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Behavior of Fibrous Light Weight Concrete in Comparison to Traditional Fibrous Concrete

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Abstract

This paper presents a focused study on hardened properties of traditional fibrous concrete in comparison to fibrous light weight concrete. Fibrous concrete is made in order to achieve tangible improvement in mechanical properties of hardened concrete. It is now well established that, one of the important properties of steel fiber reinforced concrete (SFRC/SFRLWC) is to superior resistance to cracking and crack propagation. Using fibers in virgin concrete could be capable of transfer brittle failure mode of virgin concrete to semi-ductile failure mode. As a result of this ability to stitching cracks, fiber composites possess increased compressive strength, splitting tensile strength and flexural strength. An experimental program is established to obtain the optimum volume fraction for using steel fiber then study the effects of optimum steel fiber percentage on the traditional and light weight concrete. The experimental program consist of two phases, the first one focused on testing different specimens (cubes ,cylinders and prisms) to get the optimum percentage for steel fibers used. The second phase was focused on testing standard specimens (cubes ,cylinders and prisms) which are mixed with the obtained optimum percentage of steel fibers. Number of Specimens were strengthened with external GFRP sheet then results were compared with non strengthened traditional/lightweight fibrous concrete specimens.

Keywords: *Light Weight Concrete, Fibrous Concrete, FRP.*

1. Introduction

Fiber reinforced concrete (FRC) may be defined as a composite materials made with portland cement, aggregate, and incorporating discrete discontinuous fibers. Now, we wish to add such fibers to concrete because plain, unreinforced concrete is a brittle material, with a low tensile strength and a low strain capacity. The role of randomly distributes discontinuous fibers is to bridge across the cracks that provides some post-cracking (ductility). If the fibers are sufficiently ductile, the Fibers could be capable of carrying significant stresses over a relatively large strain capacity in the post-cracking stage which characteristic is the case of corrugated steel fiber. The real contribution of the fibers is to increase the toughness of the concrete. Also, fibers tend to increase the strain at peak load and provide a great deal of energy absorption in post-peak portion of the load vs. deflection curve and enhances ductility of virgin concrete. When the fiber reinforcement is in the form of short discrete fibers, they act effectively as rigid inclusions in the concrete matrix. Physically, they have thus the same order of magnitude as aggregate inclusions; steel fiber reinforcement cannot therefore be regarded as a direct replacement of longitudinal reinforcement in reinforced and pre-stressed structural members. However, because of the inherent material properties of fiber concrete, the presence of fibers in the body of the concrete or the provision of a tensile skin of fiber concrete can be expected to improve the resistance of conventionally reinforced structural members to cracking, deflection and other serviceability conditions [1]. Light weight concrete very helpful in reducing own weight of concrete and this perfect benefit leads to reduce the percentage of steel reinforcement in structural elements specially in the slabs. One of disadvantages of light weight concrete is low compressive strength and weakness behavior of it. The aim of research slightly appears in using fibers in light weight concrete to provide the behavior of light weight concrete.

2. Objective

Concrete made with portland cement has certain characteristics. It is relatively strong in compression but weak in tension and tends to be brittle. The weakness in tension can be overcome by the use of conventional steel reinforcement and to some extent by the inclusion of a sufficient volume of certain fibers. The use of fibers also alters the behavior of the fiber-matrix composite after it has cracked, thereby improving its toughness. The aims of this paper are to provide information on the properties of the more commonly available fibers and their uses to produce concrete with certain characteristics. The parameters included in this study are the effect of using steel fiber on traditional concrete in comparison to lightweight concrete and using GFRP external sheets in case of strengthening in both cases (traditional/lightweight concrete).

3. Experimental Work Program

3.1. Introduction

Two hundred and thirty four specimens were casted and tested in this research. The research was divided into two phases. The first phase to reasoning the optimum volume fraction for using corrugated steel fiber. The second phase was included the using of obtained steel fiber volume fraction in traditional and light weight concrete to gain comparison between each behavior.

