Sudan University of Science and Technology

College of Graduate Studies

The Effect of Fiber Glass Reinforcement on Local Materials High Strength Concrete Mixture Properties

تأثير تقوية الالياف الزجاجية على خصائص الخلطة الخرسانية عالية القوه المنتجه من المواد المحلية

A Thesis Submitted in Partial of the Requirements for the Degree of Master of The Construction Engineering

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الآية

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

﴿ قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ(32) ﴾

صدق الله العظيم

سورة البقرة الآية (32)

Dedication

To my Grandmother's soul..

Now I know why you always told me to be strong.

You knew that

One day I would need the strength to bear your loss..

Acknowledge

I would like to express my sincere appreciation to Dr. Ebtihaj Abuelgasim Mohamed Ahmed, School of Civil Engineering, Couse of Engineering, Sudan University and Technology, for their help and guidance in the preparation and development of this work. The constant encouragement, support and inspiration they offered were fundamental to the completion of this research.

Finally, I would like to thank everyone who gave advice or assistance that contributed to complete this research.

Abstract

The usage of high strength glass fiber reinforced concrete (HSGFRC) in the construction applications has been increasing worldwide . these it will definitely have an impact on SUDAN. due to the vast land area available for construction, in addition to the unstable economic conditions , the fast growing population and locally available , strong and relatively cheap, and locally available repairing and strengthening material. The main objective of this investigation is to study the effect of addition of alkali resistant glass fiber reinforced polymer (AR-GFRP) with various proportions typically 0.0 , 0.75 , 1.0 , 1.25 and 1.5 by weight of cement on the mechanical behavior of plain HSC (without fiber) with 28 days cube compressive strength up to 55.2 MPa using available materials in the local market.

Results show that it is possible to produce HSGFRC in Sudan using materials that are available at the local markets if they are carefully selected. Based on the experimental results, the compressive strength, splitting tensile strength and density of HSC is found to be increases as fiber percentage increases for both ages 7 and 28 days.

The compressive strength of HSC is found in the 28 days percentage of increasing over the reference mix is found to be maximum equal to 7.46% at 1.5 fiber percentage. The density of HSC is found to be increases very slightly as fiber percentage increases from 0.0 to 1.5, typically from 2.415 to 2.442 kg/m3 . The splitting tensile strength of HSC is found in the 28 days’ percentage of increasing over the reference mix is found to be maximum equal to 52.45% at 1.5 fiber percentage.

المستخلص

إن استخدام الخرسانة عالية القوة المسلحة بالألياف الزجاجية في تطبيقات التشييد يتزايد و بشكل كبير على مستوى العالم ، و من المؤكد ان يكون له اثره في السودان ، بسبب مساحات الأراضي الواسعه المتاحة للبناء ، و التزايد الكبير في اعداد السكان ، بالإضافة الى الأوضاع الإقتصادية الغير مستقرة ، الأمر الذي يستدعي استخدام مثل هذه المواد الرخيصة نسبيا والمواد المتوفرة محليا كمواد تقوية و ترميم للمنشات المتضررة .

إن الهدف الأساسي لهذا البحث هو دراسة تأثير اضافة الألياف الزجاجية المقاومة للقلويات بعدة نسب مختلفة و هي 0.0 ، 0.75 ، 1 ، 1.25 ، 1.5 من وزن الأسمنت على خصائص القوة للخرسانة عالية القوة البحتة (بدون ألياف) بقوة تحمل ضغط للمكعب عند 28 يوم تساوي 55.2 ميجا باسكال باستخدام المواد المتوفرة بالسوق المحلي .

اظهرت النتائج انه يمكن انتاج الخرسانة عالية القوة المسلحة بالألياف الزجاجية في السودان باستخدام المواد المتوفرة محلياً في حال تم اختيارها بعناية ، بناءاً على النتائج المخبرية لقوة الضغط وقوة الشد للإنشقاق، و الكثافة للخرسانة عالية القوة وجدت بانها تزيد مع زيادة نسبة االلياف .

لقوة الضغط وجد أن نسبة الزيادة القصوى عن الخلطة المرجعية بعد 28 يوم تساوي 7.46% عند نسبة ألياف 1.5 . اما الكثافه بعد 28 يوم وجد انها تزيد بشكل طفيف جدا مع زياده نسبه الألياف من 0.0 الى 1.5 بالضبط من 2.415 الى 2.442 كجم/م^3 . قوة الشد للإنشقاق وجد أن نسبة الزيادة القصوى عن الخلطه المرجعية بعد 28 يوم تساوي 52.45% عند نسبة ألياف 1.5 .

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List of Abbreviations

ACI : American Concrete Institute

ASTM: American Society for Testing and Materials

AR-GFRC: Alkali Resistant-Glass Fibers Reinforced Concrete

Fst: Concrete Splitting Tensile Strength

Fr: Concrete Flexural Strength or Modulus of Rapture

FRC: Fiber Reinforced Concrete

GFRC: Glass Fibers Reinforced Concrete

HRWRA: High-Range Water-Reducing Admixture

NRWRA: Normal-Range Water-Reducing Admixture

HSC: High Strength Concrete

HSFRC: High Strength Fiber Reinforced Concrete

HSGFRC: High Strength Glass Fiber Reinforced Concrete

NSC: Normal Strength Concrete S Stander Deviation

W/C: Water / Cement Ratio

Chapter One

Introduction

Chapter One

Introduction

1.1General Background

High Strength Glass Fiber Reinforced Concrete (HSGFRC) is an advanced model for concrete mix , It combines the advantages of high strength concrete (HSC) and Fiber Glass (FG). By using this form of concrete mix, the problems and disadvantages that are difficult for concrete to overcome alone can be overcome by taking advantage of the properties of Fiber Glass.

HSC has a brittle behavior at ultimate limit state of loading, so, fibers can be added to improve the structural properties of concrete. It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as crack arrester and would substantially improve its mechanical behavior. The addition of fibers results in a product which has higher flexural and tensile strengths as compared with normal concrete. [1]

HSFRC shows an improved performance in the hardened state due to the addition of fibers. Many types of fibers are available; glass fiber reinforced polymer (GFRP) are preferred than other type due to high ratio of surface area to weight and high strength properties to unit cost ratio. However, glass fiber which is originally used in conjunction with cement was found to be affected by alkaline condition of cement. The alkali resistant glass fiber reinforced polymer (AR-GFRP), which is used, recently has overcome this defect and can be effectively used in concrete. [2]

1.2 Research Problem

SUDAN is a developing country that needs reconstruction, so it must focus on appropriate research, relatively cheap, easy to use and locally available materials.

Much research has been done to study the properties of (FG) , but not enough attempts have been made to add fiberglass to concrete.

In addition, most studies are available for a High Strength Glass Fiber Reinforced Concrete (HSGFRC) reinforced by insufficient proportions of fiberglass. So I will study To study the behavior of (HSGFRC) reinforced with different proportions of Fiber Glass .

1.3 Research Aim and Objectives

The aim of this research is to study the effect of the addition of Fiber Glass with various proportions on the mechanical behavior of high strength concrete develop locally using available materials in the SUDAN .

In the present experimental investigation, the following are the objectives :

1- To develop HSC using material locally available in Sudan

2- To study the strength characteristics of (HSGFRC) reinforced with percentages of Fiber Glass.

3- To evaluate the elector fibers reinforced on compressive strength, splitting tensile strength, and density .

4- To evaluate the strength gain with age of (HSGFRC) .

1.4 Methodology

- Literature Review: To conduct comprehensive literature review related to the study.
- Materials Selection and Tests: Careful selection and test of suitable ingredient materials required for the experimental study.
- Mix Proportioning: Determine the relative quantities of materials to obtain the mix design proportions that achieved the adopted design strength.
- Experimental Program: Performing mechanical laboratory tests to achieve the research objectives.

- Results and Discussion: Analyzing the experimental output test results to draw conclusions .

1.5 Thesis Organization

Chapter 1 (Introduction)

This chapter gives general background about HSGFRC, statement of problem, aim and objectives of the research, and the adopted methodology.

Chapter 2 (Literature Review)

This chapter gives general comprehensive literature review related to HSC and GFRC, in addition of the main constituent materials.

Chapter 3 (Test Program and Laboratory Works)

This chapter discusses the materials properties, adopted mix design, type of laboratory tests and procedures, samples and specimens that are required for tests, and curing condition.

Chapter 4 (Test Results and Discussion)

This chapter includes presentation of the results obtained from testing. Detailed discussion of results and mechanical properties of each mix are also included .

Chapter 5 (Conclusion and Recommendations)

This chapter includes main conclusions and recommendations drawn from this research.

Chapter Two

Literature Review

Chapter Two

Literature Review

2.1 High Strength Concrete (HSC)

2.1.1 Definition

ACI committee 363 (1997) defined the high strength concrete (HSC) as a concrete with specified compressive strength for design of 41MPa or greater. Iravani and MacGregor (1998) stated that HSC is typically recognized as concrete with a 28-day cylinder compressive strength greater than 42MPa. More generally, concrete with a uniaxial compressive strength greater than that typically obtained in a given geographical region is considered HSC, although the preceding values are widely recognized. According to Li (2011), Strengths of up to 140MPa have been used in different applications, laboratories have produced strengths approaching 480MPa.

