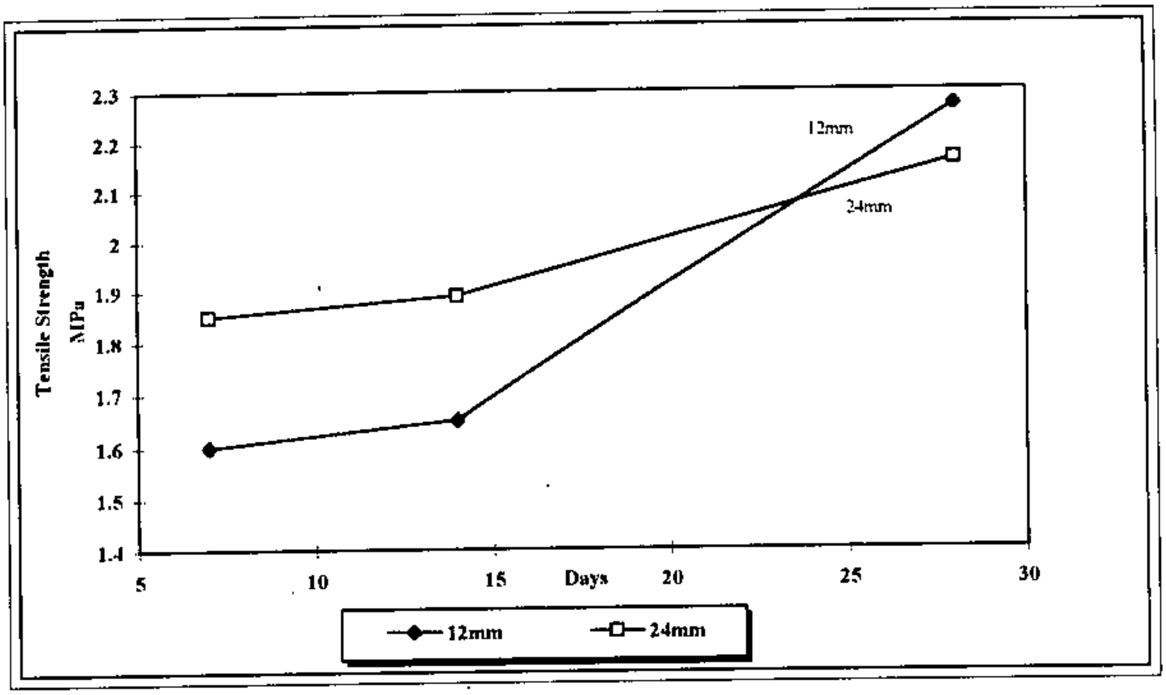

Figure 3.18 : The effect of fiber length on the tensile strength tested at 7,14 and 28 days for concrete grade 20 MPa and fiber ratio 1.0%V_f.

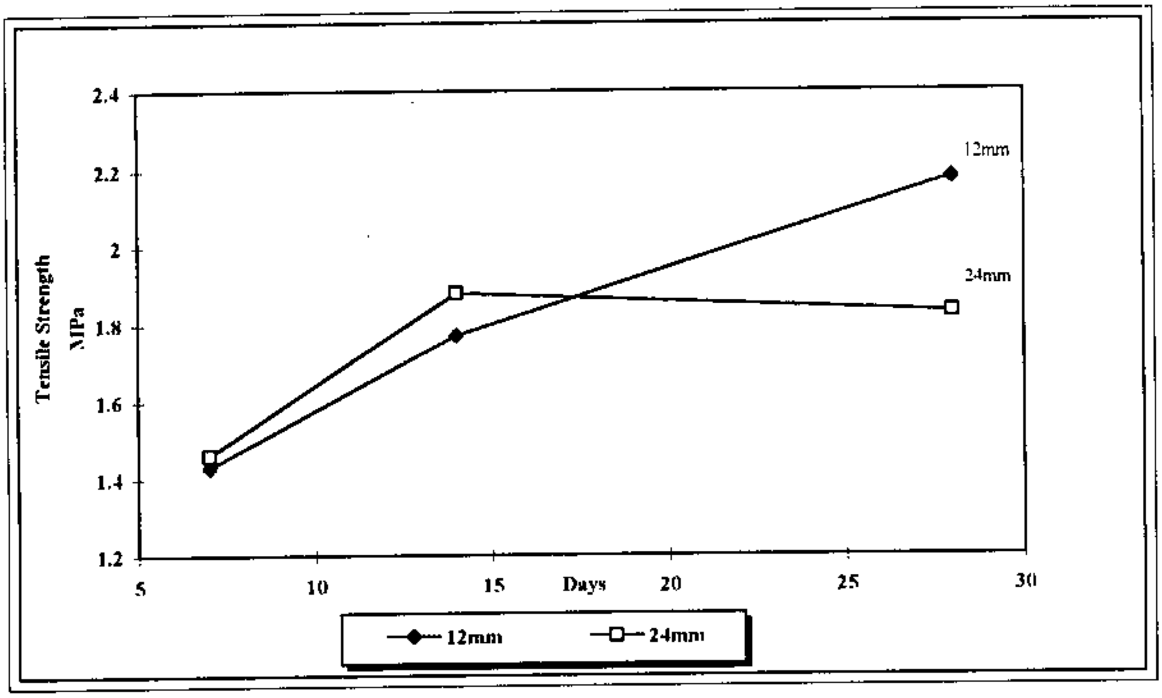

Figure 3.19 : The effect of fiber length on the tensile strength tested at 7,14 and 28 days for concrete grade 20 MPa and fiber ratio 1.5%V_f.

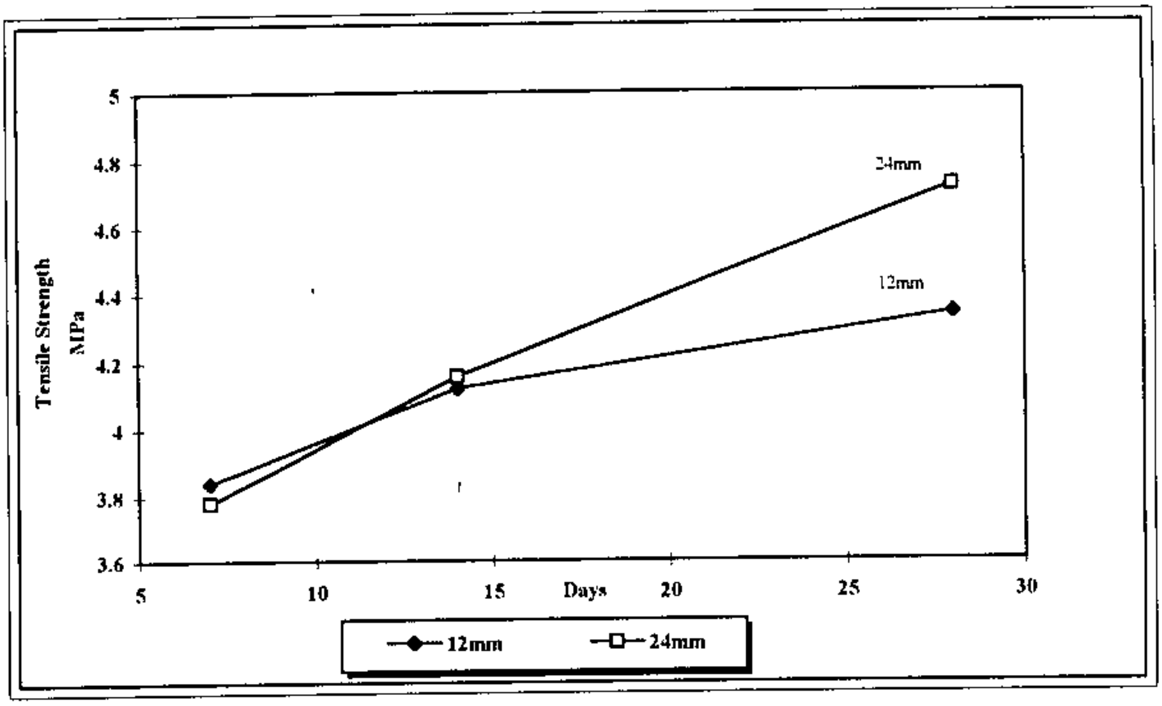

Figure 3.20 : The effect of fiber length on the tensile strength tested at 7,14 and 28 days for concrete grade 40 MPa and fiber ratio 0.25%V_f.

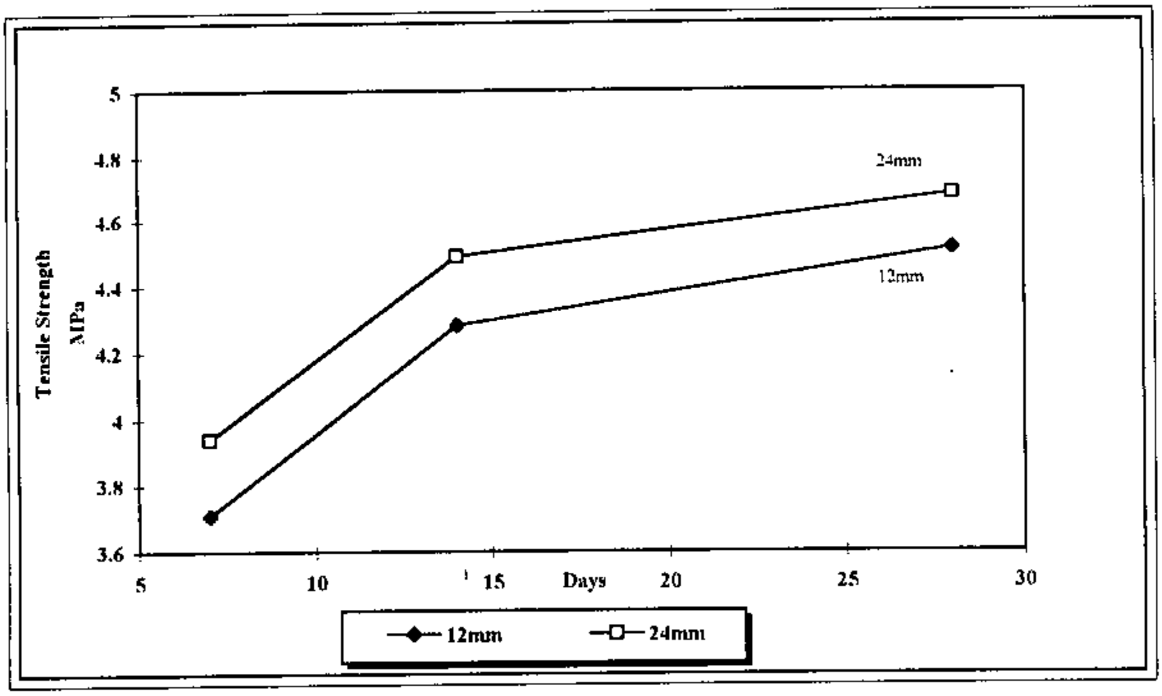

Figure 3.21: The effect of fiber length on the tensile strength tested at 7,14 and 28 days for concrete grade 40 MPa and fiber ratio 0.5%V_f.

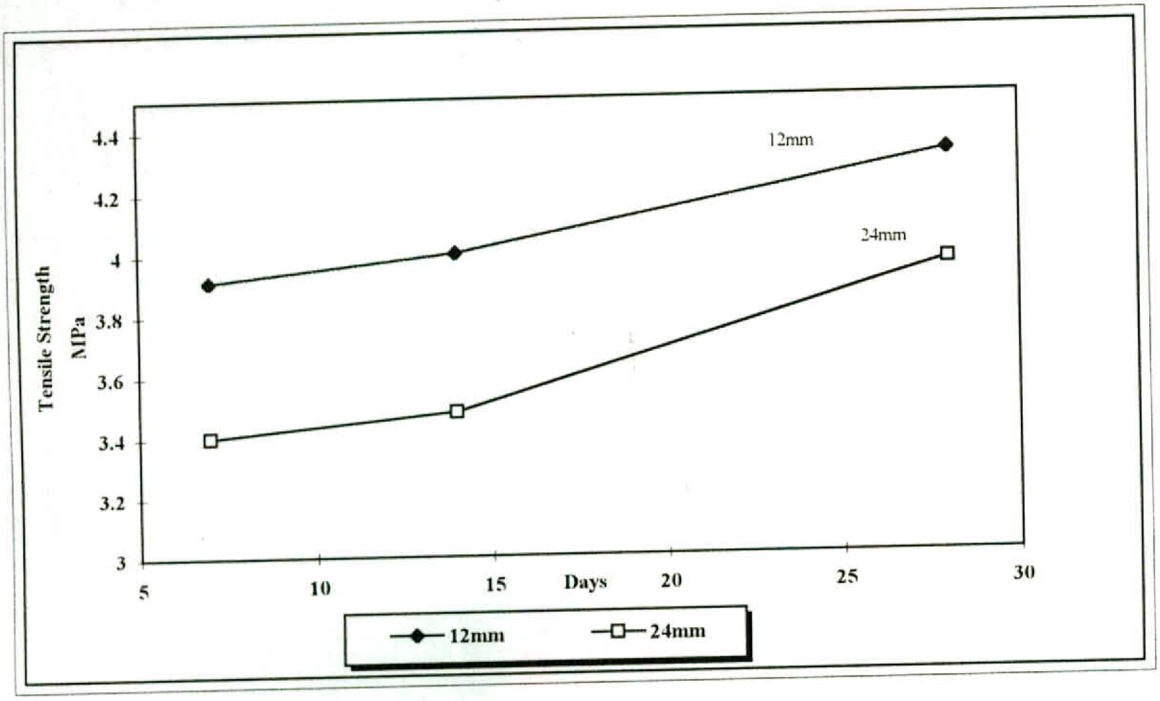

Figure 3.22: The effect of fiber length on the tensile strength tested at 7,14 and 28 days for concrete grade 40 MPa and fiber ratio 0.75%V_f.

Figure 3.23: The mode of failure for concrete cylinders with and without fiber.

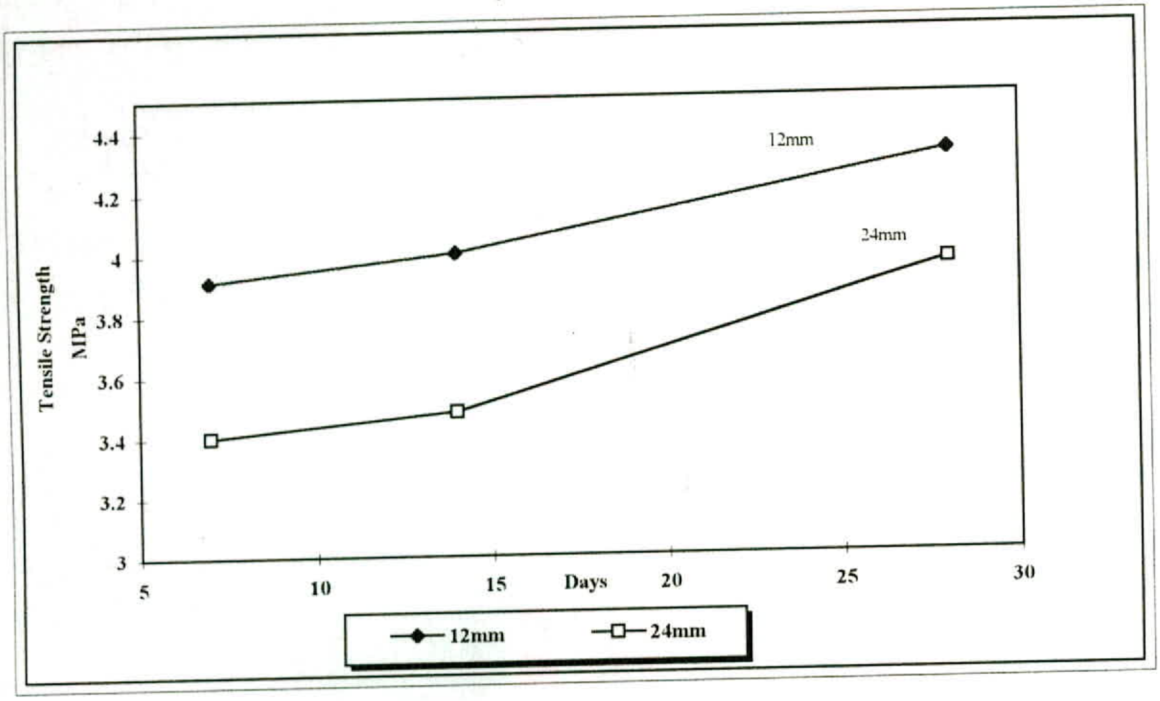

Figure 3.22: The effect of fiber length on the tensile strength tested at 7,14 and 28 days for concrete grade 40 MPa and fiber ratio 0.75%V_f.

Figure 3.23: The mode of failure for concrete cylinders with and without fiber.

Table 3.6 : Typical properties of matrix and glass fiber (Hannant, 1978).

Material	Young's Modulus, MPa	Tensile Strength, MPa
Ordinary portland concrete	25000 - 40000	1 - 4
Glass Cem-FIL strand	72000	1700

The unreinforced cylinders failed suddenly and were split into separate halves, while the fiber reinforced specimens merely cracked at failure without any sign of collapse or separation (Figure 3.23).

3.3.4 Durability

3.3.4.1 Change in Length

Tables 3.7 and 3.8 show the results of the change in length of specimens subjected to freezing and thawing cycles carried out as part of durability test for the two concrete grades 20 and 40 MPa respectively.