3.2. First Phase

One hundred and eight specimens which tested in this phase. Thirty six specimens for each specimen type, cubes, cylinders and prisms. The specimens of concrete were mixed with three different steel fiber percentages (0.5%-1%-1.5%) in addition to specimens without steel fibers marked as control specimens. The corrugated steel fiber were used. The used fibers have aspect ratio (length/diameter) of 50. Figure (1) shows the used steel fiber. The design of concrete mixes in this paper was carried out in complying with the British Standards [2]. Table (1) shows the proportions of concrete mixes. Testing of specimens were carried out after curing process at 7 days, 14 days and 28 days, Figure (2) shows one of the selected type of specimens in the curing tanks. Cubes were tested for compressive strength, cylinders for indirect tensile strength and finally prisms for flexural strength. Tests were carried out according to British Standards [2].

Figure (1) : Corrugated Steel Fiber

Figure (2) : Cured Cylinders in Water Tank

Table (1) : Concrete Mix Design Proportions

Coarse Aggregate kg/m^3	Fine Aggregate kg/m^3	Cement kg/m^3	Water kg/m^3
1200	600	350	190

Table (2) : Results of Tested Specimens

Specimen Dimensions (cm)	Type of Test	Testing Time	0% of Steel As an Average of 3 Repeats	0.5% of Steel As an Average of 3 Repeats	1% of Steel As an Average of 3 Repeats	1.5% of Steel As an Average of 3 Repeats
Cubes (15x15x15)	Compressive Strength	7 Days	156 kg/cm^2	190 kg/cm^2	229 kg/cm^2	204 kg/cm^2
		14 Days	190 kg/cm^2	243 kg/cm^2	287 kg/cm^2	265 kg/cm^2
		28 Days	237 kg/cm^2	296 kg/cm^2	342 kg/cm^2	323 kg/cm^2
Cylinders (15x30)	Indirect Tensile Strength	7 Days	13 kg/cm^2	16 kg/cm^2	24 kg/cm^2	17 kg/cm^2
		14 Days	16 kg/cm^2	19 kg/cm^2	29 kg/cm^2	23 kg/cm^2
		28 Days	19 kg/cm^2	24 kg/cm^2	36 kg/cm^2	29 kg/cm^2
Prisms (15x15x70)	Flexural Strength	7 Days	22 kg/cm^2	27 kg/cm^2	37 kg/cm^2	30 kg/cm^2
		14 Days	28 kg/cm^2	38 kg/cm^2	52 kg/cm^2	43 kg/cm^2
		28 Days	34 kg/cm^2	47 kg/cm^2	63 kg/cm^2	52 kg/cm^2

It's obvious from Table (2), that, the optimum value for using corrugated steel fibers with aspect ratio 50 in fibrous concrete is 1%. The obtained percentage will be stack to the next part of the research to compare traditional concrete to light weight concrete in the presence of corrugated steel fiber with volume fraction (1%).

3.3. Second Phase

One hundred and twenty six specimens which tested in this phase. Forty two specimens for each specimen type, cubes, cylinders and prisms. Lightweight aggregate (crushed sand stone brick) were used as a coarse aggregate for lightweight concrete by half percentage of coarse aggregate in traditional concrete (replacement). Figure (3) represents the original shape of sand stone brick before crushing. Lightweight aggregate were tested according to British Standard, B.S [3]. Lightweight aggregate were crushed to optimize the maximum aggregate size suitable for use in concrete, Figure (3) shows the process of crushing. Mix design proportion were stacked in this phase as phase one and Table (3) shows the mix proportions for traditional and lightweight concrete. In the current phase, twenty one cubes, cylinders and prisms were casted and tested. See Table (4) which is shows the details for tested specimens. Testing process classified with respect to specimens type, the cubes for compressive strength, cylinders for indirect tensile strength and finally prisms for flexural strength. All concrete mixes, except pilot ones (0% steel fiber) were mixed with 1% of steel fibers. Three specimens of cubes, cylinders and prisms were strengthened from outside with glass fiber sheets after 14 days from casting and finally were tested after 28 days.