2.1.2 Advantages and Disadvantages of High Strength

CONCRETE High–strength concrete was developed as better and as structural material of higher quality when compared to normal strength concrete. Therefore it has many benefits, both in performance and cost efficiency, so HSC advantages are reduction in structural element size, reduction in amount of longitudinal reinforcement and compression members, focusing on slenderer columns, higher strength and better performance leads to larger spans and decrease of total number of beams, columns., decreased time necessary for concrete's formwork due to early strength development, decrease in concrete cover due to lower permeability, long performance under the most critical action combinations, lower creep and shrinkage with higher resistance for freezing and thawing, increased resistance to very aggressive environments, decreased axial shortening, buckling of supporting elements, increased rentable space, due to slenderer and thinner elements, but also decreased number of supporting elements due to larger spans, decreased permanent action of self–weight of structure, decreased maintenance and repair costs and greater stiffness due to higher modulus of elasticity with high compressive and flexural strengths. Although high–strength concrete has many advantages as a material, it also has disadvantages which may occur due to some impurities or even as a consequence of some advantages mentioned above. High strength concrete disadvantages are bond strength between cement paste and aggregate does not increases with the same acceleration as compressive strength, high–vibration are required for better compaction, and to exclude possible segregations, minimal concrete cover for reinforcement protection may prevent the use of maximum benefits in reduction of element sizes, available prestressing may be inadequate for the maximum use of high–strength concrete's strength, high–strength concrete requires very detailed, precise and careful material selection and does not accept any impurities and due to low W/C ratio, high–strength concrete requires special curing and installation or placement. There is a possibility of decrease in stiffness, whereas modulus of elasticity does not respectively increase with concrete's strength, therefore use of high–strength concrete may provide slenderer elements but with lower stiffness which may lead to stability problems, whereas solution lays in very precise choice of structural systems [3]

2.1.3 Materials Selection of HSC

The selection of suitable cementitious materials for concrete structures depend on the type of structure, the characteristics of the aggregates, material availability, and method of construction. The varieties of HSC do not require exotic materials or special manufacturing processes, but will require materials with more specific properties than conventional concretes. As the target strength of concrete increases, it becomes increasingly less forgiving to variability, both material and testing related. Compared with conventional concrete, variations in material characteristics, production, handling, and testing will have a more pronounced effect with HSC. Therefore, as target strengths increase, the significance of control practices intensifies [4]

Evaluating cement and other cementitious materials, chemical admixtures, and aggregates from various potential sources in varying these materials will affect the concrete compressive strength [5]

In order to achieve high compressive strength, it is important to understand the factors that govern the strength of concrete :

1- The properties of the cement paste
2- The properties of the transition zone between the paste and the aggregate
3- The properties of the aggregate .
4- The relative proportions of the constituent materials.

All these factors must be optimized in order to make significant increases in compressive strength

2.1.3.1 Cement

Cement proportions will indicate the optimum combination of materials. Variations in the chemical composition and physical properties of any of almost any portland cement type meeting the compositional requirements of ASTM C 150 can be used to obtain concrete with satisfactory workability having compressive strength up to about 60 MPa .

However, within a given cement type, different brands will have different strength development characteristics because of the variations in compound composition and fineness that are permitted by ASTM C 150 [6]

Portland cement is indisputably the most widely used binding material in the manufacture of hydraulic-cement concrete. Selecting Portland cements having the chemical and physical properties suitable for use in high-strength concrete is one of the most important, but frequently underestimated considerations in the process of selecting appropriate materials for high-strength concrete. Cements should be selected based on careful consideration of all performance requirements, not just strength. To avoid interaction related problems, the compatibility of the cement with chemical admixtures and other cementing materials should be confirmed. Concrete producers experienced in making high-strength concrete know firsthand how critically important cement selection can be, and those inexperienced can learn in very hard, expensive ways. In the end, the benefits of the time and resources devoted to material verification testing will considerably out weigh the cost. The performance of cement can vary widely when attempting to make high-strength concrete

2.1.3.2 Water Reducing Admixtures

Water reducing admixtures are used to reduce the quantity of mixing water required to produce concrete of a certain slump, reduce water/cement ratio, reduce cement content, or increase slump. Water reducers are classified broadly into two categories: normal and high range water reducers. The normal range water reducers (NRWR) are called plasticizers, while the high range water reducers (HRWR) are called superplasticizers [7]

NRWR meeting the specifications of ASTM C 494 Type A, will provide strength increases without altering rates of hardening and reduce the water demand by 5–10%. Lignosulfonate salts of sodium and calcium are an example of NRWR. Their selection should be based on strength performance [6]

Increases in dosage above the normal amounts will generally result in significant side effects, such as decreasing on strength and retardation with some binder blends especially at lower temperatures [6]

HRWR meeting the specifications for superplasticizers which are detailed in ASTM C 494 as Type F for HRWR with normal set times or Type G for HRWR with retarded setting times. HRWR are most effective in concrete mixtures that are rich in cement and other cementitious materials. HRWR help in dispersing cement particles, and they can reduce mixing water requirements by more than 30%, thereby increasing concrete compressive strengths [5]

Reduction in water/cement ratio is against the different water reducers admixtures . While NRWR allow 5-12% reduction of water, HRWR melamine/naphthalene based admixtures reduces water 16-25 %, and HRWR polycarboxylate ether polymer based admixture reduces water 20 to 35% [8]

2.1.3.3 Aggregates

When the transition zone between the paste and the aggregate is improved the transfer of stresses from the paste to the aggregate particles becomes more effective. Consequently the mechanical properties of the aggregate particles themselves may be the ‘weakest link’ leading to limitation of achievable concrete strength. Fracture surfaces in HSC often pass through aggregate particles rather than around them. Crushed rock aggregates are generally preferred to smooth gravels as there is some evidence that the strength of the transition zone is weakened by smooth aggregates. The aggregate should have a high intrinsic strength and granites, basalts and limestone's have been used successfully, as have crushed glacial gravels. During the crushing process, aggregate particles may be severely microcracked .The number of microcracks will be greater in larger particles, consequently it is common practice to use smaller particles (10-14 mm nominal size) for high strength concrete . [9]

It is assumed that small aggregate particles will contain less internal flaws and hence produce a higher concrete strength. It must be stressed that the selection of appropriate sources of aggregate is much more critical for high strength concrete than for conventional concretes .

2.1.3.4 Mixing Water

The requirements for water quality for HSC are no more stringent than those for conventional concrete. Usually, water for concrete is specified to be of potable quality. This is certainly conservative but usually does not constitute a problem since most concrete is produced near a municipal water supply. The single most important variable in achieving HSC is the water cement ratio. HSC produced by conventional mixing technologies are usually prepared with water-cement ratios in the range of 0.22 to 0.40, and their 28 days compressive strength is about 60 to 130 MPa when normal density aggregates are used . (10)

2.1.4 Mix Proportion

Mix design of high strength concrete is influenced by properties of cement, sand aggregates and water-cement ratio have compressive strength above 40 MPa. To achieve high strength, it is necessary to use lowest possible water-cement ratio, which invariably affects the workability of the mix and necessitates the use of special vibration techniques for proper compaction. In the present state of art, a concrete with a desired 28 day compressive strength of upto 50 MPa can be made with suitably proportioning the ingredients using normal vibration techniques for compacting the concrete mix .

Thus, the trial mixture approach is best for selecting proportions for HSC. Table.2.1 shows some mixture proportions and properties of commercially available HSC .

Table (2.1): Mixture Proportions and Properties of Commercially Available HSC [7]

Units per m^3	Mix number					
	1	2	3	4	5	6
Cement, Type I, kg	564	475	487	564	475	327
Silica fume, kg	—	24	47	89	74	27
Fly ash, kg	—	59	—	—	104	87
Coarse aggregate SSD (12.5 mm crushed limestone), kg	1068	1068	1068	1068	1068	1121
Fine aggregate SSD, kg	647	659	676	593	593	742
HRWR Type F, liters	11.6	11.6	11.22	20.11	16.44	6.3
Retarder, Type D, liters	1.12	1.05	0.97	1.46	1.5	—
Water to cementing materials ratio	0.28	0.29	0.29	0.22	0.23	0.32
Fresh concrete properties						
Slump, mm	197	248	216	254	235	203
Density, kg/ m3	2451	2453	2433	2486	2459	2454
Air content, %	1.6	0.7	1.3	1.1	1.4	1.2
Compressive strength, 100 x 200-mm moist-cured cylinders						
7 days, MPa	67	71	71	92	77	63
28 days, MPa	79	92	90	117	100	85
56 days, MPa	84	94	95	122	116	—
91 days, MPa	88	105	96	124	120	92
Modulus of elasticity in compression, 100 x 200-mm moist-cured cylinders						
91 days, GPa	50.6	49.9	50.1	56.5	53.4	47.9
Drying shrinkage, 75 by 75 x 285-mm prisms						
7 days, millionths	193	123	100	87	137	—
28 days, millionths	400	287	240	203	233	—
90 days, millionths	573	447	383	320	340	—

Requirement of different ingredient materials required for producing HSC can be summarized as stated in Table (2.2) . [10]

Table (2.2): Requirements of Ingredient Materials for HSC . [10]

Material	Requirements
Cement	Portland cement. Higher content.
Water	w/b ratio 0.22 to 0.40.
Fine aggregate	Higher FM (around 3.0). Smaller sand content or coarser sand. Grading is not critical for concrete strength.
Coarse aggregate	Smaller maximum size (10 – 12 mm) is preferred. Angular and crushed with a minimum flat and elongated particle. Type of aggregate depending on the concrete strength targeted. Gradation within ASTM limits has little effect on concrete strength. Higher CA/FA ratio than that for normal strength concrete.
Admixtures (chemical and mineral)	- Type of admixture depends on the property of the concrete to be improved. - Reliable performance on previous work can be considered during selection. - Optimum dosage.
Overall basic considerations	- Quality materials - Improved quality of cement paste as well as aggregates. - Denser packing of aggregates and cement paste. - Improved bond between aggregate surface and cement paste. - Minimum numbers as well as smaller sizes of voids in the paste.