Figures 3.24 to 3.29 illustrate the influence of the presence of AR glass fiber with different percentage and different fiber lengths on the change in length of the specimen for the 20MPa concrete grade. The results indicate that expansion took place in the specimens and its value is very high since the acceptable limit of expansion should be 0.1%. Length change (expansion) is an indicator of internal disruption and deterioration in the concrete. In general, glass reinforced concrete

Table 3.7 : The change in length of specimen after n cycles of freezing and thawing for concrete grade 20 MPa, for both the fiber lengths and all the fiber ratios.

Concrete Grade : 20 MPa Change in Length, %																								
Cycle No.		0	18	27	45	54	63	72	90	99	108	117	135	144	162	180	189	207	225	234	252	270	279	300
Fiber Percent	Fiber Length																							
0	-	0.00			0.030		0.120		0.120		0.221		0.219		0.273	0.332			0.389		0.441	0.520		0.636
0.5	12	0.00			0.028		0.071		0.123		0.130		0.146		0.190	0.239			0.209		0.267	0.291		0.409
0.75	12	0.00			0.012		0.065		0.204		0.172		0.217		0.257	0.370			0.403		0.453	0.522		0.571
1	12	0.00		0.059	0.083			0.083		0.069		0.170			0.198		0.241	0.160		0.267	0.338		0.445	0.500
1.5	12	0.00		0.049	0.099			0.123		0.158		0.251			0.160		0.162	0.225		0.249	0.225		0.227	0.322
0.5	24	0.00	0.024		0.047			0.053	0.146				0.103		0.126	0.168		0.126	0.095		0.109	0.095		0.164
0.75	24	0.00		0.002		-0.050		0.121				0.026		0.079	0.111		0.148	0.154		0.190	0.209		0.294	0.235
1	24	0.00		-0.020	0.093				0.103			0.115	0.194		0.221	0.200		0.154	0.111		0.130	0.022		0.142
1.5	24	0.00	0.073		0.241		0.221					0.259		0.314	0.291		0.279	0.300		0.298	0.332		0.350	0.376

Table 3.8 : The change in length of specimen after n cycles of freezing and thawing for concrete grade 40 MPa, for both the fiber lengths and all the fiber ratios.

Concrete Grade : 40 MPa Change in Length, %																								
Cycle No.		0	18	27	45	63	72	90	108	117	135	144	153	162	171	189	207	216	225	234	252	262	279	300
Fiber Percent	Fiber Length																							
0	-	0.00		-0.020	0.016			0.038		0.077	0.006			0.026		0.008	0.049		0.123		0.117		0.113	0.279
0.25	12	0.00		0.043	0.142		0.156	0.186				0.209			0.223	0.241		0.259		0.215		0.249	0.310	0.330
0.5	12	0.00	0.095		0.045	0.101		0.103	0.069		0.223		0.237				0.249			0.277	0.241		0.235	0.229
0.75	12	0.00	0.004		0.121	0.170		0.178	0.160		0.267		0.257				0.263			0.269	0.200		0.128	0.120
0.25	24	0.00		0.012	0.097		0.111	0.038				0.164			0.186	0.178		0.180		0.182		0.186	0.283	0.332
0.5	24	0.00	-0.010		0.006	0.067		0.138	0.093		0.108		0.202				0.219			0.241	0.245		0.227	0.243
0.75	24	0.00		0.093	0.109			0.030			0.160	0.168			0.188	0.126		0.217		0.239		0.296		0.336

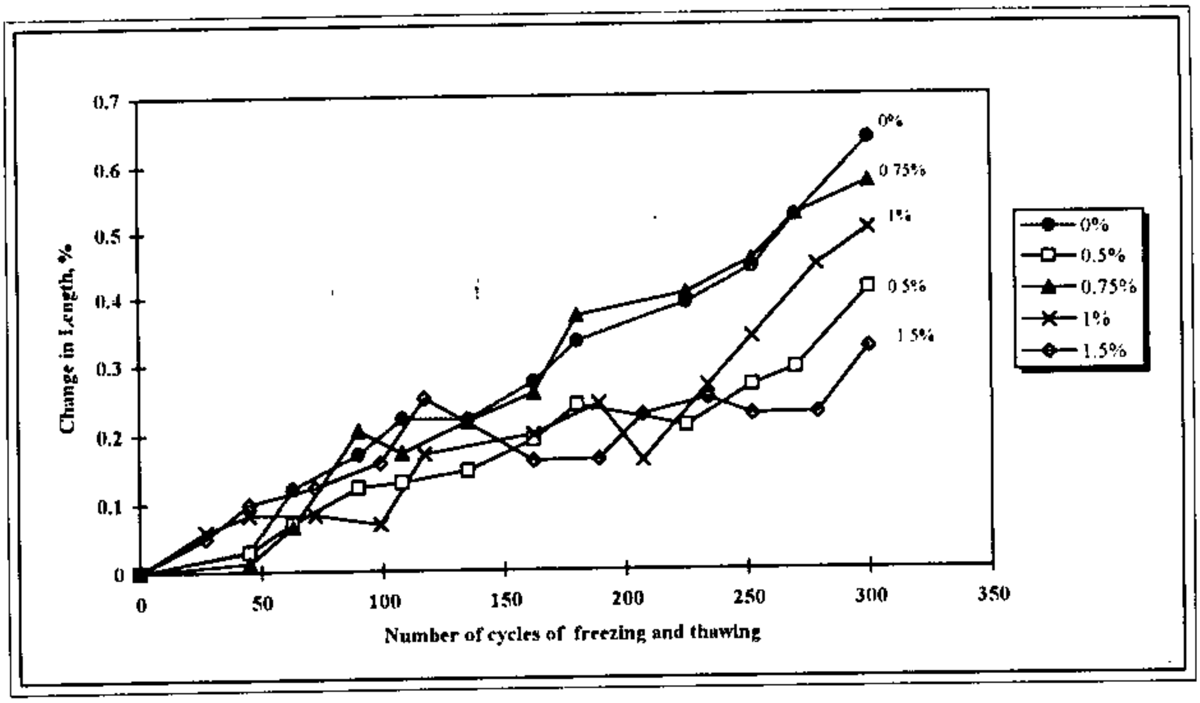

Figure 3.24 : The influence of fiber concentrations on change in length after n cycles of freezing and thawing for concrete grade 20 MPa and 12mm glass fiber length.

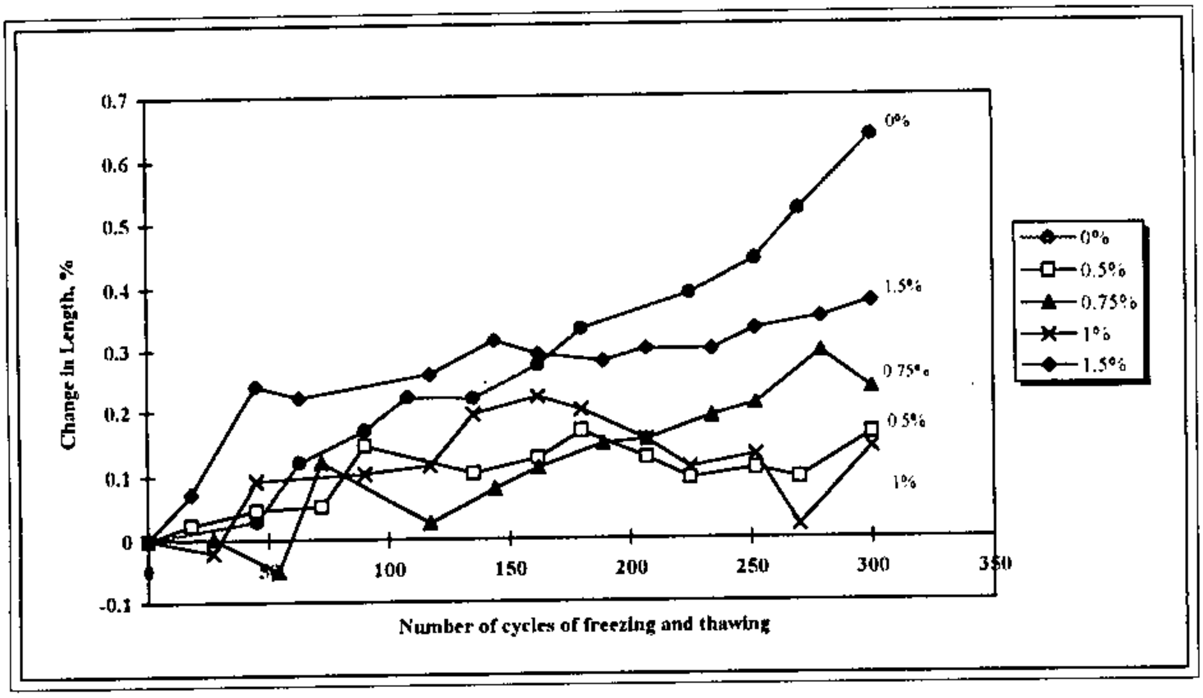

Figure 3.25 : The influence of fiber concentrations on change in length after n cycles of freezing and thawing for concrete grade 20 MPa and 24mm glass fiber length.

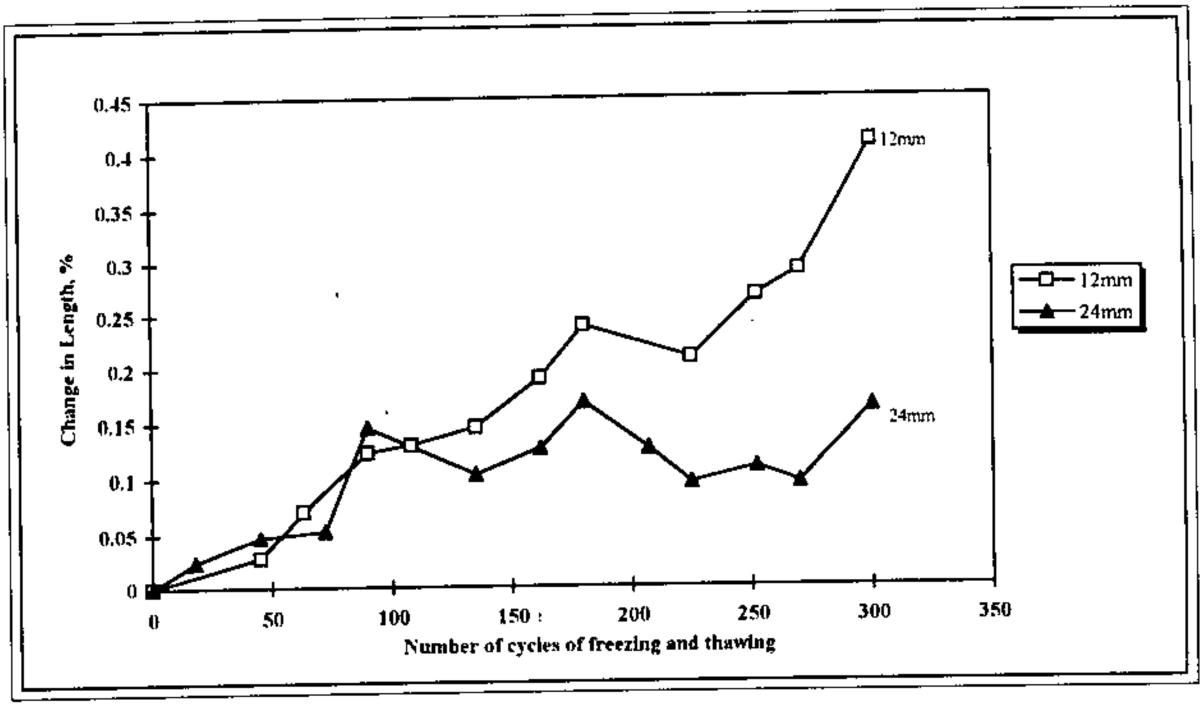

Figure 3.26 : The effect of glass fiber length on change in length of the specimen after n cycles of freezing and thawing for concrete grade 20 MPa and fiber ratio = 0.5% V_f.

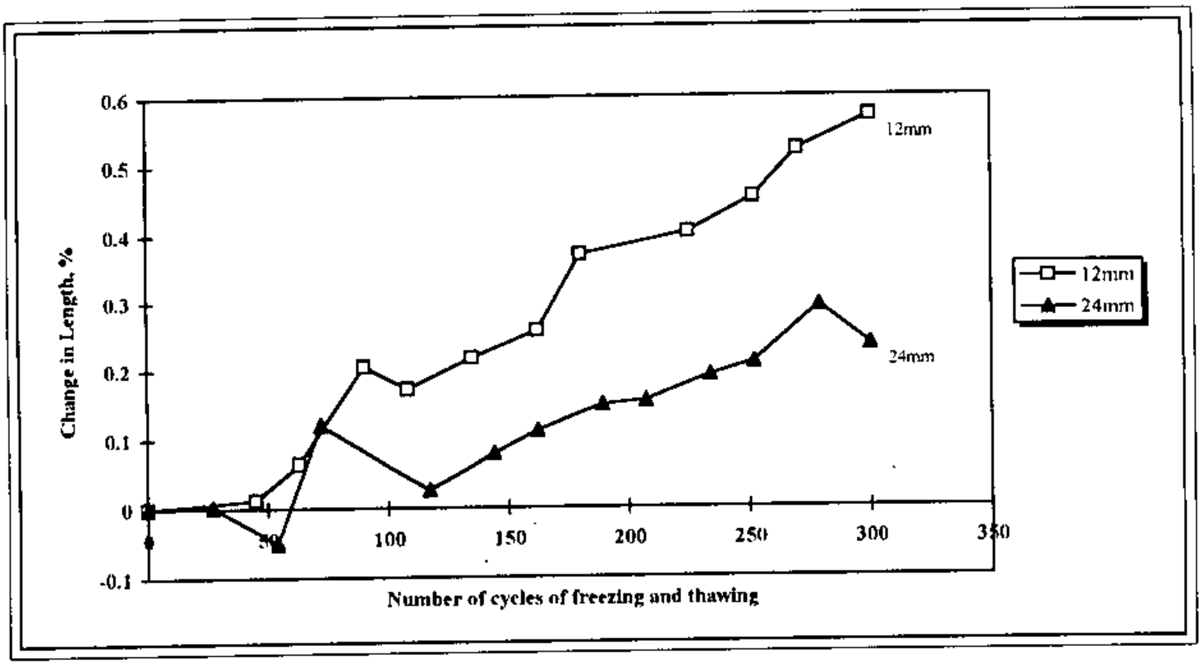

Figure 3.27 : The effect of glass fiber length on change in length of the specimen after n cycles of freezing and thawing for concrete grade 20 MPa and fiber ratio = 0.75% V_f.

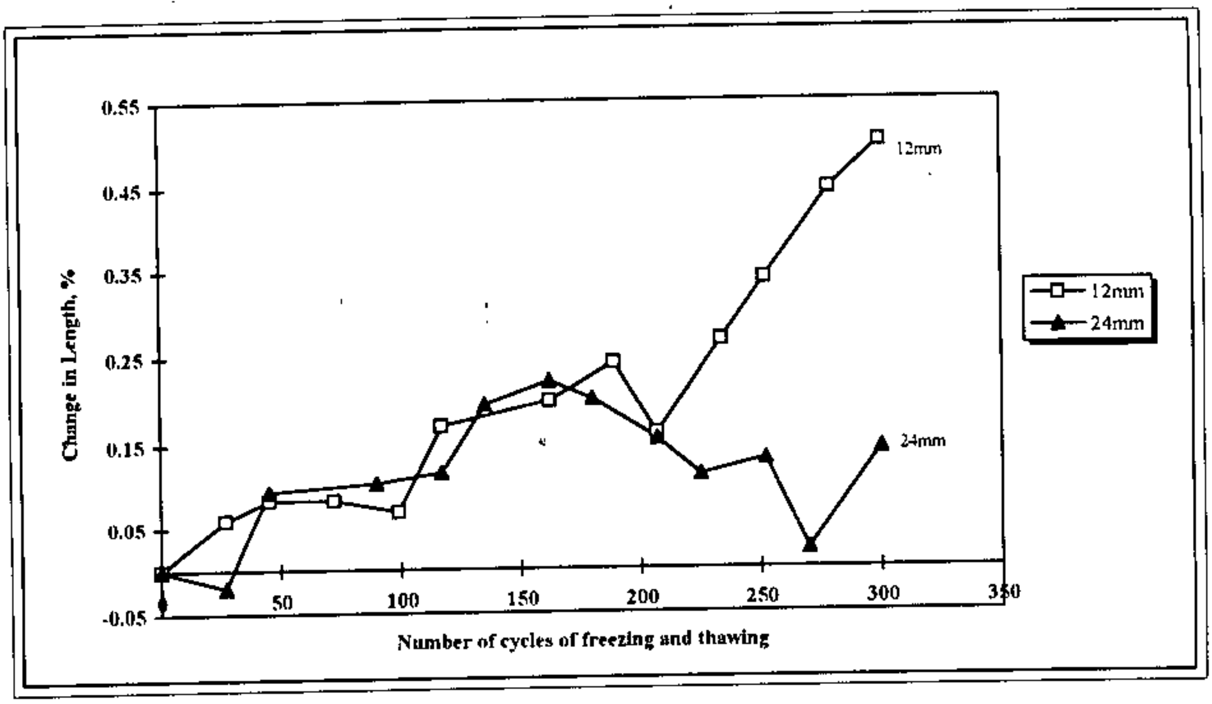

Figure 3.28 : The effect of glass fiber length on change in length of the specimen after n cycles of freezing and thawing for concrete grade 20 MPa and fiber ratio = 1.0% V_f.