Figure (3) : Sand Stone Brick

Figure (4) : Crushing Process of Sand Stone Bricks

Table (3) : Proportions of Mix Design

Type of Concrete	Coarse Aggregate Kg/m^3	Lightweight Coarse Aggregate Kg/m^3	Sand Kg/m^3	Cement Kg/m^3	Water Kg/m^3
Traditional Concrete	1200	-	600	350	190
Lightweight Concrete	600	600	600	350	190

Table (4) : Details of Tested Specimens

Specimens Dimensions (cm)	Type of Test	Traditional Concrete			Light Weight Concrete		
		Steel Fiber (%)			Steel Fiber (%)		
		0%	1%	1%*	0%	1%	1%*
		No. of Repeats for Each Test			No. of Repeats for Each Test		
Cubes (15x15x15)	Compressive Strength	9	9	3	9	9	3
Cylinders (15x30)	Indirect Tensile Strength	9	9	3	9	9	3
Prisms (15x15x70)	Flexural Strength	9	9	3	9	9	3

*Specimens Strengthened from outside with glass fiber sheets and tested after 28 days only.

3.3.1.Manufacturing Procedures of Specimens

Concrete specimens cubes, cylinders and prisms were prepared as shown in Figure (5). The mixing process took place as usual by using concrete mixer. Fresh concrete were mixed with steel fiber which is added in batches during mixing process then fresh concrete poured in steel molds. Specimens were compacted in a way to produce full compaction as much as possible by using the standard tamping rod as presented in Figure (6). Finally, specimens leveled from top to get smooth concrete surface as seen in Figure (7).

a- Cubes and Cylinders

b- Prisms

Figure (5) : Specimens Preparation

Figure (6) : Compaction Process

Figure (7) : Final Specimens

3.3.2.Strengthening of Specimens with External GFRP Sheets

The strengthening of concrete specimens were divided into three steps, the first step is cleaning and roughening concrete surface to increase bond between concrete surface and glass fiber sheet. The second step is cutting glass fiber sheet according to faceted area needed to be covered in cubes, cylinders and prisms. Glass fiber sheets were measured with over lap 10 cm to give the glass fiber sheet additional bond. The final step is to glue surface of concrete specimens with polyester which is mixed with suitable percentage of peroxide (hardener) then gluing glass fiber sheet. Figure (8) and Figure (9), represents the installation of glass fiber sheets and glue of polyester on the concrete prism. This process took place after 14 days from casting.

Figure (8) : Installing of Glass Fiber Sheets

Figure (9) : Glue on Polyester

3.4. Test Setup

Cubes were tested under axial compression, cylinders tested under indirect tension and finally prisms were tested under bending. A testing machine of capacity 50 ton was used. Testing process were carried out in accordance with British Standards [4]. Figure (6), shows the test setup for different concrete specimens.

a) Cube Test

b) Cylinder Test

c) Prism Test

Figure (6) : Testing Process

4. Results, Analysis and Discussions

Test results are summarized in Table (5) and (6). It is clear from Table (5) that the density of traditional concrete is higher than light weight concrete by 28% as an average based on the existing of steel fiber in concrete mix. Firmly established from Table (6) that steel fibers improve the mechanical properties of both traditional and light weight concrete for all ages. The enhancement in traditional concrete appears more significantly than light weight concrete. This phenomena may be attribute to percentage of aggregate were used in traditional concrete. Using GFRP external sheets also increases the enhancement value more over. The following Table (6), shows the experimental results for both mixes, traditional concrete and light weight concrete at different periods.

Table (5) : Experimental Results of Tested Concrete Specimens

Concrete Type	Mix Type	Density (t/m^3)
Traditional Concrete (T.C)	Without S.F	2.25
	With S.F (1%)	2.46
Lightweight Concrete (L.W.C)	Without S.F	1.77
	With S.F (1%)	1.89

