THE EFFECT OF ADDITION OF STEEL FIBERS ON COMPRESSIVE AND TENSILE STRENGTHS OF STRUCTURAL LIGHTWEIGHT CONCRETE MADE OF BROKEN BRICKS

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الخلاصة:

يحوي هذا البحث على دراسة تأثير إضافة الألياف الحديدية بنسبتين هما 0.5% و1% كنسبة حجميه على خرسانة إنشائية خفيفة الوزن والمصنعة باستخدام مكسر الطابوق كركام خشن .الخلطة الخرسانية الخفيفة الوزن صممت تبعا لــ ACI committee211-2-82 حيث كانت نسب الخلط الحجميه 1:1.12:3.35 ونسبة الماء إلى الإسمنت 0.5 ومحتوى الإسمنت 550 kg\m3 .

أجريت فحوصات متعددة على الخرسانة الخفيفة الوزن المرجعية منها وتلك الحاوية على الألياف وهي فحصي الهطول والكثافة الرطبة على الخرسانة الطرية وفحصي مقاومة الانضغاط والشد وقد فحصت مقاومة الشد بطريقتين هما مقاومة شد الانشطار وشد الانثناء .

أشارت النتائج إلى أن تأثير إضافة الألياف إلى الخرسانة الإنشائية خفيفة الوزن كان اكثر وضوحا على مقاومة الشد من مقاومة الانضغاط وخاصة مقاومة الانثناء حيث بلغت الزيادة القصوى بمقاومة الانضغاط ومقاومة شد الانشطار ومقاومة الانثناء بعمر 28 يوم على التوالي 38.8، 77.12 و 111.2 % للخرسانة الإنشائية الخفيفة الوزن والحاوية على نسبة ألياف حديدية مقدارها 1%.من جهة أخرى كانت نسبة اكتساب مقاومة الانضغاط بين عمري 3 و28 يوم ثابتا بالنسبة للخرسانة المرجعية وتلك الحاوية على الألياف وبنسبتي الإضافة 0.5% و1% كنسبة حجميه بينما كانت هذه النسبة تزداد بشكل ملحوظ بالنسبة لمقاومة الشد وخاصة مقاومة شد الانثناء .

Abstract

This research studies the effect of adding steel fiber in two percentage 0.5% and 1% by volume on plain structural lightweight concrete (SLWC) produced by using crushed bricks as coarse lightweight aggregates (LWA) in a lightweight concrete mix designed according to ACI committee 211-2-82 with mix proportion 1:1.12 :3.35 by volume .The w\c equal to 0.5 and cement content 550 kg\m3. Different tests where performed for fresh and hardened SLWC such slump test ,fresh and hardened unit weight ,compressive strength and two indirect tests of tensile strength (splitting tensile and flexural strength).

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

1- DEFINITIONS

Fiber reinforced concrete : Fiber reinforced concrete (FRC) is a concrete mix that contains short discrete fibers that are uniformly distributed and randomly oriented. Fiber material can be steel, cellulose, carbon, polypropylene, glass, nylon, and polyester [1]. The amount of fibers added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibers) termed Vf. Vf typically ranges from 0.1 to 3%. Aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d). Fibers with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio.

Structural lightweight concrete : The ASTM C330 [2] defines SLWC as having a compressive strength of 17 MPa or more and a 28 day dry unit weight less than 1850 kg\m3 . Similar gradients to normal weight concrete (NWC} except that it is made with

LWA or combination of lightweight and normal-weight aggregates but it has different properties . The lower density and higher insulating capacity are the most obvious characteristics of Light-Weight Aggregate Concrete (LWAC) by which it distinguishes itself from ‘ordinary’ NWC .However, these are by no means the only characteristics, which justify the increasing attention for this (construction) material. If that were the case most of the design, production and execution rules would apply for LWAC as for NWC, without any amendments.

2- INTRODUCTION

The advantages to using concrete include high compressive strength, good fire resistance, high water resistance, low maintenance, and long service life. The disadvantages to using concrete include poor tensile strength, and formwork requirement. Other disadvantages include relatively low strength per unit weight. Tensile strength of concrete is typically 8% to 15% of its compressive strength [3].This weakness has been dealt with over many decades by using a system of reinforcing bars (rebars) to create reinforced concrete; so that concrete primarily resists compressive stresses and rebars resist tensile and shear stresses. The LWC having less compressive strength than NWC .as such, a form of additional reinforcement is needed to enhance the weakness of tensile strength in SLWC . This will achieved by using steel fibers .