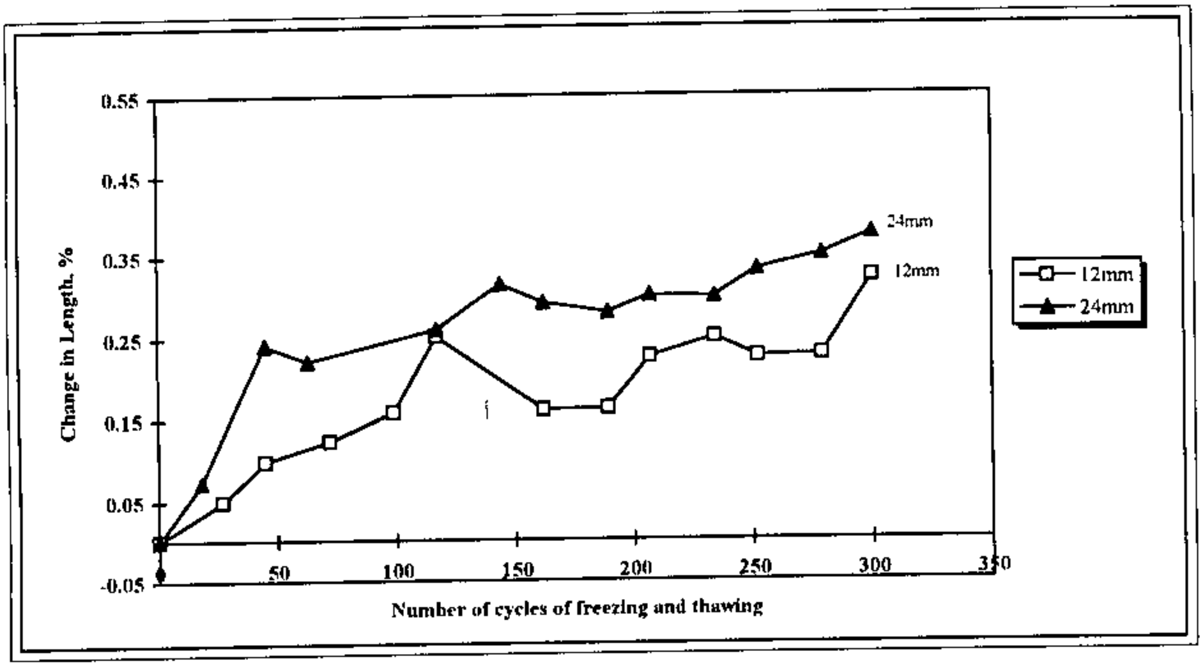

Figure 3.29 : The effect of glass fiber length on change in length of the specimen after n cycles of freezing and thawing for concrete grade 20 MPa and fiber ratio = 1.5% V_f.

exhibited lower expansion compared to plain concrete . At the same time the length change increased by increasing the fiber volume fraction. For 24mm fiber length the length change was less than the 12mm fiber length.

For concrete grade 40 MPa the behavior was slightly different. From Figures 3.30 to 3.34 it is observed that for 12mm fiber length the change in length of specimen was greater than the plain concrete and reduced by increasing the fiber ratio, while for the 24mm length, expansion increased by increasing the fiber ratio. However, the differences are very small. The 12mm fiber length expanded more rapidly than 24mm standard length.

3.3.4.2 Weight Change

Tables 3.9 and 3.10 show the results obtained from freezing and thawing test for all the mixes for concrete grades 20 and 40 MPa respectively.

Comparison of glass fiber reinforced concrete with plain concrete indicates that their behavior under freeze - thaw conditions is better since the weight loss is lower than that of control mixes. Figures 3.35 to 3.40 show the relation between the weight change and the number of cycles of freezing and thawing for concrete grade

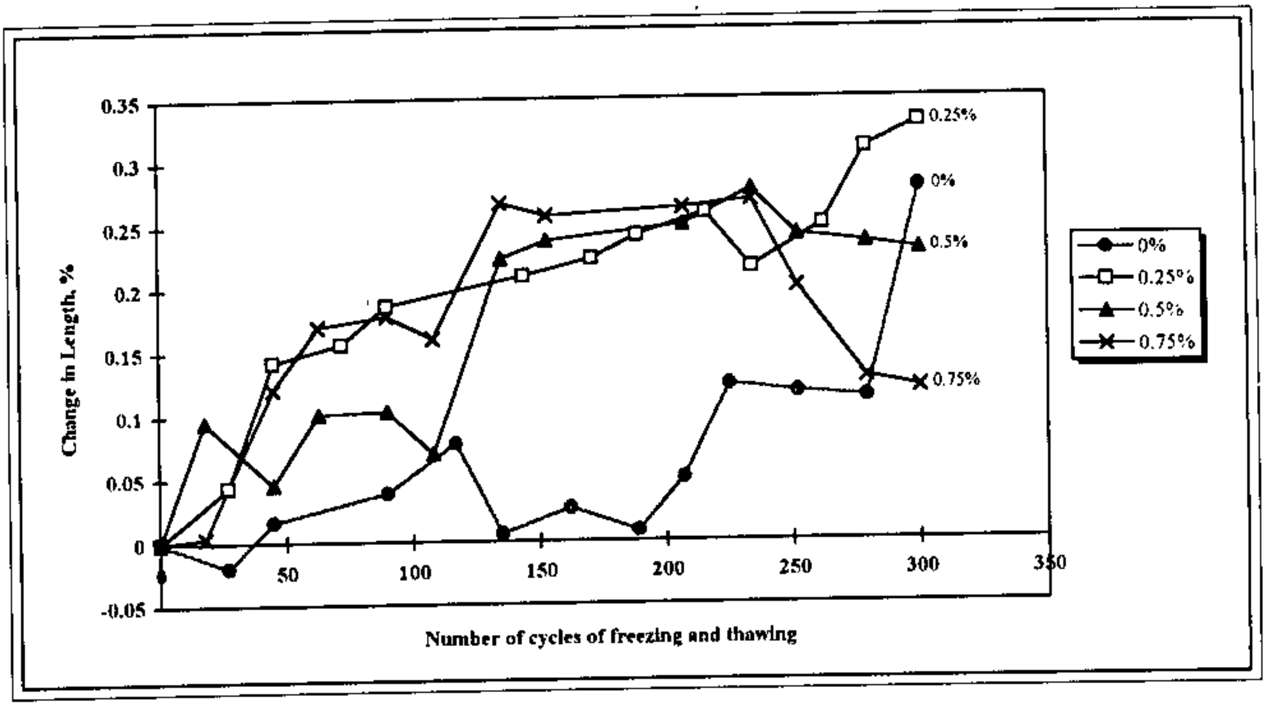

Figure 3.30 : The influence of fiber concentrations on change in length after n cycles of freezing and thawing for concrete grade 40 MPa. and 12mm glass fiber length.

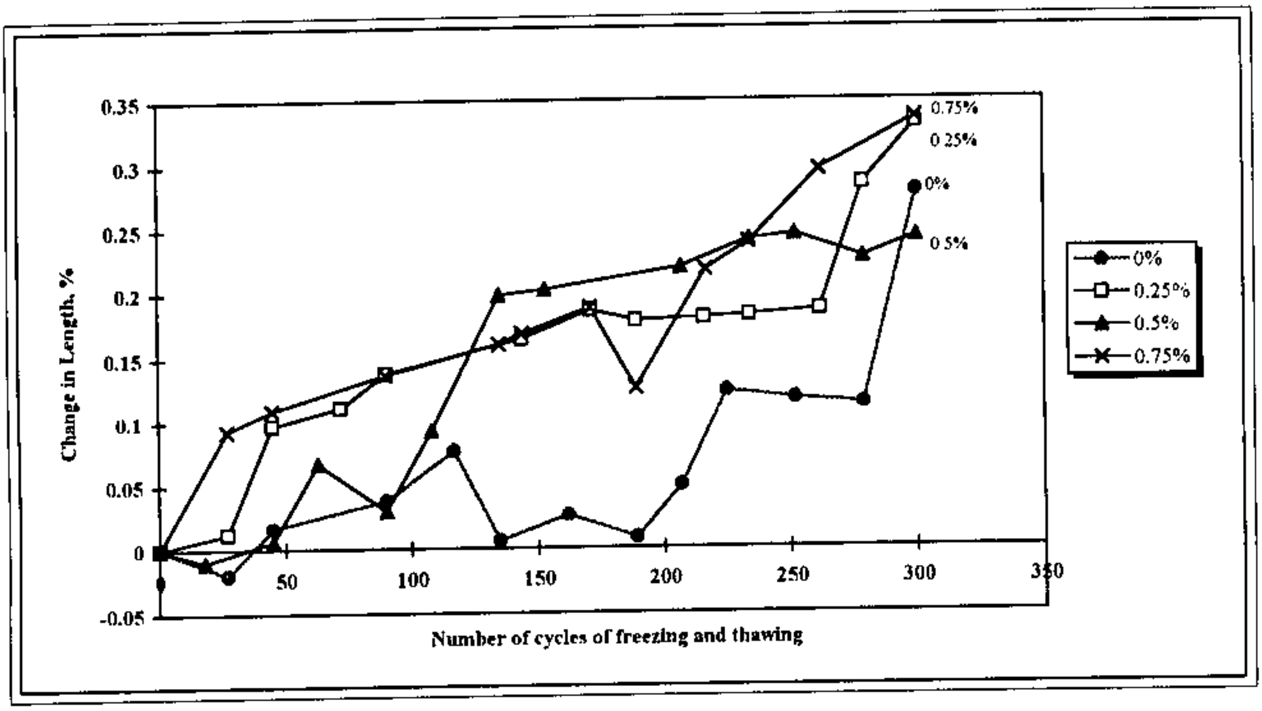

Figure 3.31 : The influence of fiber concentrations on change in length after n cycles of freezing and thawing for concrete grade 40 MPa. and 24mm glass fiber length.

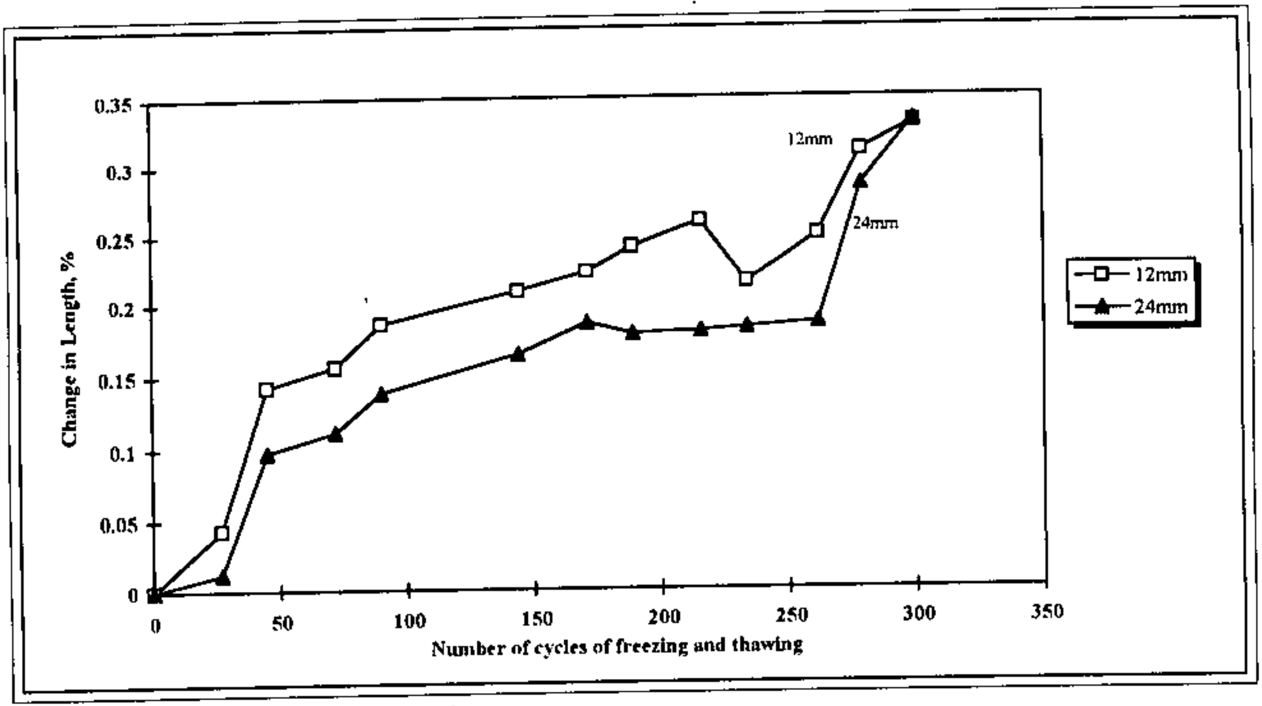

Figure 3.32 : The effect of glass fiber length on change in length of the specimen after n cycles of freezing and thawing for concrete grade 40 MPa and fiber ratio = 0.25% V_f.

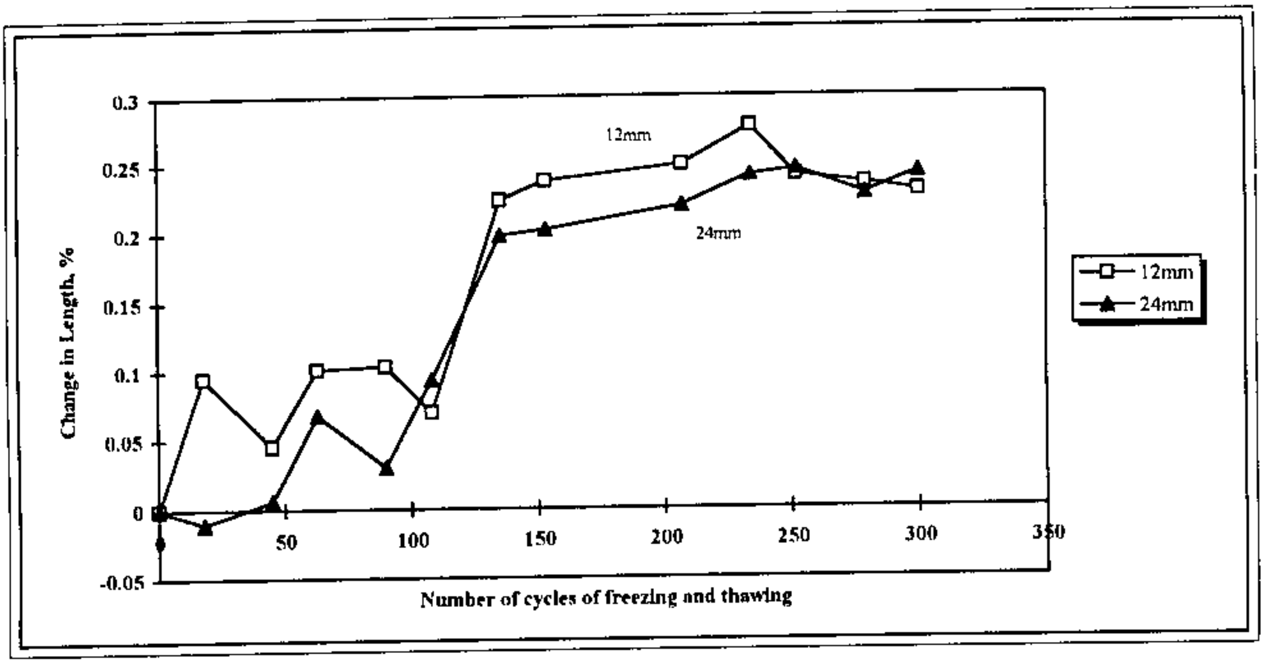

Figure 3.33 : The effect of glass fiber length on change in length of the specimen after n cycles of freezing and thawing for concrete grade 40 MPa and fiber ratio = 0.5% V_f.

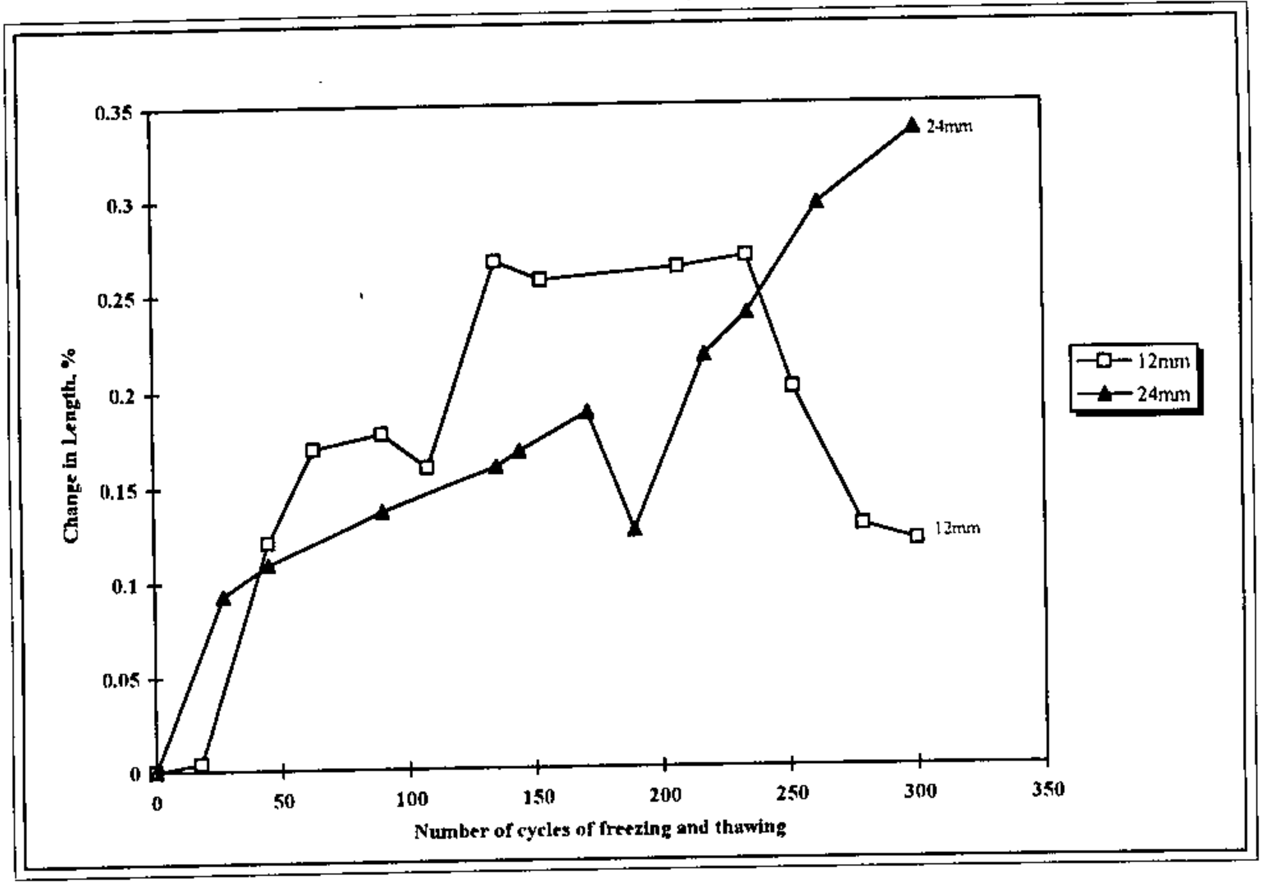

Figure 3.34 : The effect of glass fiber length on change in length of the specimen after n cycles of freezing and thawing for grade 40 MPa and fiber ratio = 0.75% V_f.