Table (6) : Experimental Results of Tested Concrete Specimens

Type of Mix	Specimen	Test Type	Testing Time	0% of Steel Fiber	1.0% of Steel Fiber	1.0% of Steel Fiber + External GFRP Sheets
				As an Average of 3 Repeats	As an Average of 3 Repeats	As an Average of 3 Repeats
Traditional Concrete T.C	Cubes	Compressive Strength	7 Days	156 kg/cm^2	229 kg/cm^2	-
			14 Days	190 kg/cm^2	287 kg/cm^2	-
			28 Days	237 kg/cm^2	342 kg/cm^2	406 kg/cm^2
	Cylinders	Indirect Tensile Strength	7 Days	13 kg/cm^2	24 kg/cm^2	-
			14 Days	16 kg/cm^2	29 kg/cm^2	-
			28 Days	19 kg/cm^2	36 kg/cm^2	67 kg/cm^2
	Prisms	Flexural Strength	7 Days	22 kg/cm^2	37 kg/cm^2	-
			14 Days	28 kg/cm^2	52 kg/cm^2	-
			28 Days	34 kg/cm^2	63 kg/cm^2	116 kg/cm^2
Lightweight Concrete L.W.C	Cubes	Compressive Strength	7 Days	146 kg/cm^2	206 kg/cm^2	-
			14 Days	183 kg/cm^2	237 kg/cm^2	-
			28 Days	219 kg/cm^2	296 kg/cm^2	349 kg/cm^2
	Cylinders	Indirect Tensile Strength	7 Days	12 kg/cm^2	21 kg/cm^2	-
			14 Days	15 kg/cm^2	25 kg/cm^2	-
			28 Days	18 kg/cm^2	31 kg/cm^2	62 kg/cm^2
	Prisms	Flexural Strength	7 Days	18 kg/cm^2	33 kg/cm^2	-
			14 Days	24 kg/cm^2	46 kg/cm^2	-
			28 Days	29 kg/cm^2	54 kg/cm^2	104 kg/cm^2

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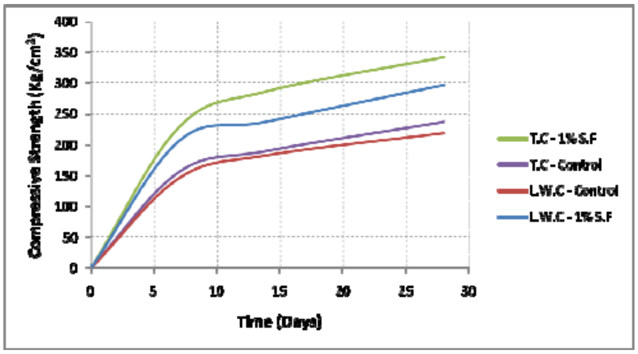

Figure (7) : Relationship Between Compressive Strength and Concrete Age for T.C and L.W.C

It's revealed from Figure (7) that the compressive strength of the traditional concrete and light weight concrete increased by about 144% to 151% and about 130% to 141% respectively. Also it is noticeable to state that wrapping the cubes by GFRP enhances the compressive strength by 119% and 118% for fibrous traditional concrete and fibrous light weight concrete, respectively. The variation between percentage based on testing time.

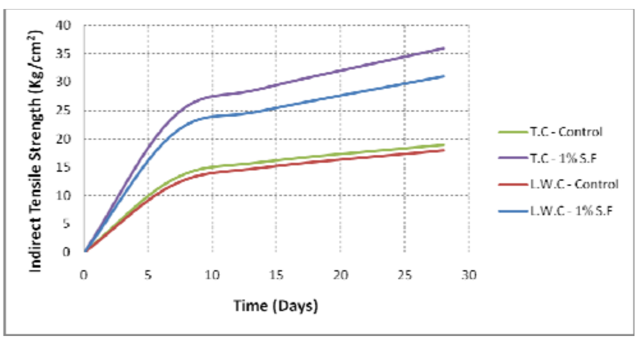

Figure (8) : Relationship Between Indirect Tensile Strength and Concrete Age for T.C and L.W.C

From Figure (8), indirect tensile strength increased by 181% to 190% in fibrous traditional concrete in compare to traditional concrete and by 167% to 175% in fibrous light weight concrete in compare to light weight concrete. Using external GFRP sheets enhanced compressive strength by 185% and 200% for fibrous traditional concrete and fibrous light weight concrete, respectively. The variation between percentage based on testing time.