Advantages of using SLWC [4] :

- Reduction in dead weight of structure.
- Savings in steel reinforcement.
- Reduction in dead weight gives better resistance to earthquake loading.
- Reduced handling, transportation and construction cost for precast concrete elements

. • Properties of FRC as compared with those of normal concrete [5] :

– Higher tensile strain at failure

– Higher toughness and resistance to impact

– Ultimate tensile strength increased only slightly

– Reduced workability of fresh concrete

– Increase fatigue life

– Similar elastic modulus

– Similar drying shrinkage

– Similar compressive creep, but lower tensile creep and flexural creep.

Applications of Fiber-Reinforced Concrete

• Slabs for parking garage

• Airport runway, taxiway and parking area

• Overlay on pavement

• Shotcrete used for tunnel lining

• Repair work

Extensive research efforts have been given to investigate the normal weight FRC [6] [7] [8] [9] [10] etc. Also those studied SLWC [11] [12] [13] [14] [15] etc. However , little has reported on fiber reinforced SLWC .A research work has been undertaken to investigate the effect of addition of steel fiber in compressive and tensile strengths of SLWC .

3- EXPERIMENTAL WORK

3-1 Materials

3-1-1 Cement

ordinary Portland cement produced by Kubaisa cement factory was used throughout this study physical properties of used cement are listed in Table (1).The results are conformed to the Iraqi specification No.5 1984 [16].

Table (1) Physical properties of used cement

Physical properties	Test results	Limits of (I.O.S) NO.5\1984
Initial setting (vicat) hr Final setting (vicat) hr	1:20 3:35	1 hr (Min.) 10 hr (Max.)
Soundness (le-chatelier) mm	4.5	10 (Max.)
Compressive strength of mortar MPa 3-day 7-day	 16.75 29.6	 15 (Min.) 23 (Min.)

3-1-2 Fine aggregate

A normal weight sand of 4.75 mm maximum size was used .Table (2) and(3)shows the grading and physical properties of used fine aggregate .The grading was conformed to the limits of Iraqi specifications No.45 1984[17] .

Table (2) Physical properties of used fine aggregates

Physical properties	Test results	Limits of (I.O.S) NO.45\1984
Specific gravity	2.65	------
Loose density (kg\m3)	1550	1450-1600
Compacted density (kg\m3)	1800	1530-1800
Absorption %	3.2	------
Material finer than 75 µ %	3.6	5(Max.)
Fineness modulus	2.33	------

Table (3) Sieve analysis of fine aggregate

Sieve size mm	% passing	Limits of (I.O.S) NO.45\1984
4.75	100	90-100
2.36	92.1	85-100
1.18	82	75-100
0.6	64.8	60-79
0.3	21	12-40
0.15	7.15	0-10

3-1-3 Coarse lightweight aggregate

A crushed bricks were used as coarse LWA .The bricks pieces which are considered as waste materials were crushed into smaller sizes by means of crusher machine (jaw crusher) .Table 2 and 3 shows the grading and physical properties of coarse LWA respectively .The grading was confirmed to ASTM C330 [2] for structural LWA .The lightweight aggregate used in a saturated surface dry (SSD) condition recommended by ACI 211-2-82 [18] after submerged in water for 1 hour and spread in laboratory until obtaining saturated surface dry aggregates

Table (4) Physical properties of LWA

Physical properties	Test results	ASTM C330
Specific gravity	2	-------
Loose density (kg\m3)	694	-------
Compacted density (kg\m3)	800	800

Table (5) Grading of LWA

Sieve size mm	Test results	Limits of ASTM C330
12.5	100	100
9.5	85	80-100
4.75	30	5-40
2.36	2.5	0-20
1.18	0	0-10

3-1-4 Water

Potable water was used in all mixes.

3-1-4 Steel fibers

Straight high tensile steel fibers were used .The properties of the used steel fibers are illustrated in Table (6) .

Table (6) Properties of used steel fibers

property	results
Fiber type	Straight
Fiber length	30 mm
Fiber diameter	0.5mm
Aspect ratio (l\d)	60
density	7860 kg\m3

3-2 Mixing of concrete

A pan mixer of 0.1% m3 capacity was used to mix the concrete ingredients .The mixer was firstly cleaned from the remaining lumps of concrete .The dry mixed ingredients were placed in the pan mixer and they were mixed for 2 minutes to ensure the homogeneity of steel fiber and to split the agglomerations of cement particle .The required quality of water was added to the mix and the whole constitutes were mixed for 3 minutes .