2.2 Fiber Reinforced Concrete (FRC)

2.2.1 General Background

Concrete is widely recognized as a cost-effective, versatile construction material. But it is also covered with a number of drawbacks that are inherent to its composition. By generally accepted engineering standards, concrete is relatively brittle and lacks flexural strength. Intertwined with these problems is concrete's propensity to crack in both its plastic (early-age) and hardened (long-term) state. Early-age cracks are microscopic fissures caused by the intrinsic stresses created when the concrete settles and shrinks over the first 24 hours after being placed. Long-term cracking is in part caused by the shrinkage that transpires over the months, perhaps years, of drying that follow. In either case, these cracks can jeopardize the overall integrity of the concrete and not allow it to maintain or possibly ever attain its maximum performance capability. The demand for high strength, crack resistant and lighter concrete resulted in development of fiber reinforced concrete. Recron3S Fiber Reinforcement Systems can provide a solution to most of these problems . [11]

Fibers made from steel, glass, and natural materials (such as wood cellulose) are available in a variety of shapes, sizes, and thicknesses; they may be round, flat, crimped, and deformed with typical lengths of 6 mm to 150 mm and thicknesses ranging from 0.005 mm to 0.75 mm (see Figure 2.1) . [7]

Figure (2.1): Steel, Glass, Synthetic and Natural Fibers [7]

2.2.1.1 Fiber type

The fiber type can be viewed with different criteria. From the size point of view, fibers can be classified into macro and microfibers. The diameter of macrofibers is in the range of 0. 2 to 1 mm and for microfibers is in a range of a few to tens of micrometers. Basically, microfibers are efficient in restraining micro cracks and macrofibers in restraining macroscopic cracks. From the materials point of view, the fibers that are commonly used in FRC are carbon, glass, polymeric (acrylic, aramid, nylon, polyester, polyethylene, polypropylene, and poly vinyl alcohol), natural (wood cellulose, sisal, coir or coconut, bamboo, jute, akwara, and elephant grass), and steel (high tensile and stainless). Different types of fibers have different values of Young's modulus, different tensile strength, different surface texture, and different elongation ability, as can be seen in Table (2.3) [7]

Table (2.3): Properties of Different Types of Fibers [7]

Fiber type	Relative density (specific gravity)	Diameter, µm	Tensile strength, MP	Modulus of elasticity, MPa	Strain at failure, %
Steel	7.80	100-1000	500-2600	210,000	0.5-3.5
Glass					
E	2.54	8-15	2000-4000	72,000	3.0-4.8
AR	2.70	12-20	1500-3700	80,000	2.5-3.6
Synthetic					
Acrylic	1.18	5-17	200-1000	17,000-19,000	28-50
Aramid	1.44	10-12	2000-3100	62,000-120,000	2-3.5
Carbon	1.90	8-0	1800-2600	230,000-380,000	0.5-1.5
Nylon	1.14	23	1000	5,200	20
Polyester	1.38	10-80	280-1200	10,000-18,000	10-50
Polyethylene	0.96	25-1000	80-600	5,000	12-100
Polypropylene	0.90	20-200	450-700	3,500-5,200	6-15
Natural					
Wood cellulose	1.50	25-125	350-2000	10,000-40,000	
Sisal			280-600	13,000-25,000	3.5
Coconut	1.12-1.15	100-400	120-200	19,000-25,000	10-25
Bamboo	1.50	50-400	350-500	33,000-40,000	
Jute	1.02-1.04	100-200	250-350	25,000-32,000	1.5-1.9
Elephant grass		425	180	4,900	3.6

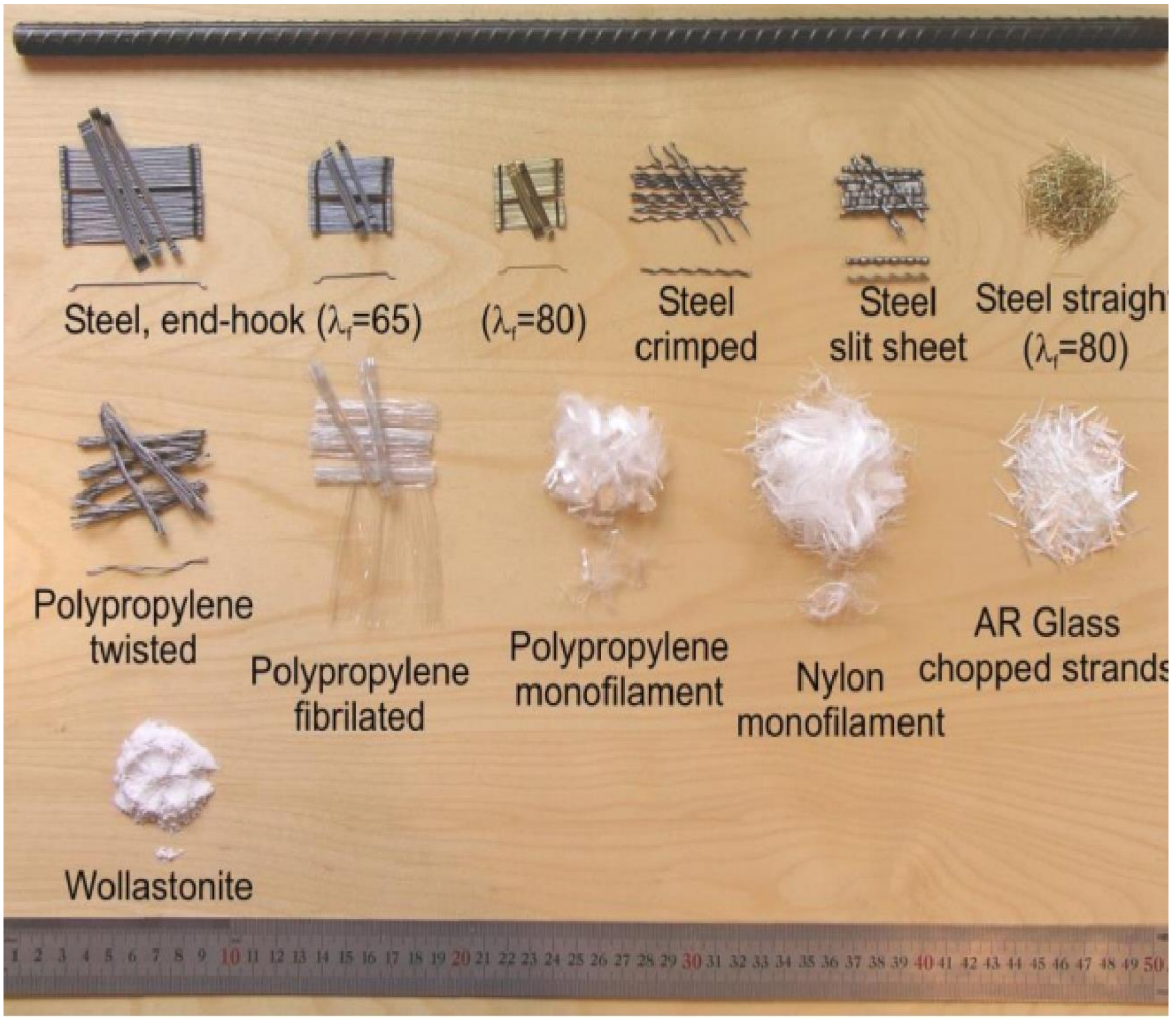


Figure (2.2) : Examples of commercially available fibers. [12]

2.2.1.2 Orientation and distribution of fibers :

The fiber orientation plays an important role for the mechanical performance of fiberreinforced composites. The technology of dispersed reinforcement provides for direct and random (free) orientation of fibers in the concrete body. Directed orientation, see Figure (2.3) (a)-(e), is realised mainly by using continuous filaments, plaits, various types of fabrics and non-fabric nets, or by special production techniques like pre-placing the fibers (e.g. SIFCON) or for example in the Hatcheck process. Body-random orientation is characterised by equi-probable and unlimited (free) distribution of short fibers throughout the body of the concrete (in three-dimensional space); see Figure (2.3) (f). The angles of inclination of the fibers relative to the surface of the component range from zero to 90 degree , as long as the dimensions of the component, in all directions, exceed the length of fibers considerably. Plane-random orientation is characterised by equiprobable and unlimited (free) distribution of fibers in a two-dimensional space. This case occurs mainly in thin-walled elements, e.g. flat sheets, plates, etc., when the thickness of an element is less than the length of the fibers used. As a result of this, the angle of inclination of fibers relative to the surface of the elements is comparatively low. Constrained-random orientation is relevant when at least two geometric parameters of a structural unit, e.g. height and width, are restricted in dimensions and limit the free, random orientation of fibers in the body of the concrete. Such a situation can be observed in the case of beams, plates, etc. The smaller the cross-section, the more restricted the possibilities of free orientation of the fibers. However, it should also be noted that for fiber-reinforced concrete there are a number of other factors influencing the fiber orientation and distribution apart from purely geometrical considerations – such as the method of placement, the equipment used (e.g. pumping), and the properties of the fresh concrete (resistance against fiber segregation) . [12]

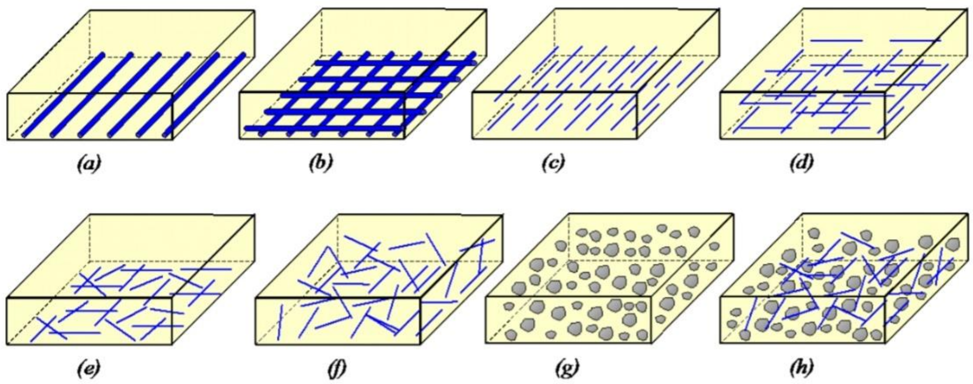


Figure (2.3) : Schematic representation of different fiber composites: (a) unidirectional continuous; (b) bi-directional continuous; (c) discontinuous with biased 1-D fiber orientation; (d) discontinuous with biased 2-D fiber orientation; (e) discontinuous with plane-random orientation; (f) discontinuous with random fiber orientation; (g) particulate composite (particle suspension); and (h) fiber-reinforced and particulate composite (e.g. fiber-reinforced concrete) .