Table 3.9 : The weight change of specimens after n cycles of freezing and thawing for concrete grade 20 MPa, for both the fiber lengths and all the fiber ratios.

Concrete Grade : 20 MPa Weight loss of Specimens, %																								
Cycle No.		0	18	27	45	54	63	72	90	99	108	117	135	144	162	180	189	207	225	234	252	270	279	300
Fiber Percent	Fiber Length																							
0	-	0.00			0.03		-0.49		-1.00		-1.61		-1.78		-1.83	-2.38			-4.50		-6.66	-8.59		-12.13
0.5	12	0.00			0.27		0.24		-0.01		-0.25		-0.46		-0.77	-1.03			-1.95		-2.84	-3.39		-4.79
0.75	12	0.00			0.38		0.26		-0.57		-1.01		-1.52		-2.24	-2.82			-4.32		-5.50	-6.26		-7.91
1	12	0.00		-0.21	-0.31			-0.56		-1.11		-1.39			-1.86		-2.49	-3.01		-4.15	-4.97		-5.60	-6.12
1.5	12	0.00		-0.45	-0.40			-0.80		-1.10		-1.47			-2.15		-3.05	-3.47		-4.81	-5.34		-6.28	-7.03
0.5	24	0.00	0.35		0.11			0.45	0.38				0.17		-0.35	-0.56		-1.15	-1.91		-2.64	-3.15		-3.85
0.75	24	0.00		0.36		0.45		0.10				-0.15		-0.21	-0.42		-1.06	-1.80		-2.01	-2.61		-3.20	-3.72
1	24	0.00		0.28	0.20				-0.09			-0.15	-0.35		-0.89	-1.39		-2.07	-2.19		-2.81	-3.30		-4.02
1.5	24	0.00	0.16		0.00		-0.20					-0.48		-0.68	-0.78		-1.09	-1.21		-1.49	-1.90		-2.93	-3.50

Table 3.10 : The weight change of specimens after n cycles of freezing and thawing for concrete grade 40 MPa, for both the fiber lengths and all the fiber ratios.

Concrete Grade : 40 MPa Weight loss of Specimens, %																								
Cycle No.		0	18	27	45	63	72	90	108	117	135	144	153	162	171	189	207	216	225	234	252	262	279	300
Fiber Percent	Fiber Length																							
0	-	0.00		-0.07	-0.16			-0.13		-0.01	0.00			0.01		0.09	0.26		0.35		0.52		0.55	0.43
0.25	12	0.00		-0.14	-0.20		-0.25	-0.46				-0.53			-0.65	-0.69		-0.70		-0.73		-0.96	-1.06	-1.21
0.5	12	0.00	0.16		0.03	0.08		0.13	-0.03		-0.14		-0.17				-0.17			-0.23	-0.24		-0.27	-0.25
0.75	12	0.00	0.06		-0.04	0.00		0.10	0.07		-0.04		-0.07				-0.10			-0.16	-0.22		-0.24	-0.22
0.25	24	0.00		0.09	0.11		0.11	0.13				0.17			0.16	0.21		0.18		0.28		0.21	0.23	0.13
0.5	24	0.00	0.03		0.06	0.14		0.30	0.27		0.26		0.30				0.37			0.31	0.35		0.44	0.43
0.75	24	0.00		0.11	0.34			0.56			0.75	0.85			1.02	1.15		1.26		1.52		1.59		1.57

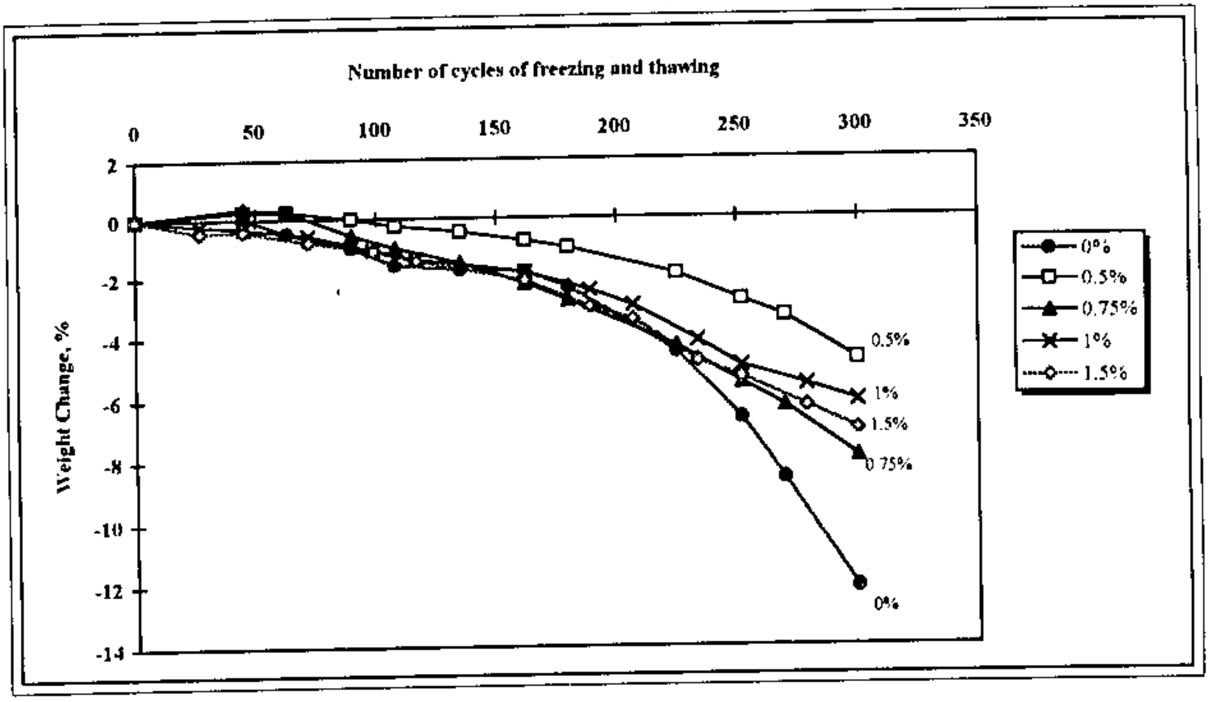

Figure 3.35 : The influence of fiber volume fraction on weight for concrete grade 20 MPa and 12mm fiber length.

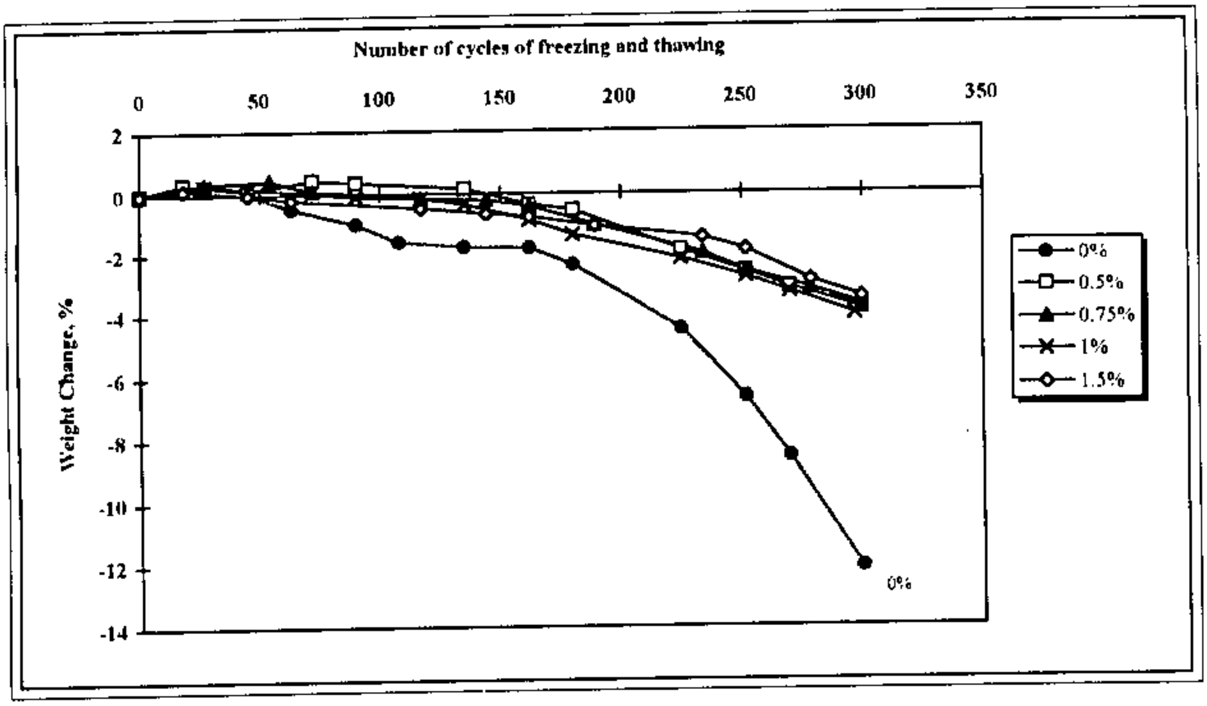

Figure 3.36 : The influence of fiber volume fraction on weight for concrete grade 20 MPa and 24mm fiber length.

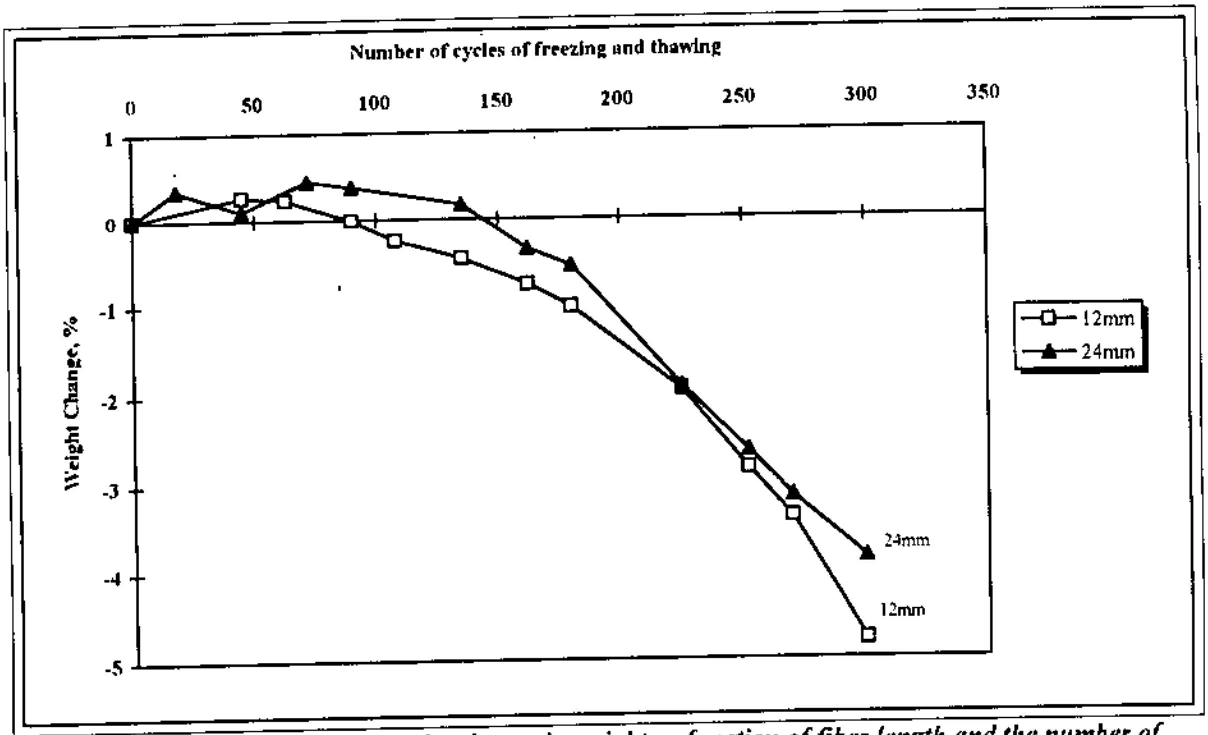

Figure 3.37 : The relation between the change in weight as function of fiber length and the number of cycles of freezing and thawing for concrete grade 20 MPa and fiber ratio = 0.5%V_f.

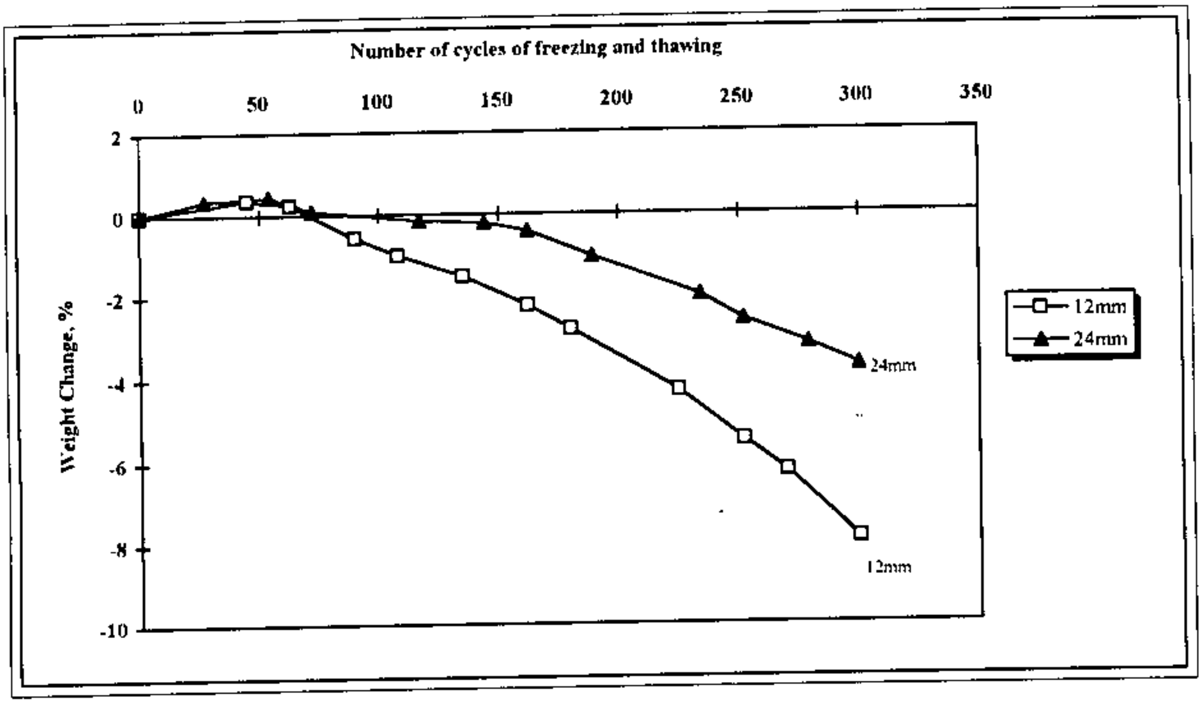

Figure 3.38 : The relation between the change in weight as function of fiber length and the number of cycles of freezing and thawing for concrete grade 20 MPa and fiber ratio = 0.75%V_f.