3-3 Preparation ,casting, curing and types of the test specimens

Steel molds were used for casting all the tested specimens .Before casting the molds were cleaned and oiled to avoid the adhesion of hardened concrete to the inside faces of molds. The fresh concrete was placed inside the molds with approximately equal layers of 50 mm for all the specimens and consolidated by the mean of vibrating table for a sufficient period .Care was taken to avoid segregation of LWA because the lightest particles of LWA tend to float on the surface of concrete causing segregation of the mix consistent .After casting ,the concrete surface was leveled and covered with nylon sheets to prevent evaporation of water so as to avoid the plastic shrinkage cracks. On the second day the specimens were demolded ,marked and immersed in tap water until the test age. 100x100x100 mm cubes ,100x200mm cylinders and 100x100x400 prisms were used for compressive ,splitting tensile and flexural tensile strengths tests respectively.

3-4 Testing program

3-4-1 Slump test

The test was performed according to ASTM C143a [19].

3-4-2 Fresh and hardened unit weights

The test was performed according to ASTM C 567-85 [20].

Note : The above tests in addition to compressive strength test at 28 days were conducted to achieve the requirements for SLWC in ASTM C330 [2]

3-4-3 Compressive strength test

The test was conducted on 100 mm cube according to BS 1881 part 116 :1989 [21] .The test was performed at ages 3,7 and 28 days .The recorded value represents an average of three readings measured on three specimens.

3-4-4 Tensile strength

3-4-4.a Splitting tensile strength test

The test was conducted on cylinders of 100x200 mm according to ASTM C496-86 [22] .The splitting tensile strength was calculated using the following equation:

$$Splitting\ tensile\ strength\ (MPa)= {}^{2p}\!/_{\pi d l}$$

Where : p : maximum applied load (N).

d : diameter of test specimen (mm).

l : length of test specimen (mm).

3-4-4.b Flexural strength test

The test was performed on prisms 100x100x400 mm according to BS 1881 part 118 , 1989 [23].The flexural strength was calculated using the following equation as the failure of all test specimens occurred in the mid part

$$Flexural\ strength\ (MPa)= {}^{pl}\!/_{bd^2}$$

Where: p : maximum applied load (N)

l : length of test specimen (mm).

d , b : depth and width of test specimen (mm)

4-1 RESULTS AND DISCUSSION

4-1-1 Compressive strength

The results of compressive strength of reference and SLWC specimens containing 0.5% and 1% fibers at 3,7and 28 days are shown in Fig(1) .From these results the following notes are observed :

- The reference-LWC is confirmed to the requirements of SLWC in ASTM C330 [2]where it had 22.6 MPa compressive strength and 1845 kg\m3 unit weight at 28days.
- All SLWC mixes ,generally exhibited continuous strength gain .This is ,generally , attributed to the continuous formation of hydration products during the curing period.

-The addition of 0.5% and 1 % steel fibers to the R-LWC increased the compressive strength at all ages:-

- 0.5%-SLWC exhibited higher compressive strength at all ages corresponding to R-SLWC .The maximum increase of such concrete was 21.1 % at 28 days.
- 1%-SLWC showed higher compressive superior increasing in the compressive strength .The maximum increase were 38.8 %and 11.1%corresponding to R-SLWC and 0.5%-SLWC respectively .

4-1-2 Tensile strength

4-1-2 a Splitting tensile strength

The splitting tensile strength results of R,0.5% and 1%-SLWC up to 28 days of water curing are illustrated in Fig(2).The results clarify that there is general progressive gain in splitting tensile strength of R,0.5% and 1%-SLWC.Results indicate that the 0.5%-SLWC showed higher splitting tensile strength corresponding to R-SLWC . The 1%-SLWC showed higher splitting tensile strength corresponding to R and 0.5%-SLWC.This may be attributed to the same factors linked to the earlier development of compressive strength but its very important to know the following:

- The effect of addition steel fibers to R-SLWC was more pronounced in splitting tensile strength corresponding to compressive strength where the maximum increase in compressive strength was 38.8 % at 28 days in 1%-SLWC while it was 77.12 % in splitting tensile concrete of such concrete at the same age. This shows the important benefit of using steel fibers to enhance the low tensile strength of SLWC. Unstable propagation of a critical tensile crack accounts for the failure of brittle solids under tension. An initial crack (a pre-existing crack-like flaw) is allowed to propagate when the stress intensity factor reaches the toughness of the brittle material. In fiber reinforced cement composites, cracks are bridged by fibers, which in turns govern the behavior of the crack in growth stability, length and crack opening profile [24] .