2.2.2 Glass Fiber Reinforced Concrete (GFRC)

Much of the original research performed on glass fiber reinforced concrete (GFRC) took place in the early l960s. This work used conventional borosilicate glass fibers (E-Glass) and sodalime-silica glass fibers (A-Glass). However, Glass compositions of E-glass and A-glass, used as reinforcement, were found to lose strength quickly due to the very high alkalinity (PH of 12.5) of the cement based matrix. Consequently, early A-glass and E-glass composites were unsuitable for long term use. Continued research resulted in the development a new alkali resistant-glass fiber reinforced polymer (AR-GFRP) that provided improved long term durability. The chemical compositions and properties of selected glasses are listed in Tables 2.4 and 2.5, respectively [2]

Table (2.4): Chemical Composition of Selected Glasses, (Percent) [2]

Component	A-glass	E-glass	AR-glass
SiO_2	73.0	54.0	61.0
Na_2O	13.0	—	15.0
CaO	8.0	22.0	—
MgO	4.0	0.5	—
K_2O	0.5	0.8	2.0
Al_2O_3	1.0	15.0	—
Fe_2O_3	0.1	0.3	—
B2O3	—	7.0	—
ZrO_2	—	—	20.0
TiO_2	—	—	—
Li_2O	—	—	1.0

Table (2.5): Properties of Selected Glasses [2]

Property	A-Glass	E-Glass	AR-Glass
Specific gravity	2.46	2.54	2.74
Tensile strength, ksi	450	500	355
Modulus of elasticity, ksi	9400	10,400	11,400
Strain at break, percent	4.7	4.8	2.5

Metric equivalent: 1 ksi = 1000 psi = 6.895 MPa

The properties of fiber reinforced cementations materials are dependent on the structure of the composite. Therefore, in order to analyse these composites, and to predict their performance in various loading conditions, their internal structure must be characterized. The three components that must be considered are:

1. The structure of the bulk cementations matrix

2. The shape and distribution of the fibers

3. The structure of the fiber–matrix interface . (13)

2.2.3 Applications and Latest Developments of GFRC

Compared to traditional concrete, GFRC has complex properties because of its special structure. As a result of the structural properties, it has suitable moulding, strong and durable structure. Moreover, because of being fast to install and easy to handle and transport, it provides low cost. It disperses or absorbs sound and it is environmentally friendly .

As total output of these properties, one of the key features of GFRC has been its versatility in use. GFRC is widely and reliably used in architecture (i.e. cladding, mouldings, landscaping), building (i.e. roofing, walls and windows, renovation, foundations and floors), engineering (i.e. permanent formwork, utilities, acoustics, bridges and tunnels, roads, water and drainage). (14)

2.3 High Strength Fiber Reinforced Concrete (HSFRC)

In recent years, high strength concrete (HSC) is becoming an attractive alternatively to traditional normal strength concrete (NSC). High strength concretes of strength in excess of 80 MPa are often used in a wide range of applications. With the increased use of HSC, concern has developed regarding the behavior of such high strength concrete. The high strength in HSC is obtained often, by reducing the amount of water, with the use of special admixture that also improves the workability. However, the lower water-cement ratio leads to lower porosity that makes HSC more brittle and make it have less tensile and flexural strength compared to NSC. High strength concrete is inherently a brittle material, with low tensile strength and limited ductility. Due to these properties, the normal high strength concrete has some limitation for application in very impotent structure, such as high-rise building, road pavements, long span bridges and construction of chimneys. The high strength concrete not only increases the strength of concrete but also it reduced the permeability. High strength concrete is generally, used for increasing the durability, tensile strength, modulus of elasticity and flexural strength of concrete. Thus high strength fiber reinforced concrete (HSFRC) is a composite material essentially consisting of conventional high strength concrete reinforced by random dispersal of short, discontinues and discrete fine fibers of specific geometry. The different types of fibers had investigated, and utilized for different applications. Each types of fiber have its own characteristic property and limitation. Several different types of fibers, both manmade and natural, have been incorporate into high strength concrete. Use of natural fibers in high strength concrete precedes the advent of conventional reinforced high strength concrete in historical context. However, the technical aspects of HSFRC systems remained essentially undeveloped. In HSFRC, thousands of small fibers are dispersed and distributed randomly in the high strength concrete during mixing, and thus improve high strength concrete properties in all directions. Fibers help to improve the post- peak ductility performance, pre-crack tensile strength, impact strength, fatigue strength, and eliminate temperature and shrinkage cracks . [15]

It was found that the inherent tensile strength and strain capacity of the matrix itself was enhanced when small fibers were used. When 4% (by volume) of fibers were added, the first cracking, indicating the elastic limit, was observed at about 30% of the maximum tensile load . [16]

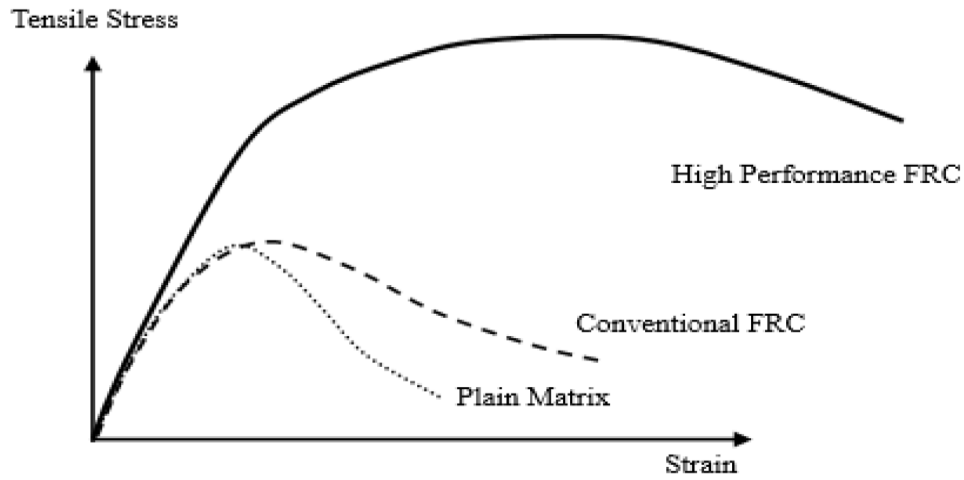


Figure (2.4): Mechanical Behavior of FRC Compared with Plain Matrix . [16]

Strain hardening is caused by the process of multiple cracking which occurs after the start of the first crack. In the post-peak region, the number of cracks remains constant while crack widths increase. Failure is obtained by fiber pullout and fiber rupture. Uniform distribution of the fibers affects the stress distribution in the matrix and hence, higher stress is required to propagate the crack. After the first crack starts, distributed multiple matrix cracking follows. The width of the cracks is usually between 1-3 mm. The multiple cracking process exhibits a ductile behavior which causes strain hardening phenomenon of the HSFRC. To increase the elastic limit of HSFRC and achieve strain hardening response, the volume content of the fibers should be increased as well. Meanwhile, the fibers should be closely spaced and well distributed. It was found that the decreasing fiber length significantly enhances the tension and flexure response of HSFRC. In general, short fibers are advantageous because they are easier to handle during mixing and result in less broken fibers and better dispersion. It was also found that the distribution of the smaller fibers was more homogeneous than that of larger fibers. [16]

Chapter Three

Test Program and Laboratory Works

Chapter Three

Test Program and Laboratory Works

3 .1 General Description

This chapter presents the experimental program and the materials selection and its properties used to produce HSGFRC associated with this research work. The laboratory investigation consisted of testing strength properties which included compressive strength tests, splitting tensile strength tests and unit weight tests was carried out to achieve the aim of this research. The test procedures, details and equipment used to assess concrete properties are illustrated in the following sections.

3. 2 Test Program

In order to achieve the research objectives, the test program illustrated in Table 3.1 was carried out. Tests which include compressive strength test, splitting tensile strength test, flexural strength test, and density were carried out to evaluate the strength properties of HSGFRC. Five fiber percentages were chosen, typically, 0.0, 0.75, 1 and 1.25 by weight of cement led to five mixtures including the reference mixtures (without fibers) made to evaluate the effect of AR-GFRP on the mechanical behavior of plain HSC. These percentages were chosen in a range that can give better observation and evaluation on the mechanical behavior of HSGFRC when contain a small amount of fiber and when contain a large amount of fiber. Each test is determined at ages 7 and 28 days, except for the density which determined at 28 days. 150 x150 x150 mm cube specimens were prepared for compressive strength test and density. The test of compressive strength was made according to BS 1881, Part 108 (1993) standard test method , the test of tensile strength was made according to BS 1881, Part 117 (1983) standard test method .

For each mix, three specimens were made for testing for each test for period of 28 days and three specimens were made for testing for each test for period of 7 days, the mean value of the specimens was considered as the test result of the experiment. A detailed description of test procedures, equipment, and curing conditions will be discussed in the following sections .

Table (3.1): Test Program

Test	Mixture Designatio	M50 F0		M50 F1		M50 F2		M50 F3	
	%GFRP by Weight of Cement	0.0		0.75		1.00		1.25	
Compression Test and Density	Ages (day)	7	28	7	28	7	28	7	28
	NO. of Specimens	3	3	3	3	3	3	3	3
	Specimen Type and Dimension (mm)	Cube 150 x150 x150		Cube 150 x150 x150		Cube 150 x150 x150		Cube 150 x150 x150	
Splitting Tensile Strength Test	Ages (day)	7	28	7	28	7	28	7	28
	NO. of Specimens	3	3	3	3	3	3	3	3
	Specimen Type and Dimension (mm)	Cube 150 x150 x150		Cube 150 x150 x150		Cube 150 x150 x150		Cube 150 x150 x150	

3.3 Materials Selection and Properties

HSGFRC constituent materials used in this research include ordinary portland cement, course aggregate, fine aggregate, normal range water reducer (NRWR), in addition to GFRP. Proportions of these constituent materials have been chosen carefully in order to optimize the packing density of the mixture .

3 .3 .1 Cement

In this research, ordinary portland cement CEM II 42.5R produced from local market was used for the production of HSGFRC .

The cement met the requirements of ASTM C150 (2007) specifications. Table 3.2 shows the physical properties of cement according to manufacturer data sheet

Table (3.2): Physical Properties of Cement According to Manufacturer Data Sheet

Properties		Cement	ASTM C150-07 Requirements
Fineness (cm2/gm.)		3500	MIN 2800
Setting Time, Vicat Test (hr:min)	Initial	2 HR	min 45 ≥
	Final	5 HR	375 min ≤
Mortar Compressive Strength (MPa)	3 days	25	> 10
	Days 28	58	> 42.5

3.3.2 Coarse Aggregates

Two types of coarse aggregate were used in this research a stepwise coarse aggregate and broken stone of nominal size of 12.5 mm. Table 3.3 illustrate the sieve analysis and the physical properties of these types.