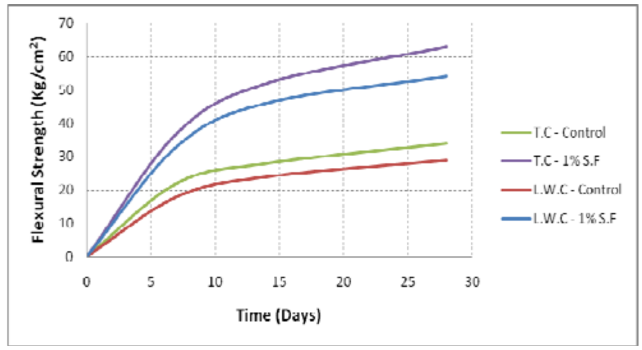

Figure (9) : Relationship Between Flexural Strength and Concrete Age for T.C and L.W.C

It's revealed from Figure (9) that the compressive strength of the traditional concrete and light weight concrete increased by about 168% to 186% and about 183% to 192% respectively. Also it is noticeable to state that wrapping the cubes by GFRP enhances the compressive strength by 184% and 193% for fibrous traditional concrete and fibrous light weight concrete, respectively. The variation between percentage based on testing time.

Failure Mode of Specimens:

-In Case of Specimens with Different Percentage of Steel Fiber:

For cubes (compression test), the failure was started by vertical cracks then crushing in concrete. The Failure can be classify as splitting crushing failure. For cylinders (indirect tension test), the failure was started by propagation of vertical cracks due to indirect tensile force then concrete failed in splitting failure mode. For prisms (flexural test), the cracks appears in the bottom side of beam due to loading under the effect of double concentrated loads. The prisms finally failed due to pure bending moments.

-In Case of Specimens with Different Percentage of Steel Fiber and Strengthened with GFRP Sheets:

For cubes (compression test), the failure were started by deboning in external GFRP sheets then vertical cracks observed and finally splitting crushing failure took place. For cylinders (indirect tension test), propagation of vertical cracks due to indirect tensile force then splitting failure in concrete detected. For prisms (flexural test), the failure was started by rupture of glass fiber sheets then flexure failure took place at the bottom side of prism due to loading under the effect of double concentrated loads. The prisms finally failed due to pure bending moments.

-The result impart to the fiber composite pronounced post–cracking ductility which is unheard in non fibrous concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fiber composite and its ability to withstand repeatedly applied, shock or impact loading.

5. Conclusions

Based on the test results presented herein the following conclusions are drawn:

1. The ideal volume fraction for steel fiber with properties of (aspect ratio 50-corrugated shape) obtains at 1% for optimum behaviors.
2. Steel fiber enhances compressive strength, indirect tensile strength, flexure strength capacity by 148%, 186% and 179%, respectively in fibrous traditional concrete regards to virgin concrete and double enhancement with steel fiber and external GFRP sheets enhances compressive strength, tensile strength, flexure strength and impact capacity by 172%, 353% and 341%, respectively in fibrous traditional concrete strengthened with external GFRP sheets regards to virgin concrete.
3. Using GFRP external sheets enhances compressive strength, indirect tensile strength, flexure strength capacity by 119%, 186% and 184%, respectively in fibrous traditional concrete strengthened with external GFRP sheets regards to fibrous traditional concrete.
4. Steel fiber enhances compressive strength, indirect tensile strength, flexure strength capacity by 136%, 172% and 187%, respectively in fibrous light weight concrete regards to light weight concrete and double enhancement with steel fiber and external GFRP sheets enhances compressive strength, tensile strength, flexure strength and impact capacity by 159%, 344% and 359%, respectively in fibrous light weight concrete strengthened with external GFRP sheets regards to light weight concrete.
5. Using GFRP external sheets enhances compressive strength, indirect tensile strength, flexure strength capacity by 118%, 200% and 192%, respectively in fibrous light weight concrete strengthened with external GFRP sheets regards to fibrous light weight concrete.
6. Generally using steel fibers in concrete transfers failure mode from brittle to semi-ductile failure due to arresting of cracks surfaces in concrete elements and GFRP sheets together with steel fibers make a good integration that absorbs energy and resist impact load perfectly and transfer the brittle failure of virgin concrete to ductile failure.

6. Future Research

It was recommended that to investigate the following parameters in the further work:

1. Increase the number of layer of GFRP sheets.
2. Usage of CFRP instead of GFRP.
3. Using epoxy resin instead of polyester resin.
4. Study behavior of light weight RC slabs.

7. References

[1] Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures, ACI:440.
[2] British Standard for Concrete Mix Design, BS:5328.
[3] British Standard for Light Weight Aggregate, BS:812.
[4]British Standard for Testing Hardened Concrete, BS:12390.