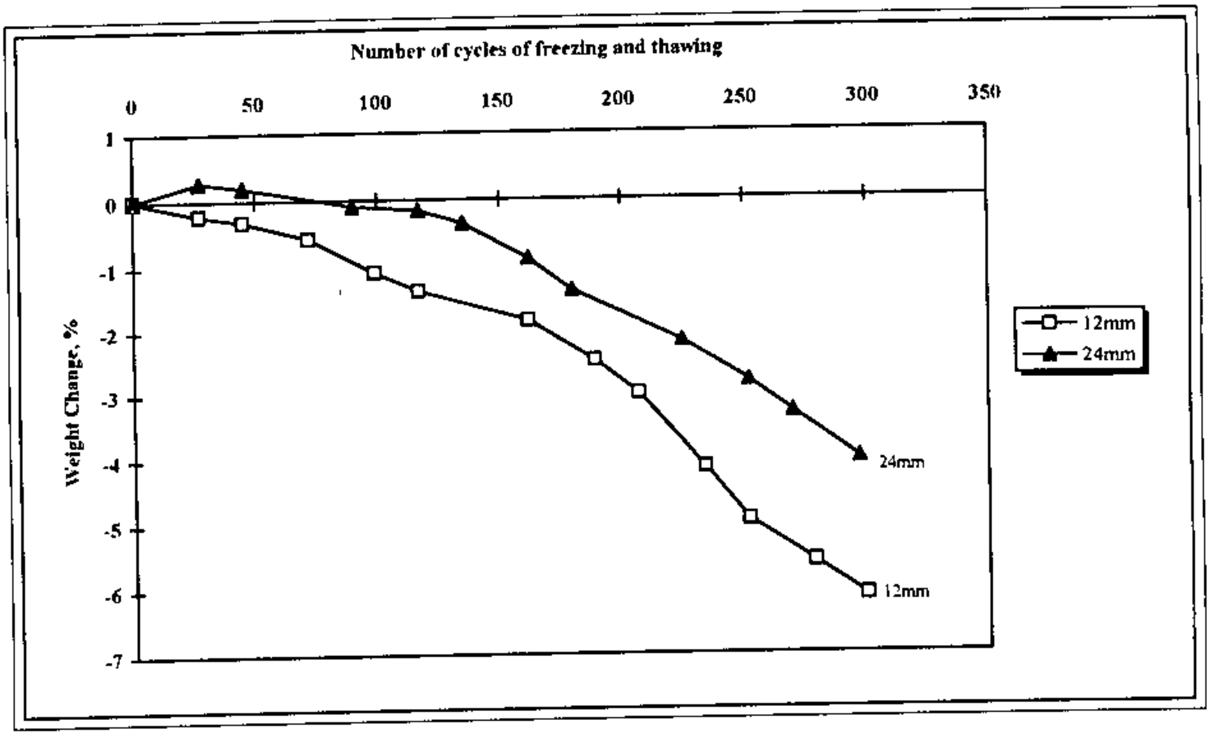

Figure 3.39 : The relation between the change in weight as function of fiber length and the number of cycles of freezing and thawing for concrete grade 20 MPa and fiber ratio = 1.0%V_f.

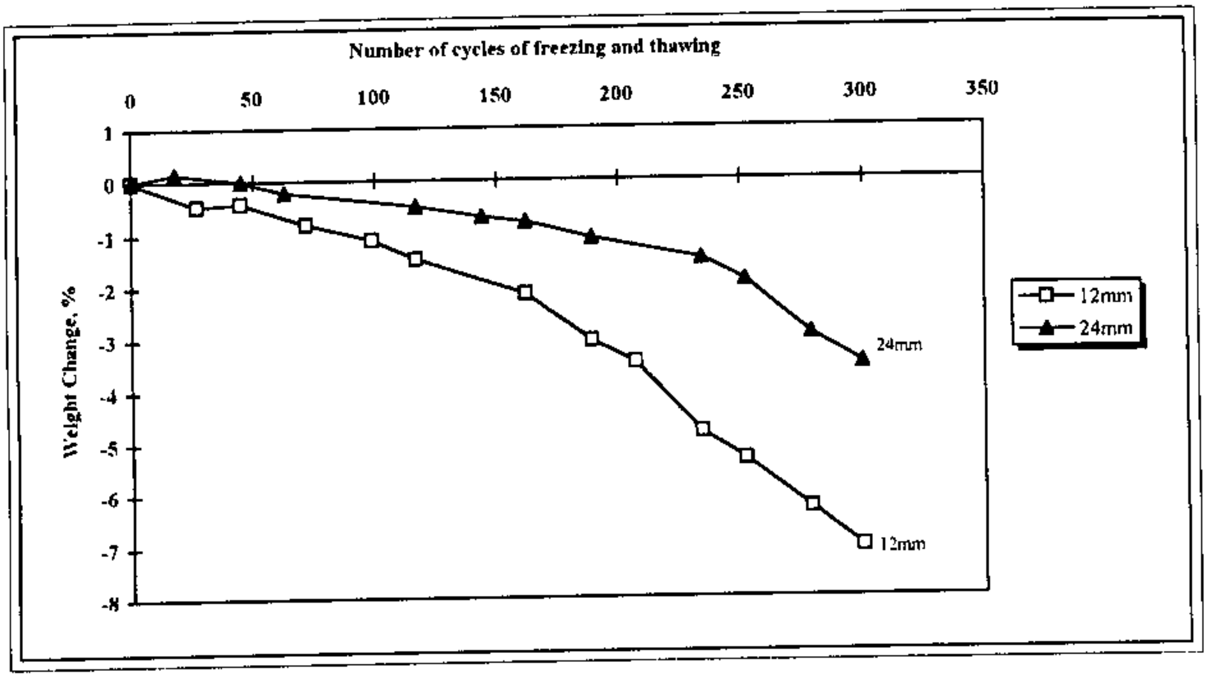

Figure 3.40 : The relation between the change in weight as function of fiber length and the number of cycles of freezing and thawing for concrete grade 20 MPa and fiber ratio = 1.5%V_f.

20 MPa. It is obvious that the control mix was severely damaged where at the end of the test the weight loss was -12.13%, this loss is attributed to the disruption caused by expansion. Adding fiber improved the weight loss and increased by increasing the fiber volume fraction. The weight loss for the 24mm fiber length was lower than that for the 12mm.(Figures 3.41 to 3.44).

On the other hand, the behavior of mixes of concrete grade 40 MPa was totally different. Figures 3.45 to 3.49 illustrate the effect of fiber length as well as fiber percentage on the weight change. It is clear that good resistance to freezing and thawing is attained since the rate of weight change for fiber length 12mm ranges from (-0.22 to -1.21)% for all the fiber ratios, and for 24mm fiber length ranges from (0.13 to 1.57)%. hence, the differences are not significant. (Figures 3.50.a and 3.50.b).

3.3.4.3 Ultrasonic Velocity

The results of ultrasonic velocity for all fiber volume fraction and both the standard fiber lengths are summarized in Table 3.11 for concrete grade 20 MPa and in Table 3.12 for concrete grade 40 MPa.

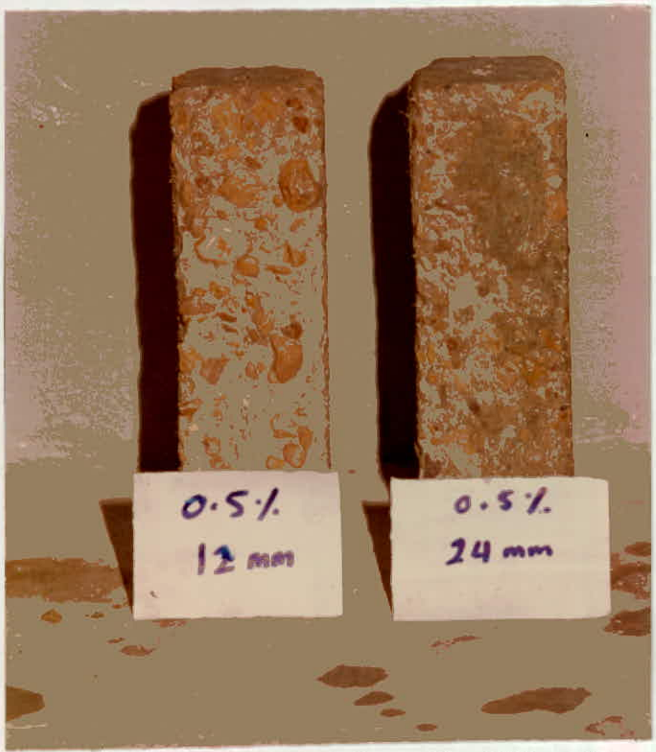

Figure 3.41 : Weight loss after 300 cycles of freezing and thawing for concrete Grade 20mpa and fiber ratio = 0.5%V_f

Figure 3.43 : Weight loss after 300 cycles of freezing and thawing for concrete Grade 20mpa and fiber ratio = 1.0%V_f

Figure 3.42 : Weight loss after 300 cycles of freezing and thawing for concrete Grade 20mpa and fiber ratio = 0.75%V_f

Figure 3.44: Weight loss after 300 cycles of freezing and thawing for concrete Grade 20mpa and fiber ratio = 1.5%V_f

المجموعة الاخرى فكانت (٠,٢٥ ، ٠,٥ ، ٠,٧٥) ٪ . تم عمل ١٦ خلطة احتوت على ٢٢٤ عينة منها ١٤٤ إسطوانة ، ٤٨ مكعب و ٣٢ منشور.

بينت الفحوصات المخبرية إن إضافة الألياف الزجاجية للخرسانة تقلل من درجة التشغيل و الكثافة و تزيد من المحتوى الهوائي، و كان تأثيرها واضحا" في زيادة قوة الشد و تحسين الديمومة. أما بالنسبة لقوة الضغط فأن تأثيرها قليل جدا" إذا لم يكن سلبيا" .

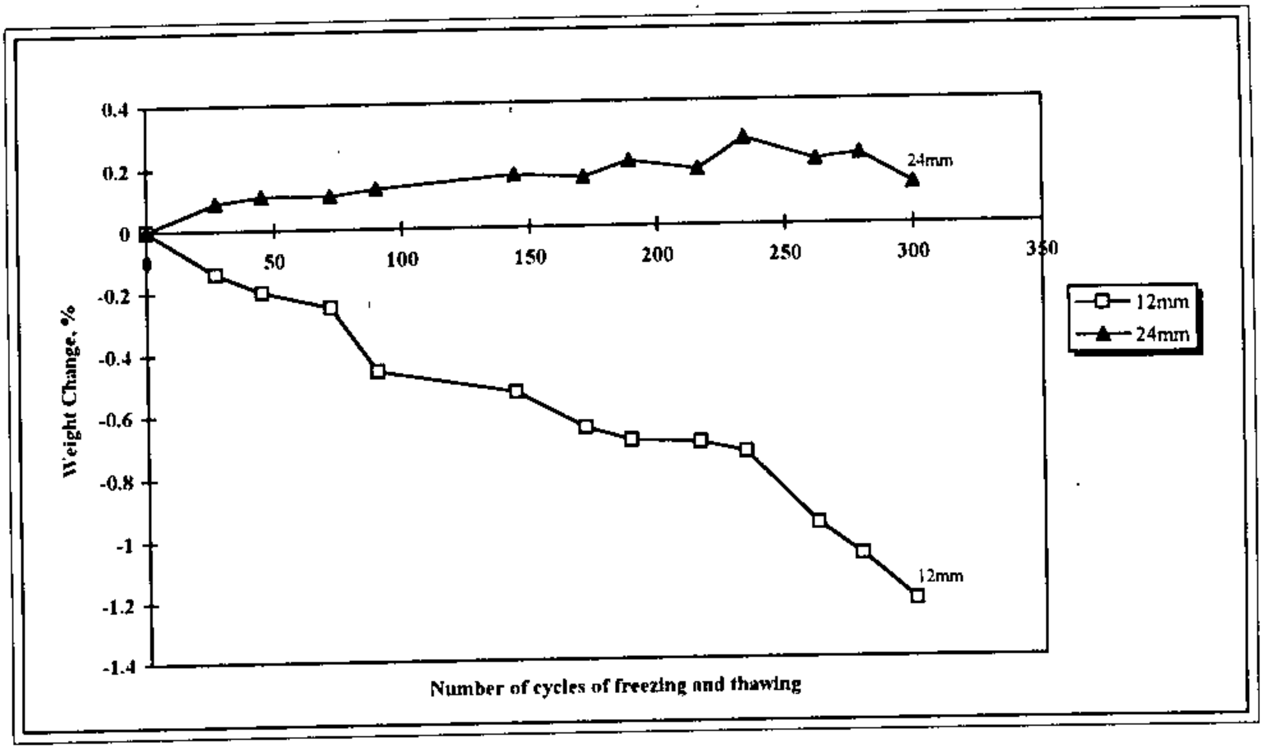

Figure 3.47 : The relation between the change in weight as function of fiber length and the number of cycles of freezing and thawing for concrete grade 40 MPa and fiber ratio = 0.25%V_f.

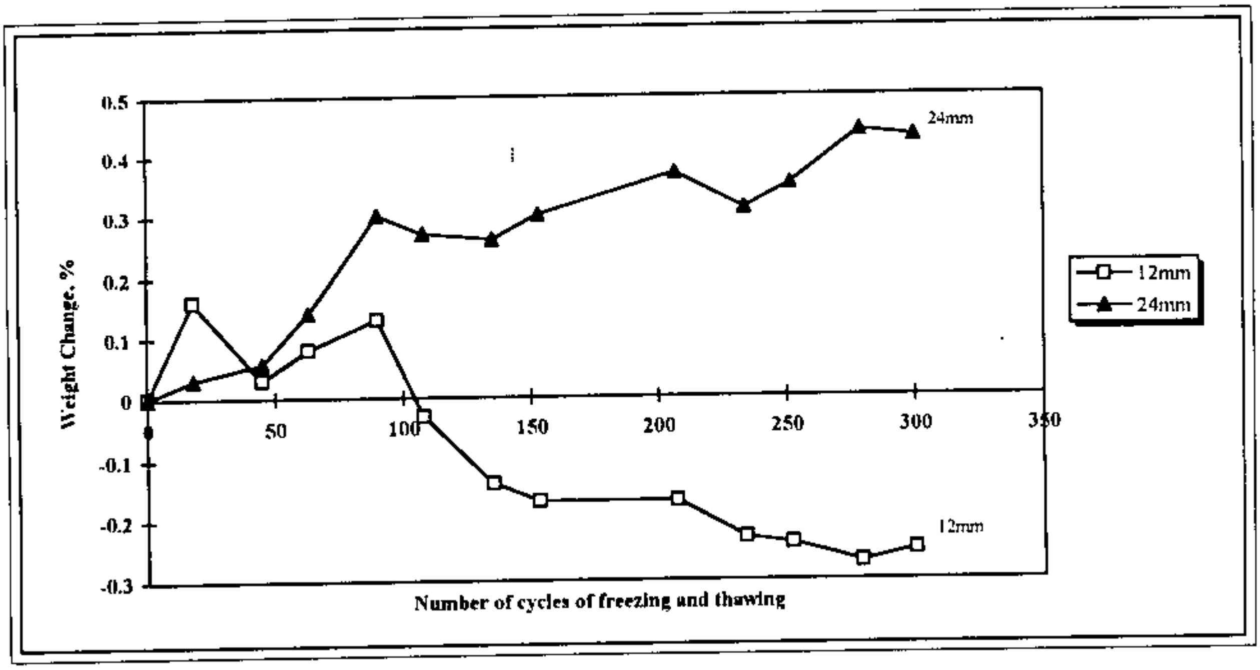

Figure 3.48 : The relation between the change in weight as function of fiber length and the number of cycles of freezing and thawing for concrete grade 40 MPa and fiber ratio = 0.5%V_f.

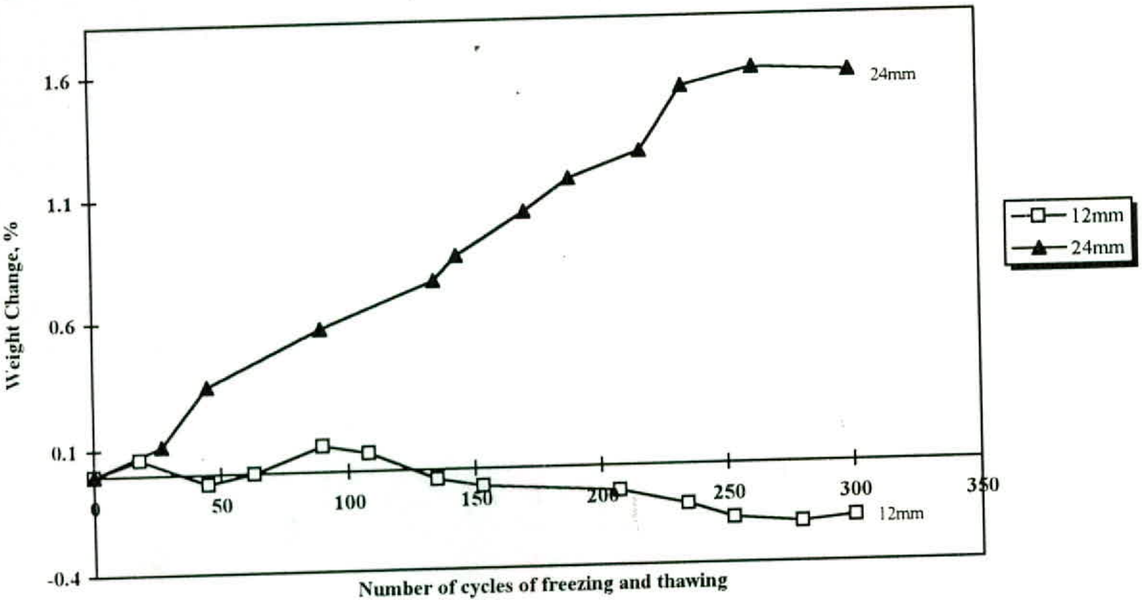

Figure 3.49 : The relation between the change in weight as function of fiber length and the number of cycles of freezing and thawing for concrete grade 40 MPa and fiber ratio = 0.75%V_f.