Table (3.3): Sieve Analysis and Physical Properties of Coarse Aggregate Types

Sample Description	**Type (1)**	**Type (2)**
Sieve Size (mm)	%Passing	**%Passing**
25	100	**100**
19	100	**100**
12.5	93.82	**100**
9.5	30.94	**92.5**
4.75	4.67	**35.72**
2.36	1.03	**8.12**
1.18	0.34	**2.04**
Dry unit weight (Kg/m3)	1522	**1480**
Dry specific gravity	2.63	**2.60**
Saturated specific gravity	2.67	**2.63**
Absorption%	2.5	**3.3**

To achieve the ASTM C33 (2003) standard requirements for coarse aggregate, a mix design of these two types by 50% of type 1 and 50% of type 2 was prepared as shown in Table (3.4) .

Table (3.4): Sieve Analysis of Combined Coarse Aggregate According to ASTM C33 (2003) and Physical Properties.

Sieve Size (mm)	%Passing
25	100
19	100
12.5	96.9
9.5	61.71
4.75	20.08
2.36	4.53
Unit Weight (KG/m3)	1501
Dry Specific Gravity	2.61
Saturated Specific Gravity	2.65
Absorption%	2.9

3.3.3 Fine Aggregate

Table 3.5 illustrate the grain distribution of fine aggregate used on this research and its properties.

Table (3.5): Grain Distribution of Fine Aggregate and Physical Properties

Sieve Size (mm)	Passing (%)
4.75	100
2.36	100
1.18	96
0.6	87.66
0.425	71.52
0.3	32.81
0.15	2.02
0.075	0
Fineness Modulus FM	1.81
Dry Unit Weight (Kg/m3)	1650.17
Dry Specific Gravity	2.60
Saturated Specific Gravity	2.64
Absorption(%)	0.82

3.3.4 High Range Water Reducing Admixture (HRWR)

A highly effective super plasticizer a set retarding effect for producing free-flowing concrete in hot cli-mates .Also ,a substantial water reducing agent for promoting high early and ultimate strengths.

Sikament-R2004 is used wherever high quality concrete is demanded under difficult placing and climatic conditions

Table (3.6): Properties of High Range Water Reducer

Type	Property
Appearance	brown liquid
Basis	Modified synthetic dispersion
Dose	2.5 to 0.6 % by weight of cement
Toxicity	Non-Toxic under relevant health and safety codes

3.3.5 Glass Fiber Reinforced Polymer (GFRP)

In this research, alkali resistant glass fiber reinforced Polymer (AR-GFRP) is used, According to manufacturing data sheet, the properties of AR-GFRP used on this research are shown in Table (3.7) .

Table (3.7): Properties of AR-GFRP .

Trade Name	CEM FIL anti crack high dispersion Glass fibers
Number of fibers	212 million / kg
Aspect Ratio	857 : 1
Typical addition rate	0.6 to 1.0 kg/m3 of concrete
Tensile Strength	1700 MAP
Modulus of Elasticity	73 GPA
Corrosion resistance	Excellent
Specific gravity	2.6
Density	26 KN/m3
Diameter	14 microns
Fiber Length	12 mm

3.3.6 Water

Potable tap water without any salts or chemical was used in the study for the experimentation and for the curing process. The water source was the laboratory of the Faculty of Engineering Gezira University.

3.4 Mix Proportioning of HSGFRC

The key to successful production of HSC is maintaining a consistent and low water/cement ratio together with effective mixing. HSC has been produced successfully but in all cases, stringent control of all sources of water in the mix is

1- critical. These include:

2- Added mix water.

3- Water in liquid admixtures or silica fume slurry.

Free moisture on fine and coarse aggregates. It should be noted that small changes in the moisture content of the fine aggregate have a proportionately greater effect on water/cement ratio and hence strength of HSC, than it does for normal strength concrete.

The reference concrete mixture (without GFRP) was developed to obtain 28-day cylinder compressive strength for design of 50 MPa. The first trail mixture was based on British Standards Institution. BS 8110, then modifications were applied to obtain the best determinable mix design proportions that achieved the target design strength which illustrated in Table 3.8.

Table (3.8): Mix Proportioning for 1 m^3 of Concrete for The Reference Mixture .

Material Type	Units / m^3
Cement (kg)	553
Fine Aggregate (kg)	552
Coarse aggregate (kg)	1025
HRWR (Lit.)	6
W/C	0.38

3.5 Preparation of HSGFRC and Mixing Procedure

After selection of all needed constituent materials and amounts to be used (mix proportioning); all materials are weighed properly. Then mixing with a power-driven revolving drum mixer showed in Figure 3.1 started to ensure that all particles are surrounded with each other.

Figure (3.1): The Power-Driven Revolving Drum Mixer Used on This Research.

For the reference mixture M50 F0 (without fibers), mixing procedures was applied in accordance with ASTM C192 (2002). However, for addition of the glass fibers; careful attention must be given when mixing the glass fibers. The glass fibers are always added last and mixed for the minimum time required to achieve uniform dispersion. It is important to ensure that minimum time is spent mixing the fibers because they can be damaged by excessive mixing. In addition, mixing the glass fibers at the higher speed would also damage the fibers.

3.6 Testing Procedure

In this section, testing procedures to evaluate the strength properties of HSGFRC are presented .

3.6.1 Compressive Strength Test

A significant portion of this research focused on the behaviors of HSGFRC cube specimens under compressive loading. The compressive tests discussed on this section were all completed nominally according to BS 1881, Part 108 (1993) standard test method. Total of 24 cubes were manufactured. For each batch of HSGFRC made, 150x150x150 mm cube specimens were prepared, (See Figure 3.2). The cubes were filled with fresh concrete and then compacted by rod method in accordance to the standard, after preparing the specimens .

(b) (a)

Figure (3.2): (a) and (b) Cube Specimens

After 24 hours; Cubes extracted from forms and stored in water (curing phase) up to the time of test The testing machine used on this research for compressive strength is MATEST C104 Servo Plus 2000 KN capacity shown in Figure (3.3) .

Figure (3.3): MATEST C104 Servo Plus 2000 KN Capacity Compression Test Machine .

The compressive strength was determined at different ages 7, and 28 days. Three cubes were tested for each mix for period of 28 days and Three cubes were tested for each mix for period of 7 days, the mean value of the specimens was considered as the compressive strength of the experiment .

3.6.2 Tensile Strength Test

Splitting test is technically less difficult test for determining the tensile strength of cementitious composites. It is standardly realized on cube-shaped specimens 150 * 150 * 150 mm or on cylindrical specimens with diameter of 150 mm and high of

300 mm. The specimen is loaded by compression force, which is equally distributed on the opposite surfaces of specimen. Standard loading rate (increase of splitting stress) is 0.04 - 0.06 MPa/s .(17)

The material tensile splitting strength determined on cubes is given by:

$$F_{fct,sp,cube} = 2\,f / \pi\,a^2 \qquad (3.1)$$

Where :

F = Splitting tensile strength in MPa:

f = is value of load force at macro cracking

a = is length of cube edge.

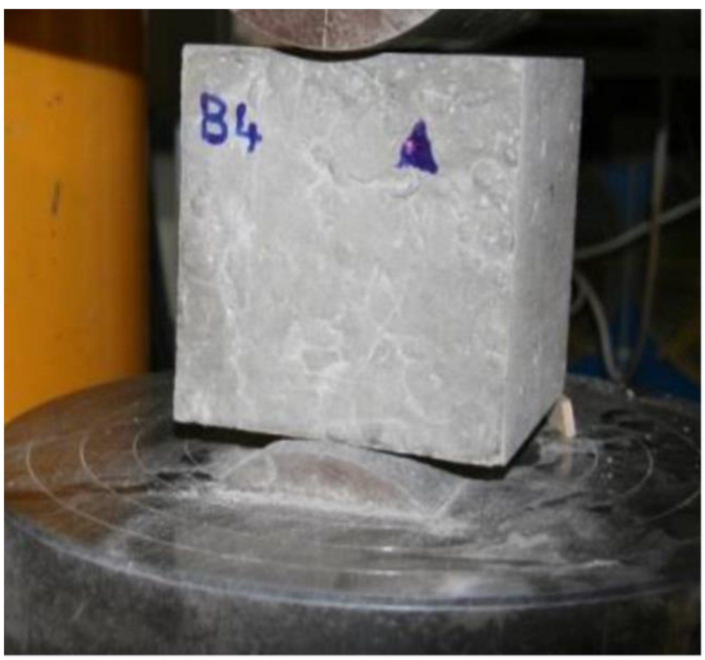


Figure (3.4): Variants of splitting test

Total number of 24 cubes of 150 x 150 x 150 mm were manufactured. The cubes were filled with fresh concrete and then compacted by rod method in accordance to the standard, after preparing the specimens, cubes were covered with plastic sheets for about 24 hours to prevent moisture loss prior to the curing stage. All cube specimens were tested after 28 days from casting. The rate of loading was constant for the tests equal 1.4 MPa/min. The testing machine used on this research for split tensile strength is MATEST C104 Servo Plus 2000 KN capacity, the same that used for compression test.

The split tensile strength was determined at different ages 7, and 28 days. Three cubes were tested for each mix for period of 28 days and Three cubes were tested for each mix for period of 7 days, the mean value of the specimens was considered as the split tensile strength of the experiment.

The maximum fracture strength can be calculated based on Eq. (3.1) according to ASTM C496 (2004).

3.7 Curing Procedure

Curing is an important process to prevent the concrete specimens from losing of moisture while it is gaining its required strength. Lack of curing will tend to lead the concrete specimens to perform less well in its strength required. All concrete samples were placed in curing basin after 24 hours from casing (See Figure 3. 5). All samples remained in the curing basin up to time of testing at the specified age. Curing water temperature is around 25^{o}C. The curing condition of lab basin followed the ASTM C192 (2004).

Figure (3.5): Specimens in Curing Basin.