- The increasing percentage of compressive ,splitting and flexural strengths of R ,0.5% and 1%-SLWC at 28 days are shown in Fig(4).From this Fig it is clearly to note the difference between the effect of steel fibers addition on compressive ,splitting and flexural strengths of SLWC .Pull out strength of steel fibers significantly improve the post cracking tensile strength of concrete .Nevertheless, addition of steel fibers does not significantly increase compressive strength, but it increases the tensile toughness, and ductility. It also increases the ability to withstand stresses after significant cracking (damage tolerance) and shear resistance [25].

4-1-2 b Flexural strength

The flexural strength was determined at 3,7 and 28 days and illustrated in Fig (3) .The results indicate that the SLWC mixes had similar behavior in flexural strength corresponding to splitting tensile strengths .This may be related to the fact that the splitting and flexural strength tests are indirect tests of tensile strength .The difference is the higher values of flexural strength at all ages due to the different between tests procedures and the shape of test specimens. Fig (5) shows the different between the rate of compressive ,splitting and flexural strengths gain between 3 and 28 days for R,0.5% and 1%-SLWC.The compressive strength gain of was approximately constant for all SLWC mixes. The R-SLWC showed higher splitting tensile strength gain corresponding to 0.5 and 1%-SLWC.This will not offset the fact that it had lower values of splitting tensile strength at 3 and 28 days. This is because the full integrity of steel fiber with the R-LWC may be need long time to achieve the full benefits of using such fibers where the full benefits of using fibers in concrete obtained when the tension failure occurs in fibers themselves not in the transition zone between fibers and cement paste [26].On the other hand, Fig(5) demonstrates that 1%-SLWC showed higher flexural strength gain between 3 and 28 days corresponding to 0.5% and R- SLWC .

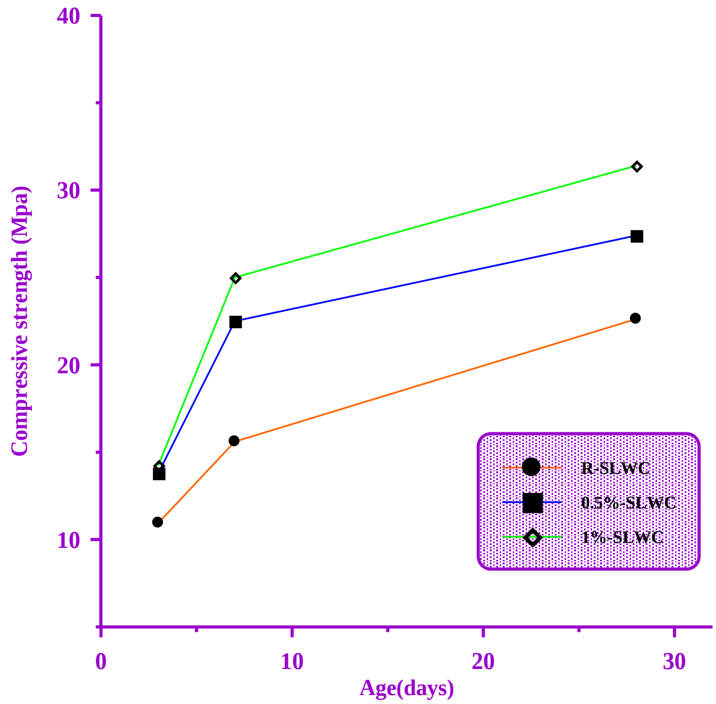


Fig (1) Compressive strength development of plain SLWC and SLWC containing 0.5% and 1% steel fiber.