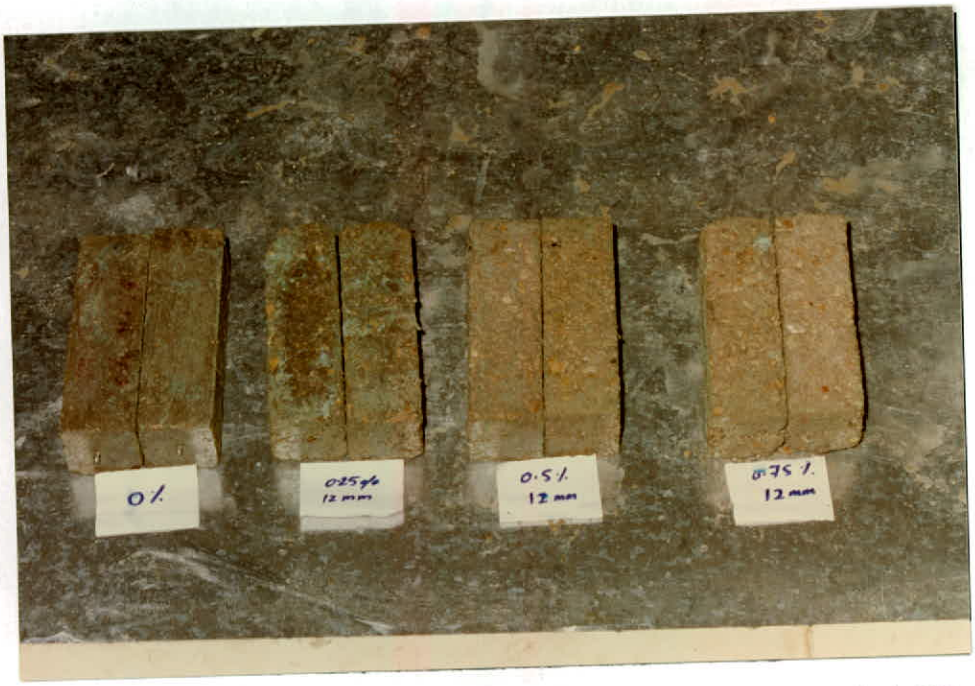

Figure 3.50.a : Weight change after 300 cycles of freezing and thawing for concrete grade 40 MPa, and for all the fiber ratios and 12mm fiber length.

It is shown that the ultrasonic pulse velocity which is an indicator to microcracking improved by the addition of glass fibers. Figures 3.51 to 3.56 show the effect of fiber length and fiber percentage on the velocity for concrete grade 20MPa. It is observed that the velocity decreased by increasing the fiber percent and is higher for 12mm than 24mm fiber length. An exception to this behavior was noticed for fiber percent 0.75%V_f where the reverse was true. The lower value for 24mm is attributed to the higher air content and lower density since the velocity is directly proportional to the density.

Figure 3.50.b : Weight change after 300 cycles of freezing and thawing for concrete grade 40MPa, and for all the fiber ratios and 24mm fiber length.

Table 3.11 : The ultrasonic velocity after n cycles of freezing and thawing for concrete grade 20 MPa, for both the fiber standard lengths and all the fiber percentages.

Concrete Grade : 20 MPa Ultrasonic Velocity, Km/sec.																								
Cycle No.		0	18	27	45	54	63	72	90	99	108	117	135	144	162	180	189	207	225	234	252	270	279	300
Fiber Percent	Fiber Length																							
0	-	3.99			2.42		2.17		2.00		2.31		2.31		1.95	1.47			1.33		1.29	1.25		1.27
0.5	12	3.73			4.23		3.47		3.49		3.31		3.33		2.91	2.74			2.50		2.04	2.01		1.64
0.75	12	3.63			3.60		3.02		2.66		2.28		2.36		2.05	1.56			1.40		1.17	1.14		1.07
1	12	4.05		3.69	3.47			3.39		3.44		3.02			3.02		2.64	2.43		2.06	2.00		1.73	1.79
1.5	12	3.77		3.37	3.36			3.05		2.94		2.81			2.52		2.38	2.18		1.69	1.81		1.16	1.25
0.5	24	4.13	3.92		4.13			4.07	3.77				3.43		2.90	2.46		2.19	2.12		1.79	1.73		1.50
0.75	24	4.17		4.01		3.98		3.95				3.86		3.71	3.54		3.07	2.88		2.54	2.49		2.31	1.78
1	24	4.04		4.03	3.76				3.18			2.53	2.15		1.88	1.85		1.71	1.72		1.67	1.56		1.29
1.5	24	4.36	4.13		3.16		3.18					3.12		3.17	3.04		2.79	3.01		2.78	2.43		2.26	2.00

Table 3.12 : The ultrasonic velocity after n cycles of freezing and thawing for concrete grade 40 MPa, for both the fiber standard lengths and all the fiber percentages.

Concrete Grade : 40 MPa Ultrasonic Velocity, Km/sec.																								
Cycle No.		0	18	27	45	63	72	90	108	117	135	144	153	162	171	189	207	216	225	234	252	262	279	300
Fiber Percent	Fiber Length																							
0	-	4.76		4.84	4.80			4.86		4.76	4.86			4.80		4.71	4.59		4.55		3.97		3.83	3.33
0.25	12	4.97		4.86	4.45		4.59	4.59				4.67			4.73	4.71		4.68		4.67		4.44	4.28	3.84
0.5	12	4.88	4.74		4.57	4.76		4.72	4.46		4.45		4.39				4.42			4.48	4.52		4.57	4.51
0.75	12	4.76	4.56		3.98	3.88		3.52	3.37		3.14		3.31				3.54			3.34	3.43		3.48	3.39
0.25	24	5.03		4.89	4.70		4.68	4.66				4.66			4.78	4.77		4.65		4.66		4.36	4.00	3.45
0.5	24	4.79	4.84		4.70	4.80		4.75	4.52		4.39		4.42				4.38			4.38	4.33		4.49	4.44
0.75	24	4.69		4.35	4.44			4.26			4.46	4.49			4.50	4.43		4.22		4.20		3.77		3.40

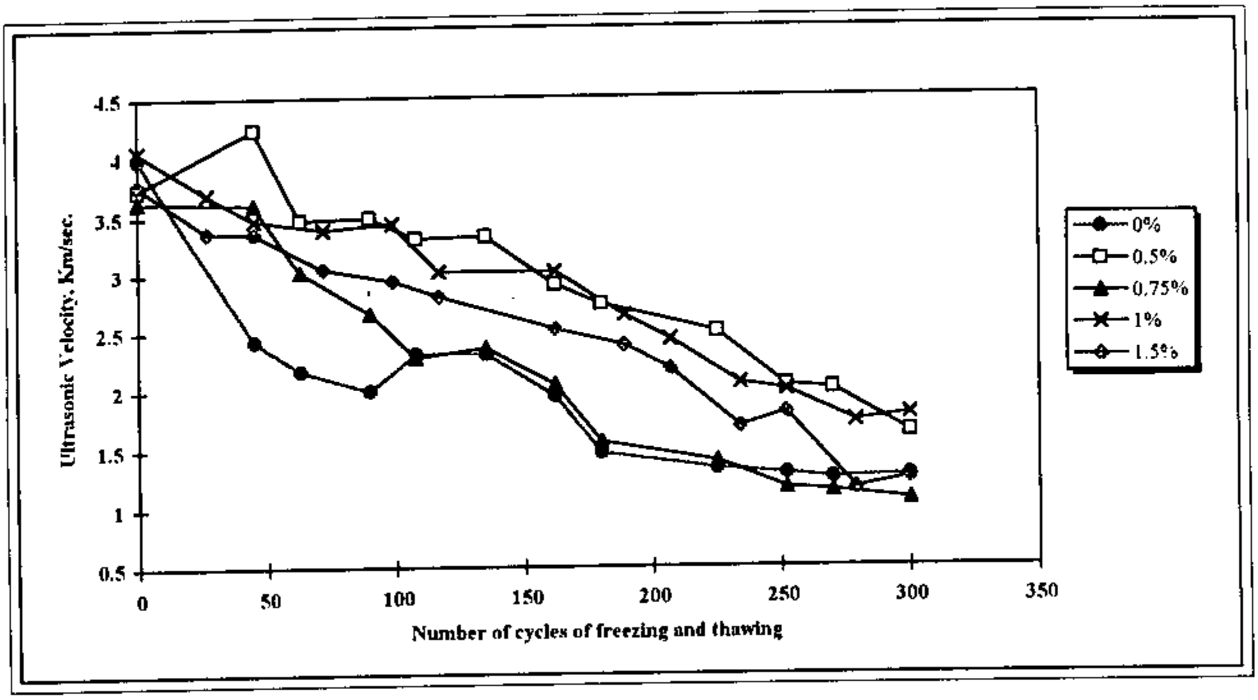

Figure 3.51 : The influence of fiber percentage on ultrasonic velocity after n cycles of freezing and thawing for concrete grade 20 MPa and 12mm standard length.

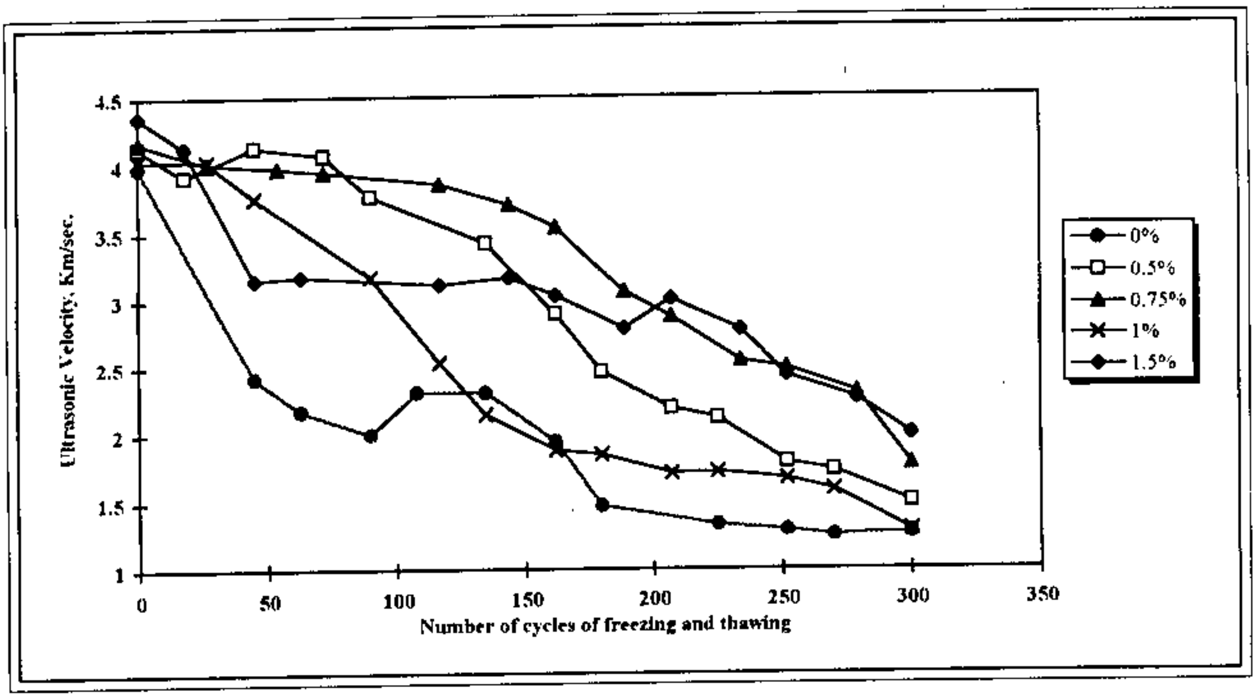

Figure 3.52 : The influence of fiber percentage on ultrasonic velocity after n cycles of freezing and thawing for concrete grade 20 MPa and 24mm standard length.

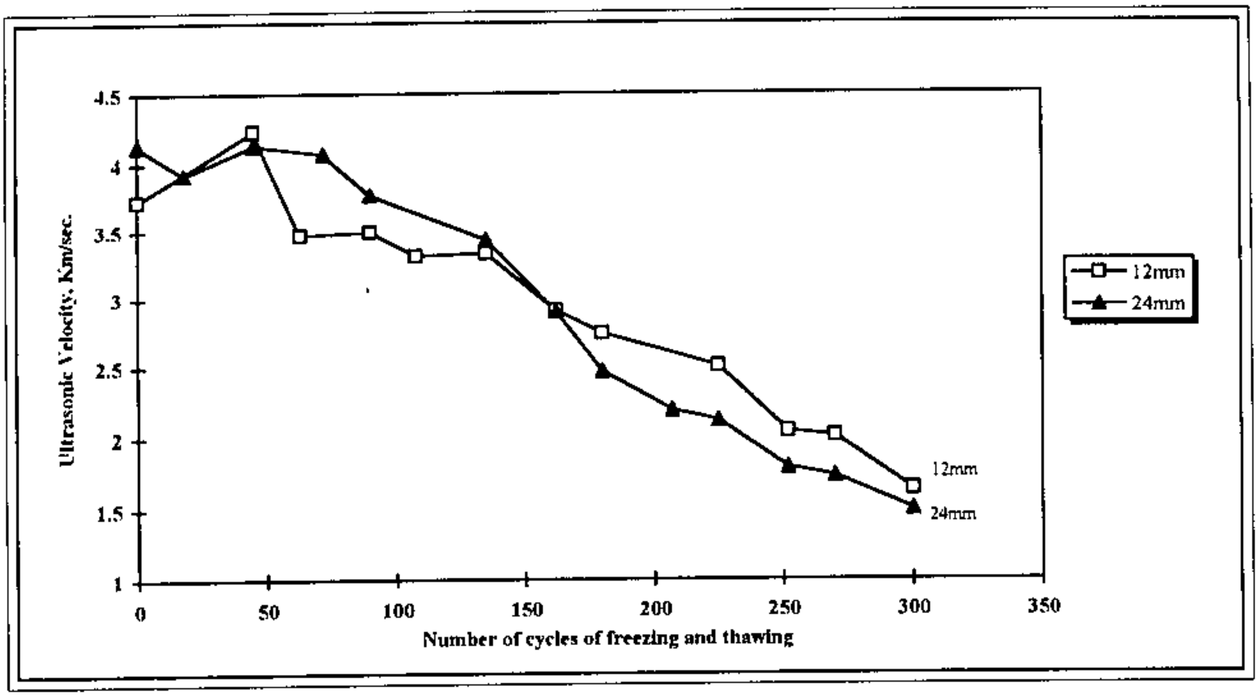

Figure 3.53 : Relation between ultrasonic velocity and the number of cycles of freezing and thawing as a function of fiber length for concrete grade 20 MPa. and fiber ratio = 0.5%V_f.

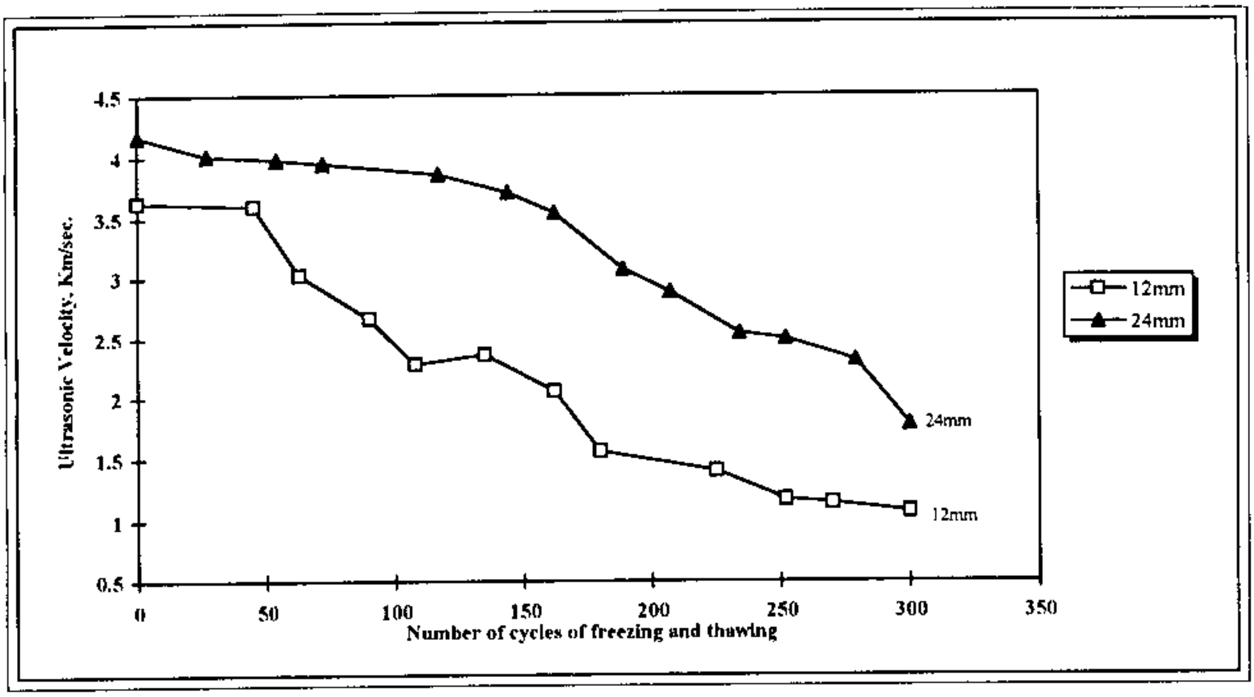

Figure 3.54 : Relation between ultrasonic velocity and the number of cycles of freezing and thawing as a function of fiber length for concrete grade 20 MPa. and fiber ratio = 0.75%V_f.