Chapter Four

Test Results and Discussion

Chapter Four

Test Results and Discussion

4.1 Compressive Strength and Density Test Results

The results of 7 and 28 days compressive strength and 28 days density are shown in Table 4.1 and Table 4.2. As mentioned before in chapter three, the 28 days cylinder compressive strength of plain HSC specimens (without fiber) obtained from adopted mix proportion that achieve the target design strength used on this research was equals to 55.2 MPa, however, the 28 days cube compressive strength of plain HSC specimens as shown in Table 4.2 equal to 59.38 .

According to Neville (2011), the restraining effect of the bearing plates of the testing machine may extends over the entire height of a cube specimen, however, it leaves unaffected part of cylinder specimen. It is, therefore, to be expected that the strength of cubes specimen is greater than for cylinder specimen made from the same concrete. For NSC, the ratio of cylinder to cube compressive strength is around 0.8, but, in reality, there is no simple relation between the strength of the specimens of two shapes. However, for HSC, the effect of specimen's size and shape on the compressive strength is insignificant as for NSC. The ratio of cylinder to cube compressive strength increases strongly with an increase in strength and is nearly 1 at strength of more than 100 MPa.

Table (4.1): Cube Compressive Strength and Density Test Results.

Designation	% GFRP by Cement Wt.	Specimens	Density (t/m3)	Cube Compressive Strength (MPa)	
			28 Days	7 Days	28 Days
M50 F0	0	1	2.424	47.86	57.82
		2	2.391	46.49	61.13
		3	2.429	51.93	59.38
M50 F1	0.75	1	2.426	50.60	61.42
		2	2.424	48.45	60.33
		3	2.430	51.55	62.69
M50 F2	1	1	2.431	52.17	63.42
		2	2.426	47.77	60.90
		3	2.433	52.64	64.10
M50 F3	1.25	1	2.439	53.80	62.76
		2	2.436	51.31	63.34
		3	2.441	49.10	65.11
M50 F4	1.5	1	2.446	54.37	62.42
		2	2.438	50.91	65.89
		3	2.444	50.62	63.10

Table (4.2): Average Cube Compressive Strength and Density Test Results

Designation	% GFRP by Cement Wt.	Density (t/m^3)	Average Compressive Strength (MPa)		M50 F0% 7 Days / 28 Days	% Increase Over the Reference Mix 28 Days
		28 Days	7 Days	28 Days		
M50 F0	0	2.415	48.76	59.38	82.1	0
M50 F1	0.75	2.426	50.20	61.48	81.6	3.54
M50 F2	1	2.430	50.86	62.80	81.0	5.00
M50 F3	1.25	2.438	51.40	63.73	80.6	7.33
M50 F4	1.5	2.442	51.96	63.81	80.1	7.46

4.1.1 Effect of AR-GFRP on the Compressive Strength of HSC

From Table 4.2, it is observed that with increase in fiber percentage, the compressive strength also increases. As shown in Figure 4.1, the 28 days' compressive strength increases sharply from 59.38 to 63.73 MPa with increase in fiber percentage from 0.0 to 1.25 respectively. Then, a very slight increase is observed in the compressive strength from 63.73 to 63.81 MPa when fiber percentage increases from 1.25 to 1.5 respectively. In general, as shown in Figure 4.2, the percentage of increase over the reference mix at fiber percentage of 1.25 and 1.5 is 7.33 and 7.46 percent respectively, hence it is established that fiber percentage of 1.25 can be consider the optimum value of fiber addition for compressive strength enhancement since the difference between those values of fiber percentage is insignificant.

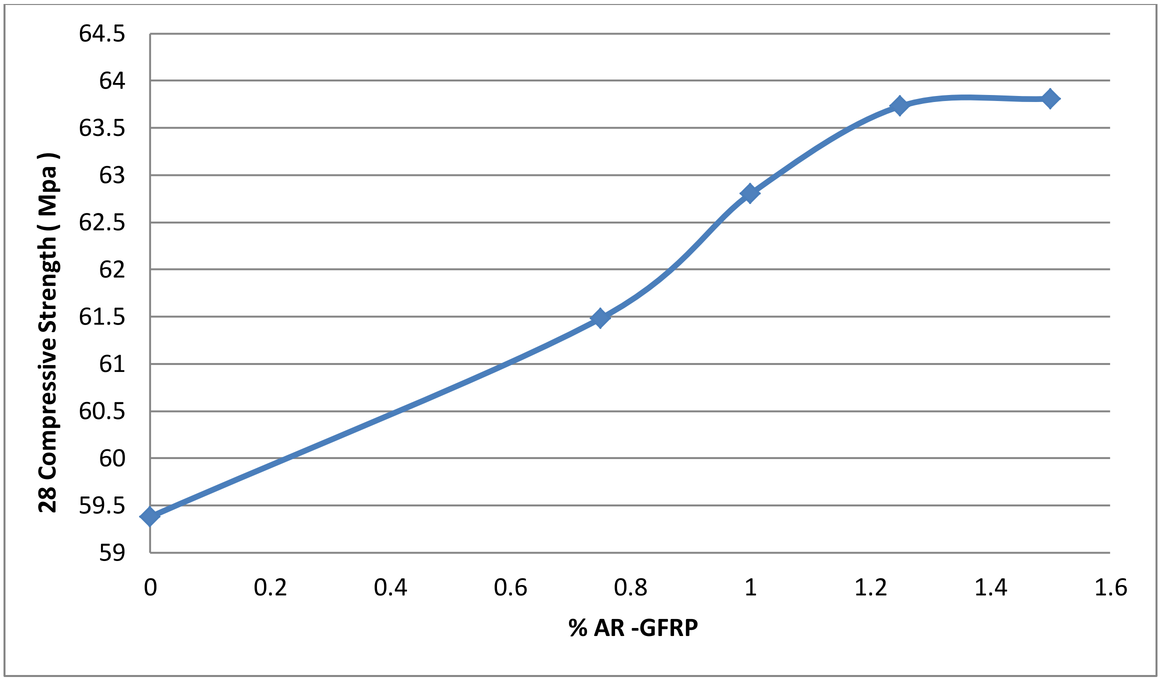


Figure (4.1): Effect of AR-GFRP on 28 Days Compressive Strength of HSC.

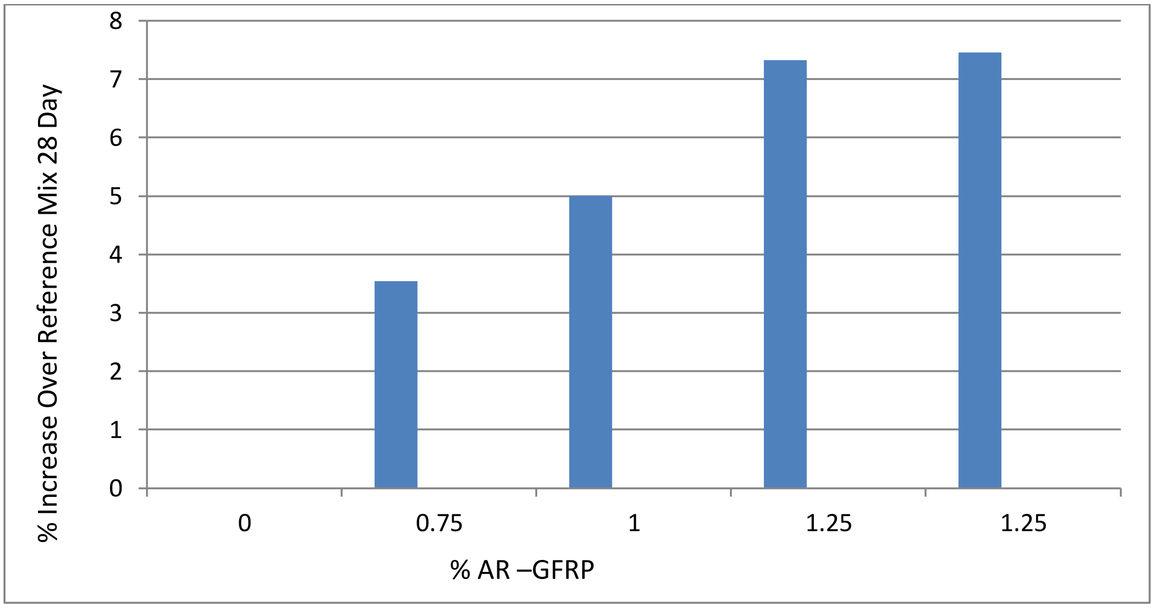


Figure (4.2): The Percentage of Increase in Compressive Strength Over the Reference Mix Due to Addition of AR-GFRP on HSC .

Test result show good agreement with other researcher studied the effect of addition of GFRP on structural concrete, Mahmoud Mazen Hilles (2017) show that the concrete compressive strength can increased obviously when small amount of fiber used, however, there was no additional significant enhancement in compressive strength when fiber percentage increased upper the optimum value as shown in Figure (4.3).