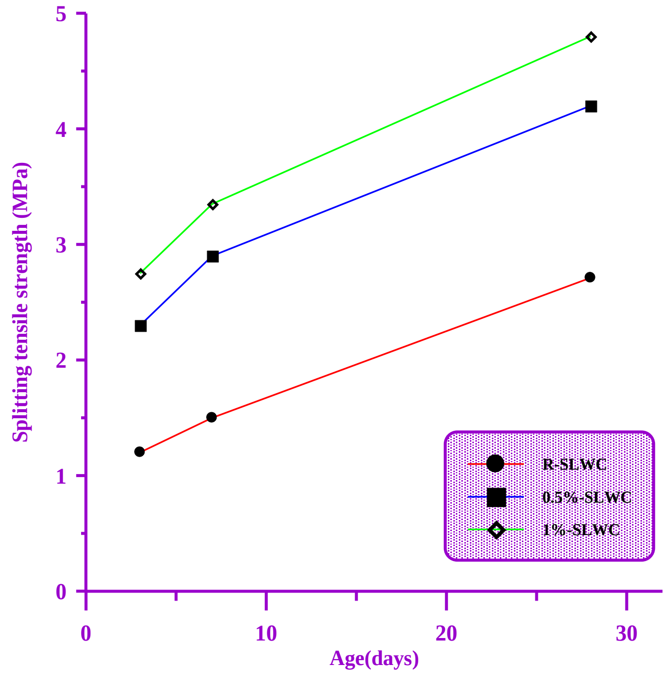


Fig (2) Splitting tensile strength development of plain SLWC and SLWC containing 0.5% and 1% steel fiber.

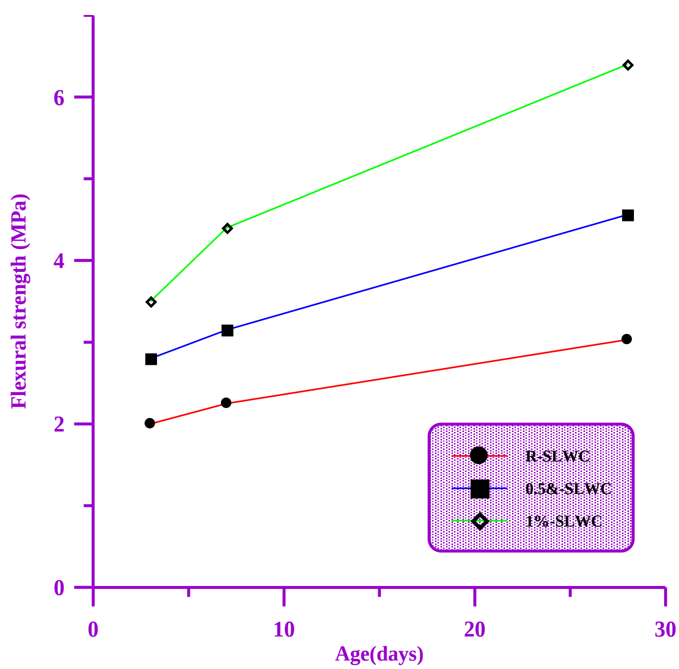


Fig (3) Flexural strength development of plain SLWC and SLWC containing 0.5% and 1% steel fiber.

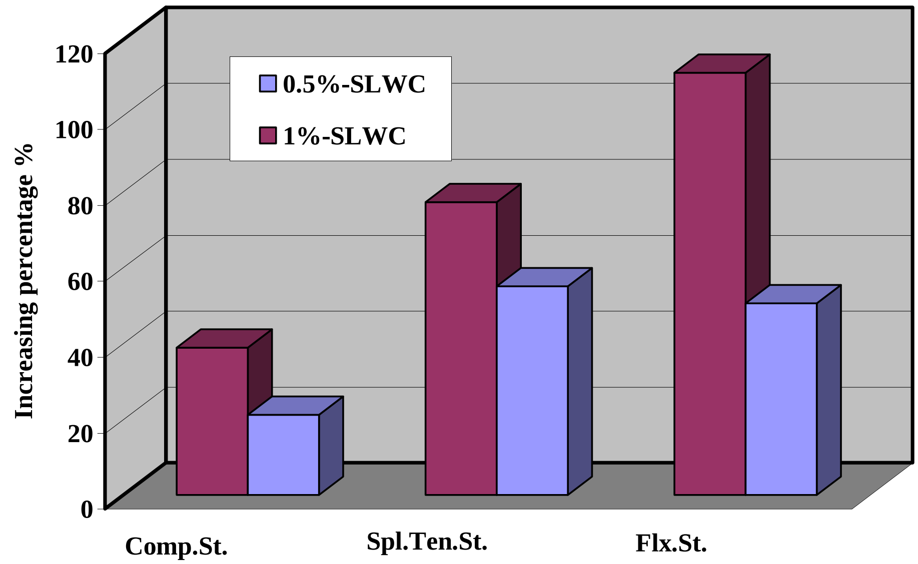


Fig (4) Increasing percentage of compressive ,splitting tensile and flexural strengths of SLWC containing 0.5% and 1% steel fiber corresponding to R-SLWC at 28-days.