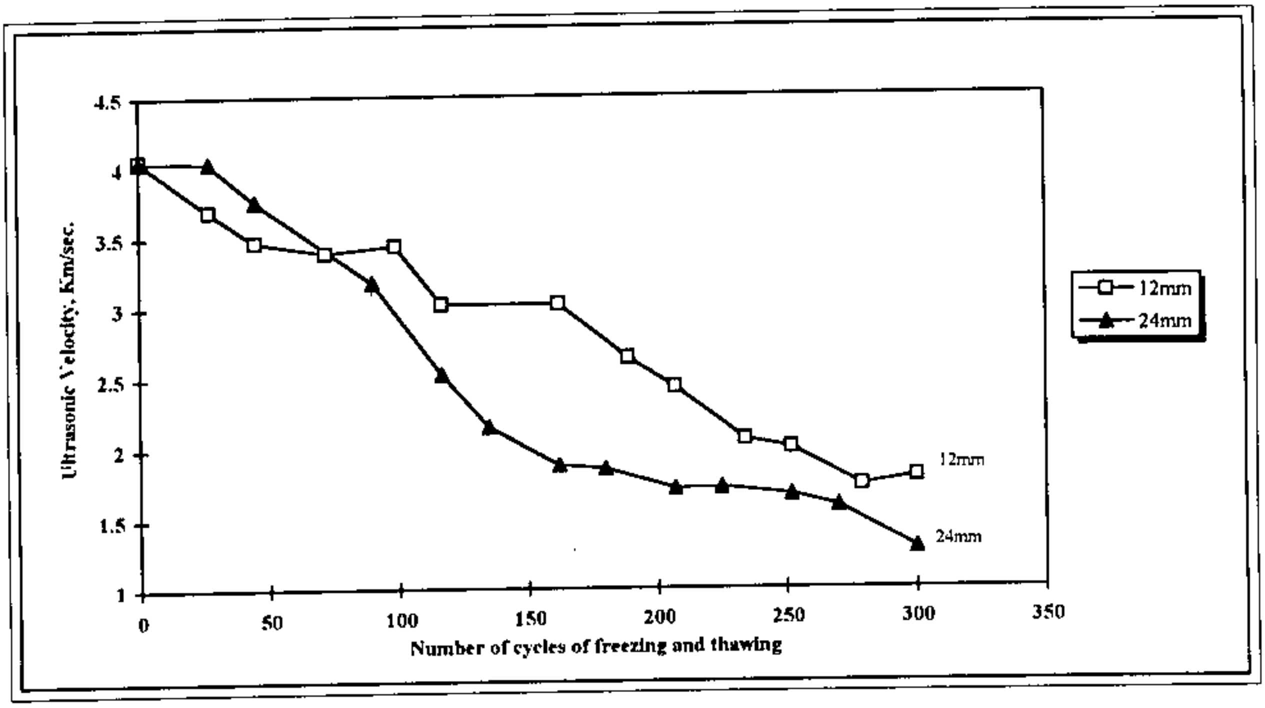

Figure 3.55 : Relation between ultrasonic velocity and the number of cycles of freezing and thawing as a function of fiber length for concrete grade 20 MPa. and fiber ratio = 1.0%V_f.

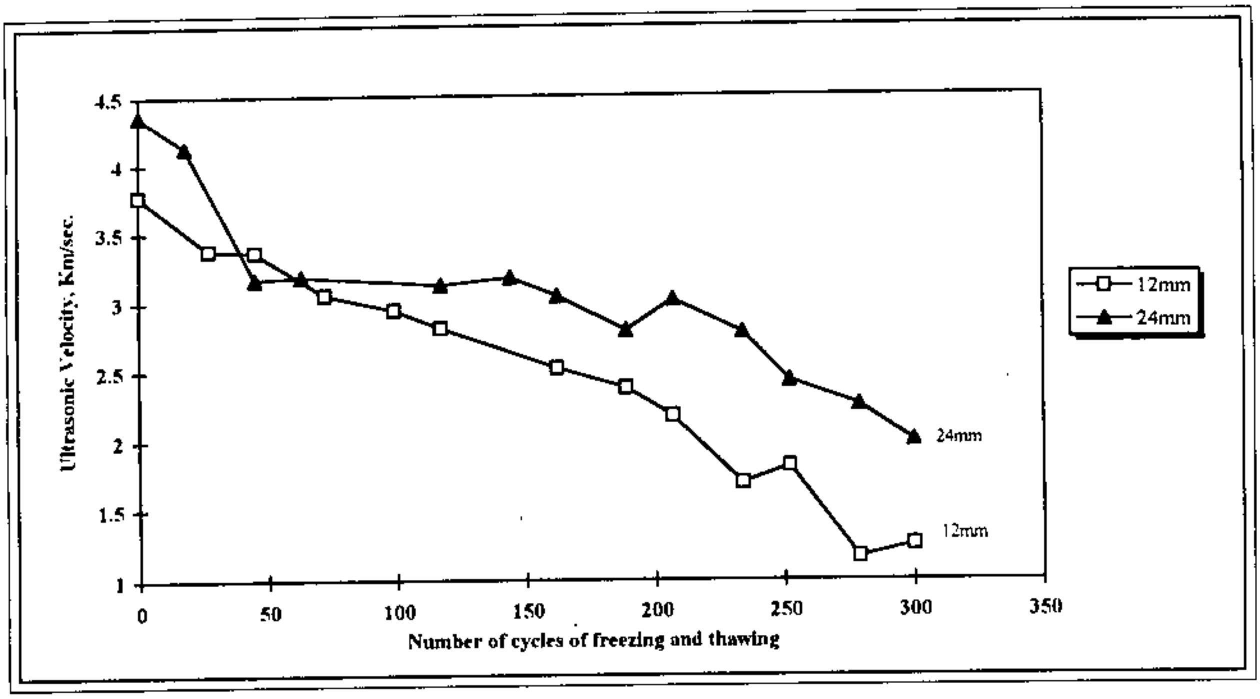

Figure 3.56 : Relation between ultrasonic velocity and the number of cycles of freezing and thawing as a function of fiber length for concrete grade 20 MPa. and fiber ratio = 1.5%V_f.

For concrete grade 40 MPa the effect of fiber ratio as well as fiber length is illustrated in Figures 3.57 to 3.61. The differences between the 12mm and 24mm fiber length are negligible for fiber ratio 0.25 and 0.5%V_f, while for fiber volume fraction o.75%V_f' the velocity was greater for the longer fiber and this behavior is strange since the air content is greater thus it should be less.

The classification of concrete according to the ultrasonic pulse velocity is shown in Table 3.13 from which it is evident that the quality of 20 MPa concrete grade ranges from poor to very poor, meanwhile, it ranges from good to doubtful for the 40 MPa concrete grade.

Table 3.13: Classification of the quality of concrete on the basis of ultrasonic pulse velocity measured at 300 cycles of freezing and thawing.(Neville, 1989)

Concrete Grade 20 MPa				***Concrete Grade 40 MPa***			
Fiber Ratio %V_f	Fiber Length mm	Pulse Velocity Km/sec.	Quality of Concrete	Fiber Ratio %V_f	Fiber Length mm	Pulse Velocity Km/sec.	Quality of Concrete
0	-	1.27	Very Poor	0	-	3.33	Doubtful
0.5	12	1.64	Very Poor	0.25	12	3.84	Good
0.75	12	1.07	Very Poor	0.5	12	4.51	Excellent
1	12	1.79	Very Poor	0.75	12	3.39	Doubtful
1.5	12	1.25	Very Poor				
0.5	24	1.50	Very Poor	0.25	24	3.45	Doubtful
0.75	24	1.78	Very Poor	0.5	24	4.44	Good
1	24	1.29	Very Poor	0.75	24	3.40	Doubtful
1.5	24	2.00	Poor				

Another classification was conducted for the quality of concrete according to the durability factor which is calculated as the square of the ratio of pulse velocity at 300 cycles to initial pulse velocity. The results are presented in Table 3.14, it should be mentioned that there are no established criteria for acceptance or rejection of concrete in terms of durability factor; its value thus primarily in comparison of different concretes.(Neville, 1989)

Table 3.14: Classification of the quality of concrete according to the durability factor estimated from the pulse velocity (Neville, 1989)

Concrete Grade 20 MPa				***Concrete Grade 40 MPa***			
Fiber Ratio %V_f	Fiber Length mm	Durability Factor %	Quality of Concrete	Fiber Ratio %V_f	Fiber Length mm	Factor %	Quality of Concrete
0	-	10	Unsatisfactory	0	-	48.9	Doubtful
0.5	12	19	Unsatisfactory	0.25	12	59.7	Doubtful
0.75	12	8.7	Unsatisfactory	0.5	12	85.4	Satisfactory
1	12	19.5	Unsatisfactory	0.75	12	50.7	Doubtful
1.5	12	11	Unsatisfactory				
0.5	24	13.2	Unsatisfactory	0.25	24	47	Doubtful
0.75	24	18.2	Unsatisfactory	0.5	24	85.9	Satisfactory
1	24	10.2	Unsatisfactory	0.75	24	52.6	Doubtful
1.5	24	21.0	Unsatisfactory				

Figure 3.62 shows the relation between the fiber volume fractions and the durability factor as a function of fiber length.

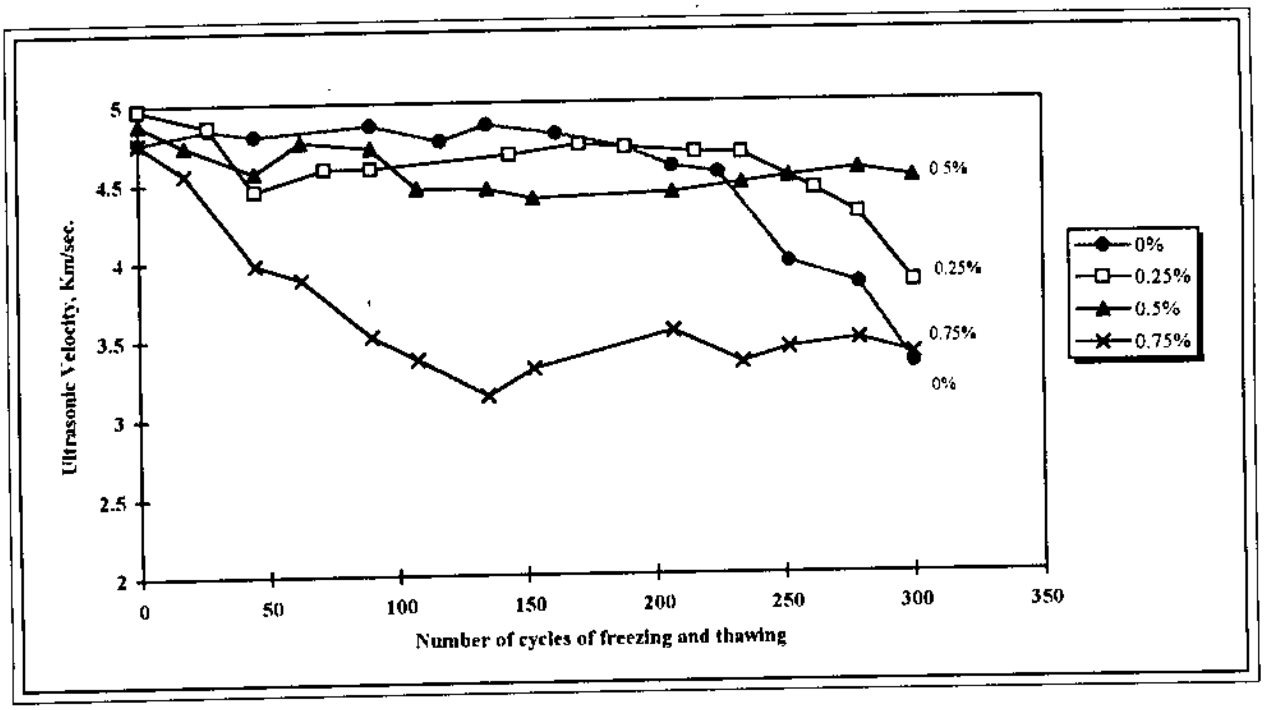

Figure 3.57 : The influence of fiber percentage on ultrasonic velocity after n cycles of freezing and thawing for concrete grade 40 MPa and 12mm standard length

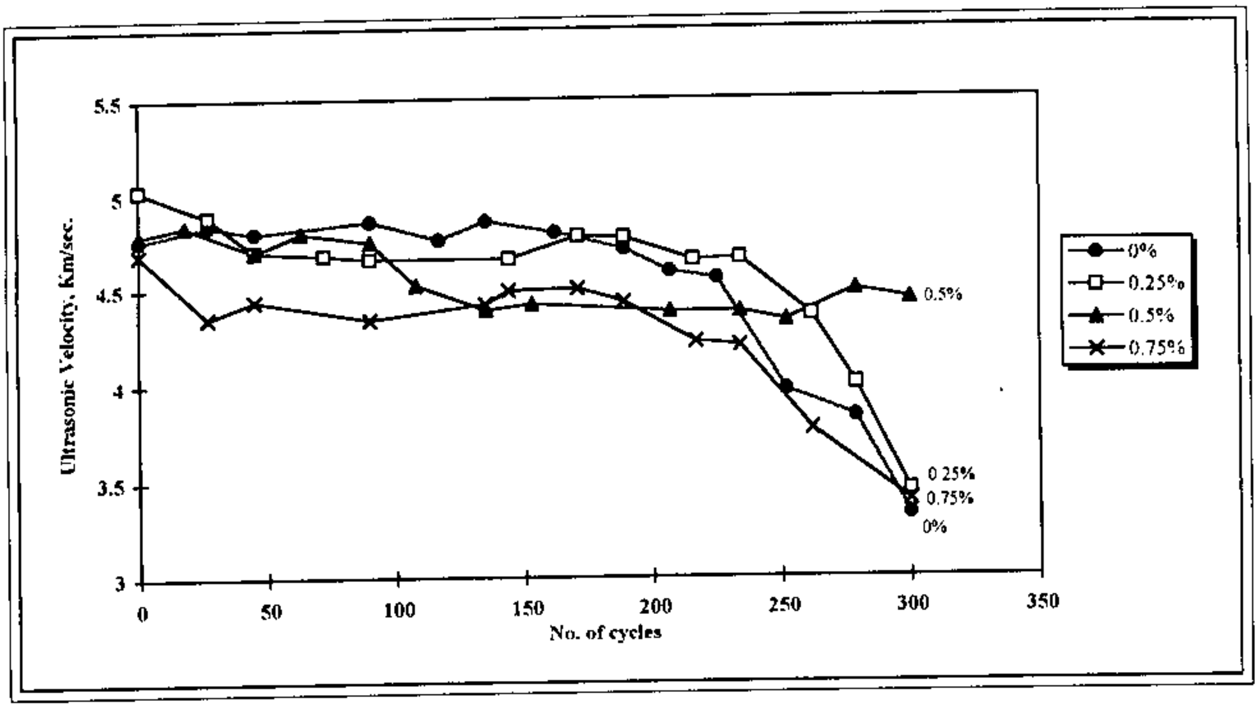

Figure 3.58 : The influence of fiber percentage on ultrasonic velocity after n cycles of freezing and thawing for concrete grade 40 MPa and 24mm standard length

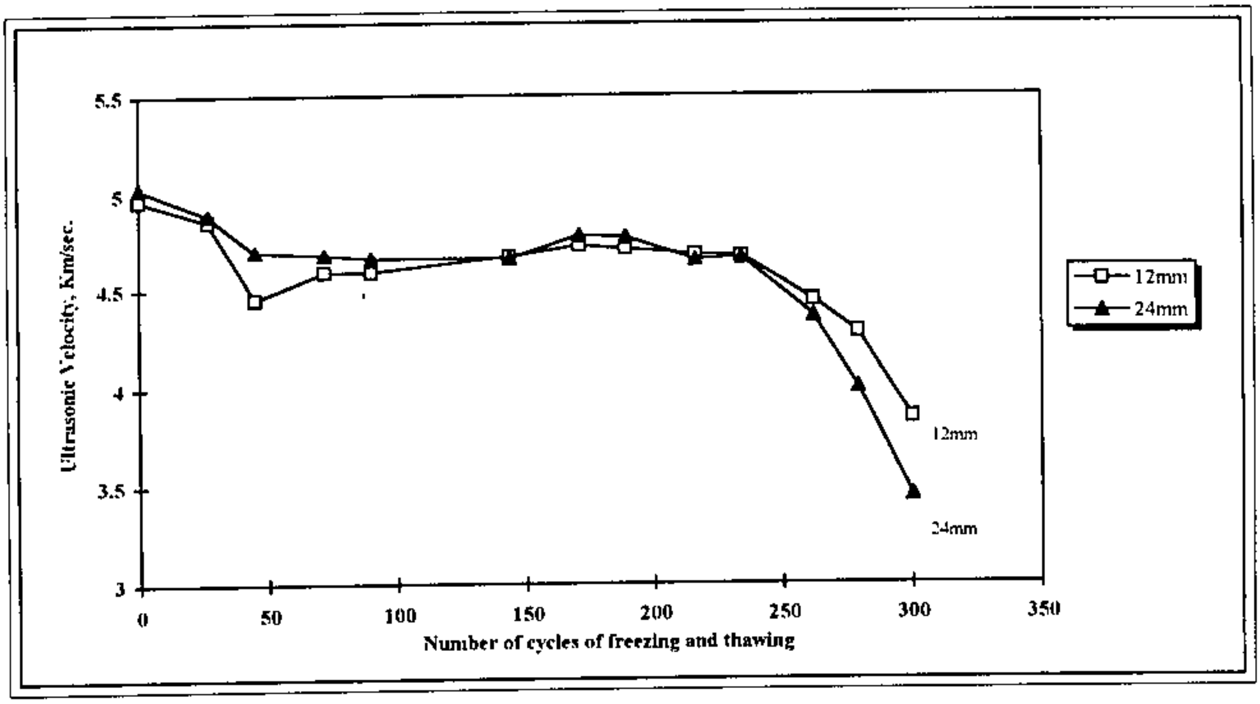

Figure 3.59 : Relation between ultrasonic velocity and the number of cycles of freezing and thawing as a function of fiber length for concrete grade 40 MPa and fiber ratio = 0.25%V_f