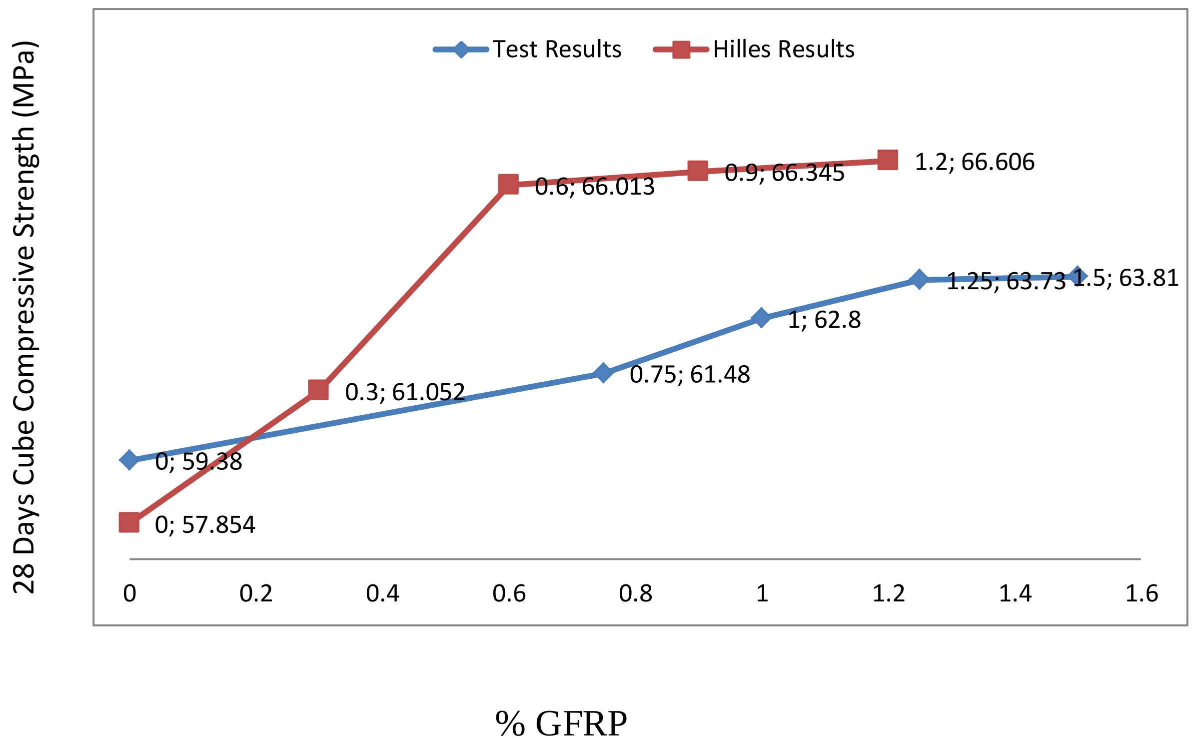
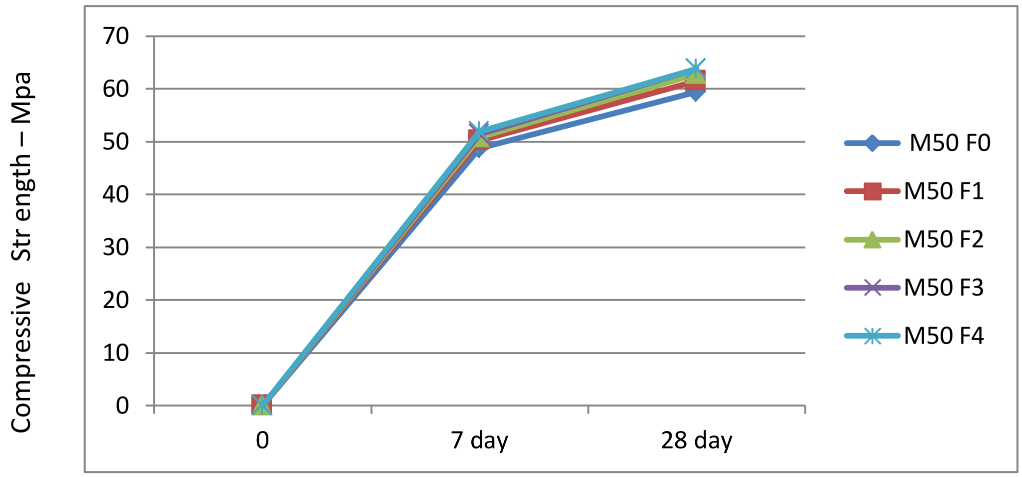


Figure (4.3): Comparisons of compressive strength test results with other related researches.

4.1.2 Effect of AR-GFRP on the Strength Gain with Age of HSC

Figure 4.4 illustrate the strength gain with age for each mix. From Table 4.2, it is obvious that the ratio of 7 days to 28 days compressive strength for the reference mix (M50 F0) is higher than for normal strength grade, typically 82.1 percent. However, according to ACI committee 363 (2010), it has been recognized that HSC shows a higher rate of strength gain at early ages compared to lower strength concrete. The higher rate of strength development of HSC at early ages is caused by an increase in the internal curing temperature in the concrete mixtures due to a higher heat of hydration and shorter distance between hydrated particles due to low water cement ratio. However, as shown in Figure 4.5, the ratio of 7 days to 28 days' compressive strength decrease from 82.1 to 80.1 as fiber percentage increase from 0.0 to 1.5 respectively. This can be explained simply that fiber can absorb a part of increased temperature and can make the distance between hydrated particles longer result in less internal curing temperature in the concrete mixtures.



Age-Days

Figure (4.4): Effect of AR-GFRP on the Strength Gain with Age of HSC.

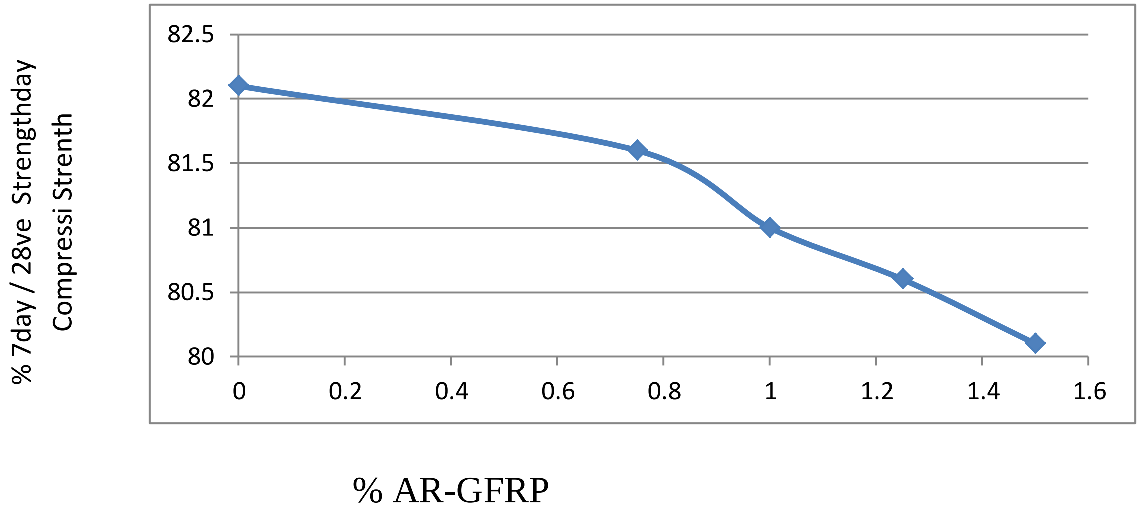
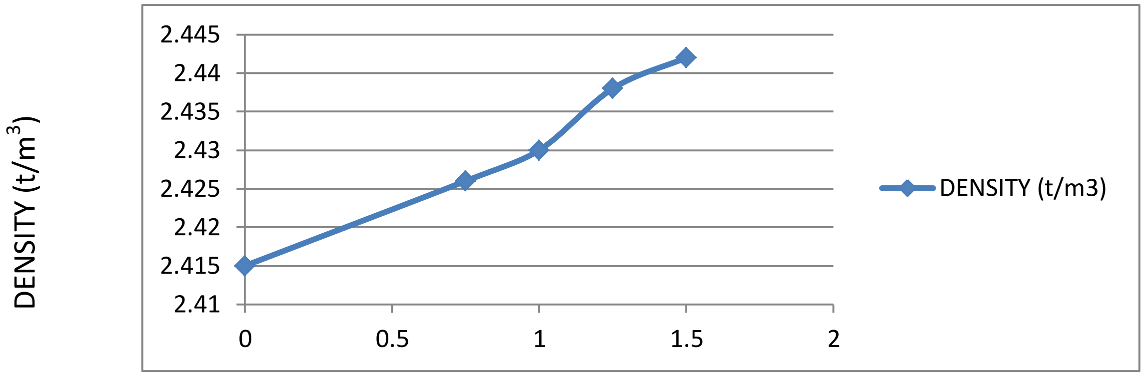


Figure (4.5): Effect of AR-GFRP on %7days / 28days Compressive Strength

4.1.3 Effect of AR-GFRP on the Density of HSC

From Figure 4.6, it is observed that with increase in fiber percentage, the density increases very slightly, this can be explain due to the extremely light weight and high ratio of surface area to weight of AR-GFRP .



% AR-GFRP

Figure (4.6): Effect of AR-GFRP on Density of HSC.

4.2 Splitting Tensile Strength Test Results

The results of 7day and 28 days splitting tensile strength are shown in Table 4.3 and Table 4.4. According to ACI Committee 363 (2010), Eq. 4.1 was recommended for the prediction of the splitting tensile strength of HSC with 28 days compressive strength within 21 to 83 MPa.

$$Fsp = 0.59\sqrt{fc'} \qquad (4.1)$$

As mentioned before, the 28 days compressive strength of plain HSC (without fiber) was equals to 59.38 MPa.from Which the predicted splitting tensile strength Fsp using Equation 4.1 equals to 4.55 MPa which seems very close with the average experimental value of plain HSC specimens (M50 F0) which is equal to 4. 23MPa shown in Table 4.4 .

Table (4.3): Splitting Tensile Strength Test Results

Designation	% GFRP by Cement Wt.	Specimens	Split Tensile Strength (MPa) 7 Day	Split Tensile Strength (MPa) 28 Day
M50 F0	0	1	3.34	4.34
		2	2.99	3.98
		3	3.39	4.37
M50 F1	0.75	1	3.66	4.71
		2	3.81	4.93
		3	3.75	4.79
M50 F2	1	1	3.83	5.25
		2	4.05	5.35
		3	3.91	5.18
M50 F3	1.25	1	4.28	5.65
		2	4.12	5.43
		3	4.56	5.78
M50 F4	1.5	1	5.18	6.50
		2	4.97	6.19
		3	5.33	6.66

Table (4.4): Average Splitting Tensile Strength Test Results.

Designation	% GFRP by Cement Wt.	Average Split Tensile Strength (MPa) 7 Day	Average Split Tensile Strength (MPa) 28 Day	% Increase Over the Reference Mix (28 Day)
M50F0	0	3.24	4.23	0
M50F1	0.75	3.74	4.81	13.71
M50F2	1	3.93	5.26	24.35
M50F3	1.25	4.32	5.62	32.86
M50F4	1.5	5.16	6.45	52.45

4.2.1 Effect of AR-GFRP on the Splitting Tensile Strength of HSC

From Table 4.4, it is observed that with increase in fiber percentage, the splitting tensile strength also increases significantly. As shown in Figure 4.7, the splitting tensile strength increases continuously from 3.24 to 5.16 MPa with increase in fiber percentage from 0.0 to 1.5 respectively for 7 days, and 4.23 to 6.45 MPa when fiber percentage increase from 0.0 to 1.5 respectively for 28 days. From the test results shown in Table 4.4, it is observed that the percentage of increase in the splitting tensile strength over the reference mix due to addition of fibers is much higher than for the compressive strength as shown in Figure 4.8.

In addition, the mode of increasing in splitting tensile strength due to addition of fibers is keeping continuous ascending until the highest value of 6.45 MPa (28 Days) at the highest fiber percentage of 1.5 as shown in Figure 4.7, comparing with the increasing in compressive strength where Figure 4.1 shows continuous ascending just until 1.25 fiber percentage and then at fiber percentage from 1.25 to 1.5, the increasing turned to very slight. This difference between the increasing mode of compressive strength and splitting tensile strength curves shown in Figure 4.1 and Figure 4.7 can be explained simply that the defects that caused by higher fiber percentages during the micro level, which are as discussed before, the voids due to fiber debonding and pullout process, and the weakness of the aggregate interlock due to softening and polymeric characteristic of fibers, appear strongly when the concrete fail due to compressive stress. However, in splitting tensile test, although the cylinder specimen subjected to compressive load, the specimen fail due to the induced tensile stresses before reach its ultimate compressive strength capacity.

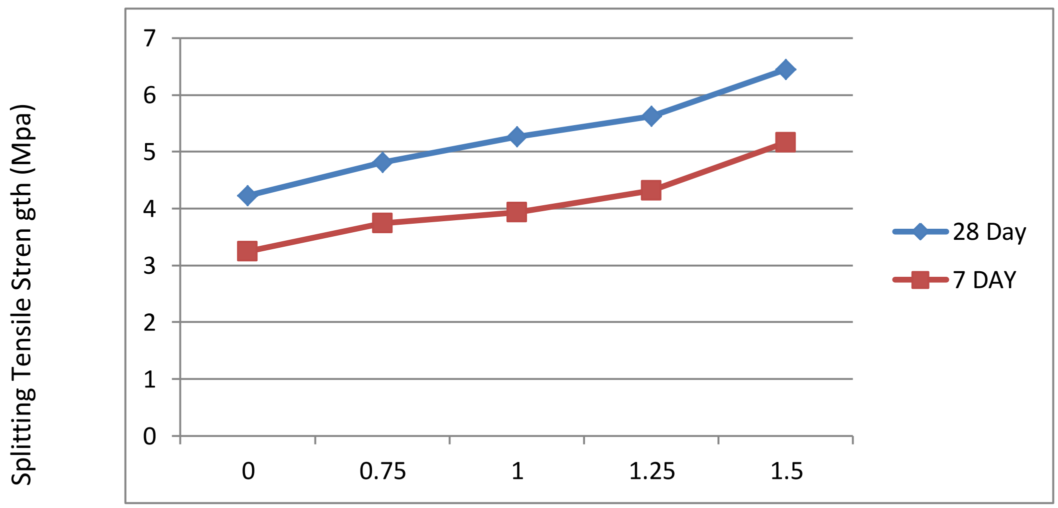


Figure (4.7): Effect of AR-GFRP on Splitting Tensile Strength of HSC.

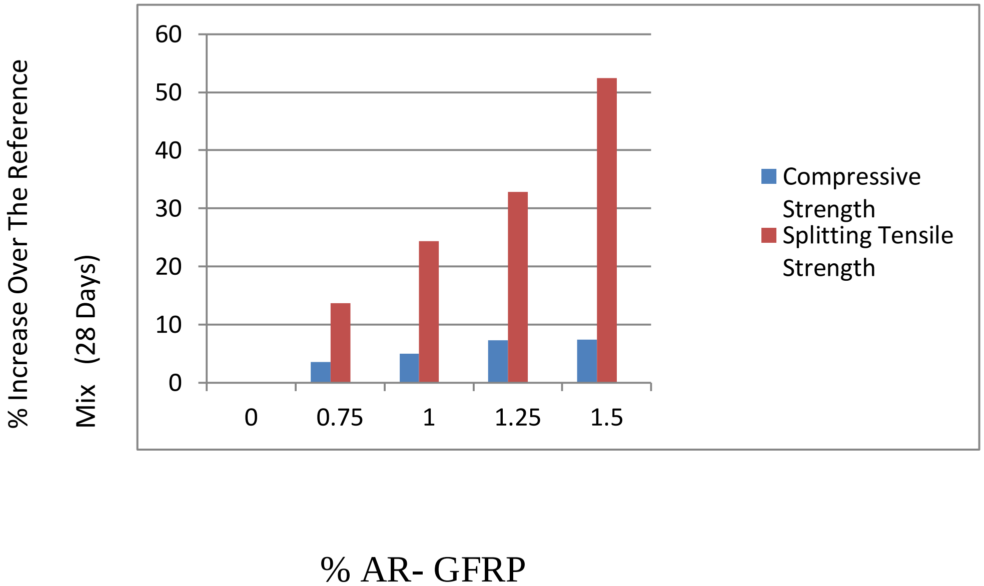


Figure (4.8): The Percentage of Increase Over the Reference Mix Due to Addition of AR-GFRP on HSC: Comparison between Compressive Strength and Splitting Tensile Strength.

Test result show good agreement with Hilles (2017) . The author show that the concrete splitting tensile strength can increased significantly with addition of glass fiber even when large amount was used as shown in Figure 4.9.

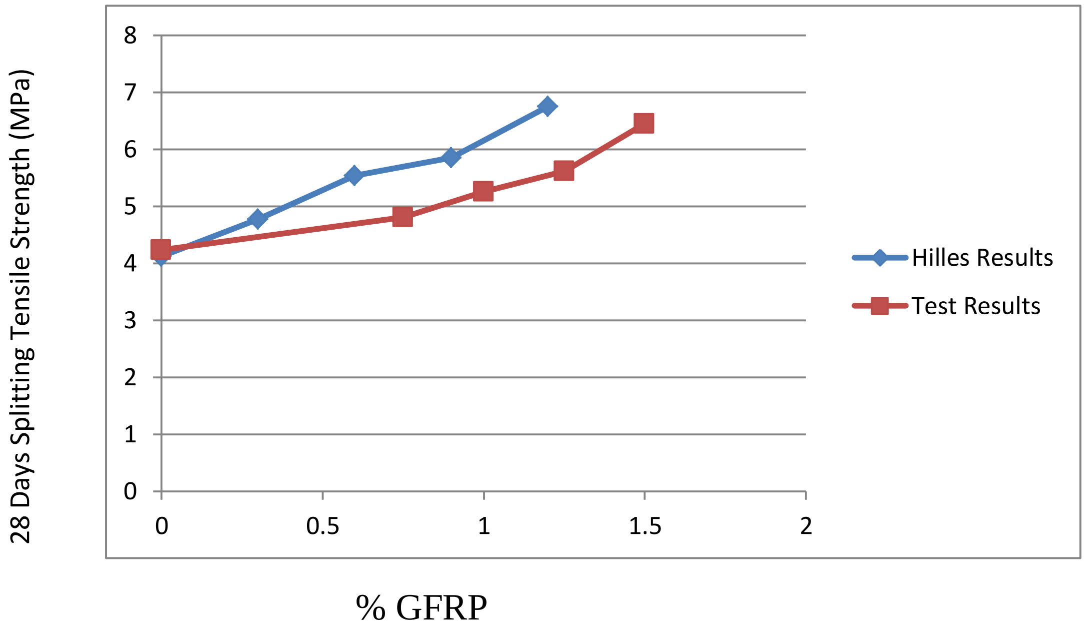


Figure (4.9): Comparisons of splitting tensile strength test results with other related research .

Chapter Five

Conclusions and Recommendations

5.1 Conclusions

Effect of addition of alkali-resistant glass fiber reinforced polymer (AR-GFRP) with the various ratios on the mechanical behavior of HSC with up to 55.

The cube pressure resistance was MPa for 28 days using materials available in the local market.

The main aim of this investigation was to compare the strength and Properties in different proportions From AR-GFRP with normal HSC (without fibers), by lab tests at different ages 7day And 28 days related to compressive strength and splitting tensile strength, and density. Based on the empirical investigation conducted on this research, the following Conclusions are drawn:

1- The compressive strength of HSC increase by 7.46% at 1.5 percentage of added compared with the strength of the reference mix. However, it considered that the optimum percentage of fiber was 1.25 with 7.33 percentage of increasing over the reference mix since the difference between those values of fiber percentage is insignificant.

2- The ratio of 7 days to 28 days compressive strength is found to be decrease as fiber percentage increase, from 82% to 80% as added fiber percentage increase from 0.0 to 1.5 respectively.

3- The density of HSC is found to be increases very slightly as fiber percentage increases from 0.0 to 1.5, typically from 2.415 to 2.442 kg/m3, this can be explained due to the extremely light weight and high ratio of surface area to weight of AR-GFRP.

4- The splitting tensile strength of HSC is found to be increases continuously until the highest value of 1.5 fiber percentage with 52.45 percentage of increasing over the reference mix at 28 days.

5- Test result show good agreement with ACI committee 363 and other researchers studied the effect of addition of GFRP on structural concrete.

5.2 Recommendations:

- Based on the results it in recommended to :

According to research laboratory experiments , FR for concrete with an addition of 1.25% is recommended.

It greatly increases compression and tensile strength.

- The following recommendations are proposed for further research.

1- Study the effect of AR-GFRP on the mechanical properties of HSC with more research variable such as various strength grade, various fiber percentages and various fiber size.

2- Study the stress-strain behavior in compression and tension and develop a generalized stress-strain curve for HSGFRC.

3- Study the performance of HSGFRC under other conditions such as impact load.

4- Study the effect of AR-GFRP on the fresh properties of HSC such as workability.

5- Investigate the durability aspects of HSGFRC such as performance under high temperatures and chemical resistance.

6- Further testing and studies needed to be carry out, to test the behavior of HSGFRC when used as a repair and strengthening material to rehabilitate the different deteriorated structural elements.

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