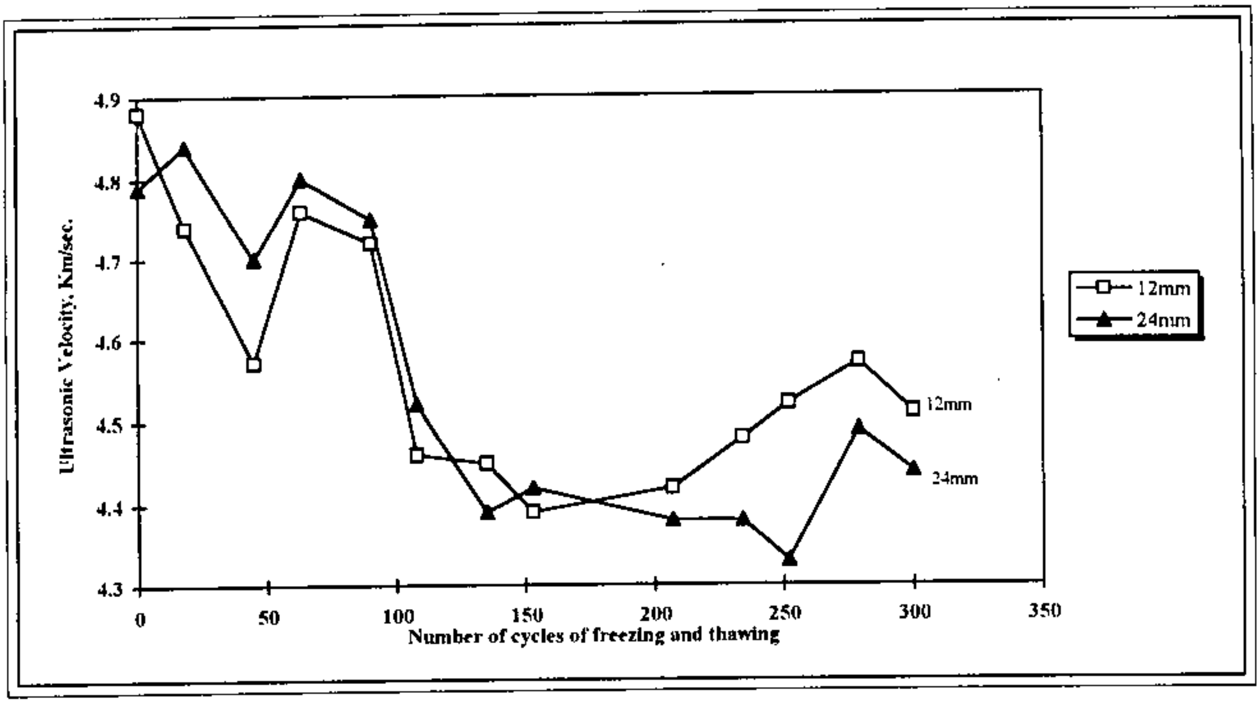

Figure 3.60 : Relation between ultrasonic velocity and the number of cycles of freezing and thawing as a function of fiber length for concrete grade 40 MPa and fiber ratio = 0.5%V_f

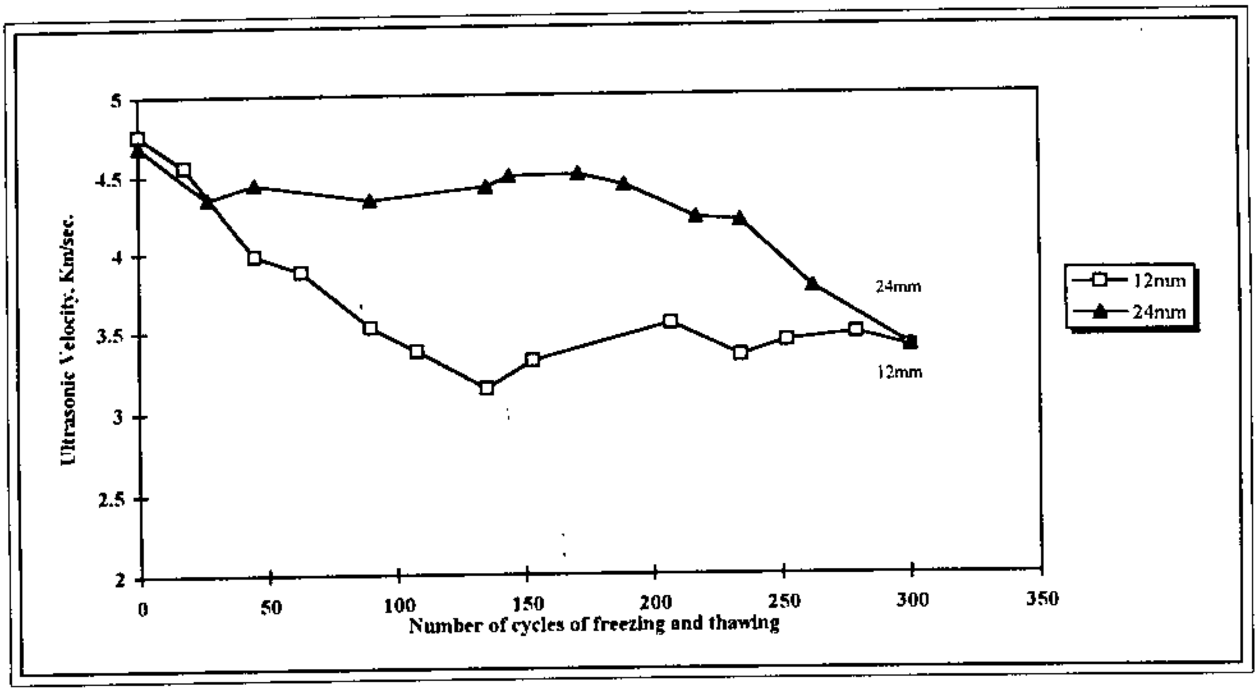

Figure 3.61 : Relation between ultrasonic velocity and the number of cycles of freezing and thawing as a function of fiber length for concrete grade 40 MPa and fiber ratio = 0.75%V_f

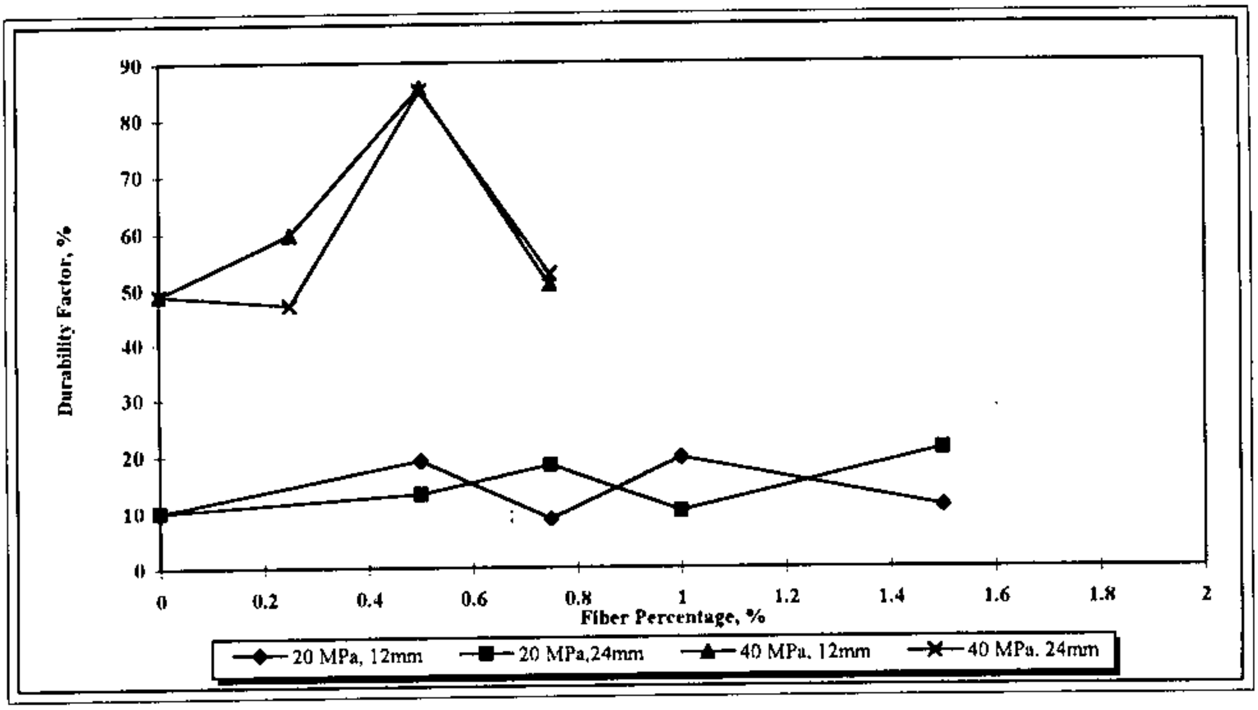

Figure 3.62 : Relation between durability factor and the fiber volume fraction as a function of fiber Lengths for the two concrete grades.

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Based on the results of this investigation, the following conclusions can be drawn regarding the behavior of AR glass reinforced concrete :-

i. The slump value increased by reducing the amount of glass fibers and the fiber length. The presence of fiber turned the consistency of the mixes to stiff and difficult to handle, segregation and honeycombing was noticed. The workability of the glass reinforced mixes was generally poor to very poor.

ii. More air was entrapped in concrete mixes containing fibers than the control mixes. Since fibers tend to interlock in some fashion to form a mat like a bird nest from which it is very difficult to dislodge and compact.

iii. Glass reinforced concrete density was lower than that of plain concrete.

iv. The addition of fibers has little or no effect on the compressive strength of concrete. As the fiber percentage and length are increased, the probability of these fibers nesting together and leaving large voids in the concrete is greater thereby reducing the compressive strength.

v. With large aggregate sizes, the glass fibers will disrupt and will lose some of its strength, thereby become less effective.

vi. The results indicate clearly that the tensile strength is more affected by the presence of randomly distributed glass reinforcement than the compressive strength of concrete.

vii. The addition of glass fibers changes the way in which concrete failed. Plain concrete failed suddenly while glass fiber reinforced concrete developed cracks first, then the cracks widened and gradually failed (increase the ductility).

viii. The presence of fibers improves the durability compared to control mixes by decreasing the weight loss, reducing the change in length and increasing the pulse velocity. On the other hand, increasing fiber percentage reduces the durability.

ix. The behavior of concrete mixes of grade 40 MPa was better than 20 MPa since their classification according to velocity and durability factor was good to doubtful while for 20 MPa was poor.

x. Bleeding occurred in mixes of concrete grade 20 MPa. It is observed that the presence of fiber reduces bleeding.

4.2 RECOMMENDATIONS

The following recommendations may be useful in improving the fiber incorporation in concrete :

i. Use the superplasticizers should be considered mainly as an aid to increase the workability.

ii. Fiber bundles are porous themselves and the introduction of large quantities of such reinforcement also requires greater amounts of mixing water, so it may be advisable to immerse glass fiber in water for a period of time before mixing.

iii. In theory, 24mm chopped strands should produce greater strength than 12mm, but it was observed from practice that there are often little differences so it is preferable to use 12mm strand length because it is easier to incorporate.

iv. The effective fiber volume fraction shall not exceed 0.5% V_f, since beyond this limit segregation and non homogenous mixes were produced.

v. Additional research studies are required to :

- Study the effect of varying the water/cement ratio, or the aggregate cement ratio.
- Try to optimize the effective quantity of the glass fiber from which the workability and the strength requirements are fulfilled.
- To find a way to minimize the damage of glass fibers.

References

ACI Committee 544.1, *State-of-the-Art Report on Fiber Reinforced Concrete*, American Concrete Institute, Detroit, 1984.

ACI Committee 544.2, *Measurement of Properties of Fiber Reinforced Concrete*, American Concrete Institute, Detroit, 1984.

ACI Committee 544.3, *Guide for Specifying, Mixing, Placing and Finishing Steel Fiber Reinforced Concrete*, American Concrete Institute, Detroit, 1984.

Akihama S., Suenaga T., Tanaka M., and Hayashi, M. 1987, Properties of GFRC with low Alkaline Cement, in : *Fiber Reinforced Concrete Properties and Applications*, S. P. Shah and G. B. Batson (editors), **SP- 105 ACI** : 189-209.

Brown, J. H. 1988. *Durability and GRC Permanent Formwork*, Project for Cem-FIL International Ltd.

Cem-FIL International Ltd., *A Guide to Vibration Cast Premix GRC*, The Parks, Newton - Le - Willows, Merseyside, England, 1995.

Cem-FIL International Ltd., *Cem-FIL Composites : Technical Data*, The Parks, Newton - Le - Willows, Merseyside, England, 1995.

Cem-FIL International Ltd., *Cem-FIL News*, The Parks, Newton - Le - Willows, Merseyside, England, 1995.

Cem-FIL International Ltd., *Cem-FIL Range Product Details*, The Parks, Newton - Le - Willows, Merseyside, England, 1995.

Control S.P.A., *Controls Testing Equipment for the Construction Industry*, Italy, 1993.

Hannant, D. J. 1978. *Fiber Cements and Fiber Concretes*, 1st. Edition, John Wiley & Sons Ltd., New York.

Hannant, D. J. 1995. Fiber Reinforcement in the Cement and Concrete Industry, *Materials Science Technology*, **11**: 853-861.

Humboldt MFG. Co., *Automatic Freezing and Thawing Equipment*, Chicago, 1985.

Majumdar, A. J. 1975. Properties of Fiber Cement composites, in: *Fiber Reinforced Cement and Concrete*, Rilem Symposium, Adam Neville (editor).

Margolis, J. 1986. *Advanced Thermoset composites Industrial and Commercial Applications*, Van Nostrand Reinhold Company, New York.

McDougle and Edwin, A. 1995. GFRC Comes of Age, *Construction Specifier*, **48(12)** : 6.

Mindess, S. and Young, J. F. 1981. *Concrete*, 3rd edition, Prentice-Hall

Ministry of Industry and Trade, Directorate of Specifications and Standardization, *Jordanian Standard Specification No. 96 for Aggregates for Cement*, Amman, 1987.

Ministry of Industry and Trade, Directorate of Specifications and Standardization, *Jordanian Standard Specification No. 30 for Portland Cement*, Amman, 1993.

Neville, A. M. 1989. *Properties of Concrete*, 3rd edition, Longman, England.

Parviz S., Tlili A., Yohena M., and Tilsen, B. L. 1993. Durability Characteristics of Polymer-Modified Glass Fiber Reinforced Concrete, *ACI Materials Journal*, **90-M6** : 40-48.

Pigeon, M. and Lachance, M. 1981. Critical Air Void Spacing Factors for Concrete Submitted to Slow Freeze-Thaw Cycles, *ACI Materials Journal*,**78-26**: 282-291.

Prestressed Concrete Institute 1985. Glass Fiber Reinforced Concrete : A Most Innovative Material, Reported by *Concrete International*, **7(3)** : 69-70.

Proctor, B. A. and Litherland, K. L. 1985. *Improving the strength retention of GRC by Matrix and Fiber Modifications*, GRC Congress, Darmstadt, Germany.

Proctor, B. A. 1990. Long Term Strength Properties of GRC, in: *Composite Materials in Building: State of the Art, Research and Prospects*, Preliminary International Symposium under the aegis of Italian Ministry of University and Scientific and Technological Research.

SKW TROSTBERG, *Melment Applications in Concrete*, Germany, 1990.

Zonsveld, J. J. 1975. Properties and Testing of Concrete Containing Fibers other than Steel, in: *Fiber Reinforced Cement and Concrete*, Rilem Symposium, Adam Neville (editor).

ملخص

تأثيرات قصيرة المدى للالياف الزجاجية
على خصائص الخرسانة.

إعداد

منى فهد المصري

المشرف

الدكتور باسل حناينة

الخرسانة المسلحة بالألياف الزجاجية تحتوي على الإسمنت و الحصى و الألياف الزجاجية. إن توزيع الألياف الزجاجية المقاومة للقاعدية توزيعا" عشوائيا"، و الهدف منها تحسين بعض الخصائص الميكانيكية للخرسانة.

لذا تم عمل دراسة مخبرية شاملة لمعرفة تأثير إضافة الألياف الزجاجية بنسب متفاوتة و أطوال مختلفة على الخصائص الميكانيكية و الفيزيائية مثل : درجة التشغيل، نسبة المحتوى الهوائي، الكثافة، قوة تحمل الضغط، قوة تحمل الشد و الديمومة.

تم إجراء التجارب على مجموعتين من القوة الخرسانية هما ٢٠ نيوتن/مم^{٢} و ٤٠ نيوتن/مم^{٢} . حيث استخدم طولين من الألياف الزجاجية هما ١٢ مم و ٢٤ مم . أما النسب فكان توزيعها على النحو التالي: (٠,٥ ، ٠,٧٥ ، ١، ١,٥) ٪ من الحجم النهائي للمجموعة الاولى و هي ٢٠ نيوتن/مم^{٢} ، أما