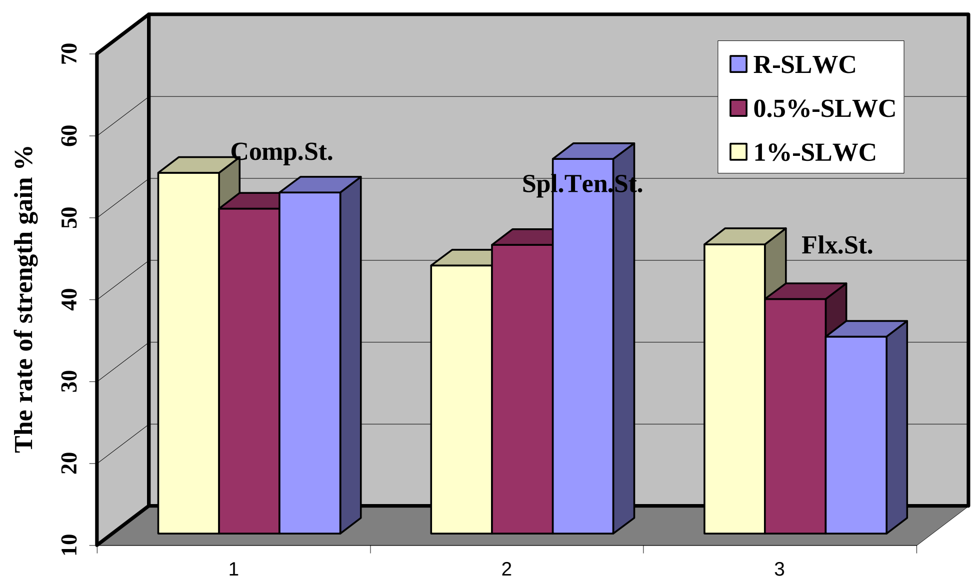
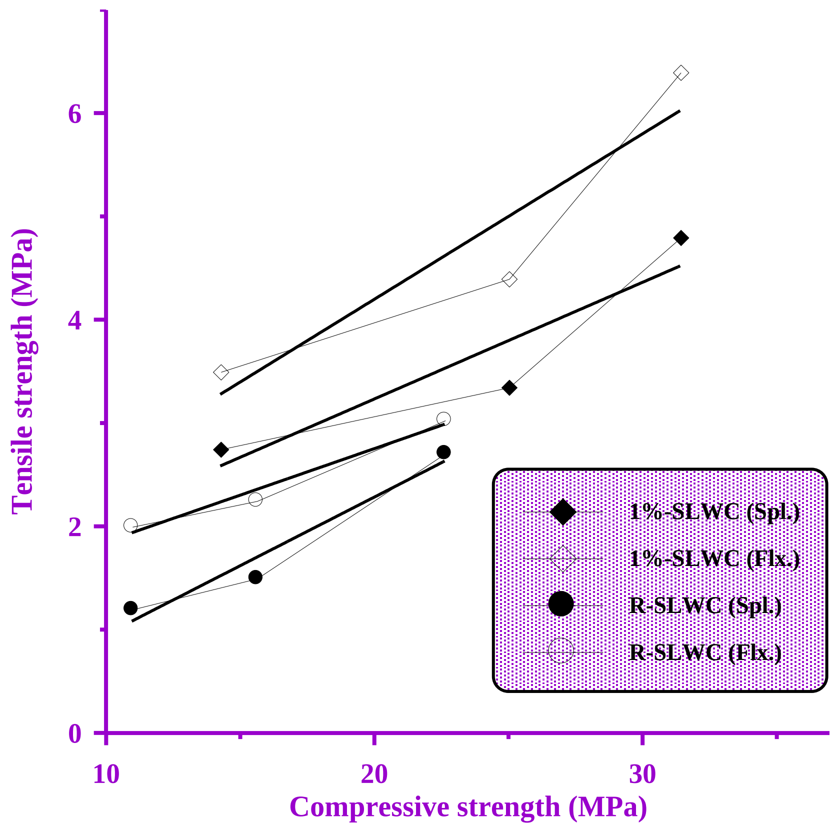


Fig (5) The rate of compressive ,splitting tensile and flexural strengths gain of plain SLWC and SLWC containing 0.5% and 1% steel fiber between 3 and 28 days.

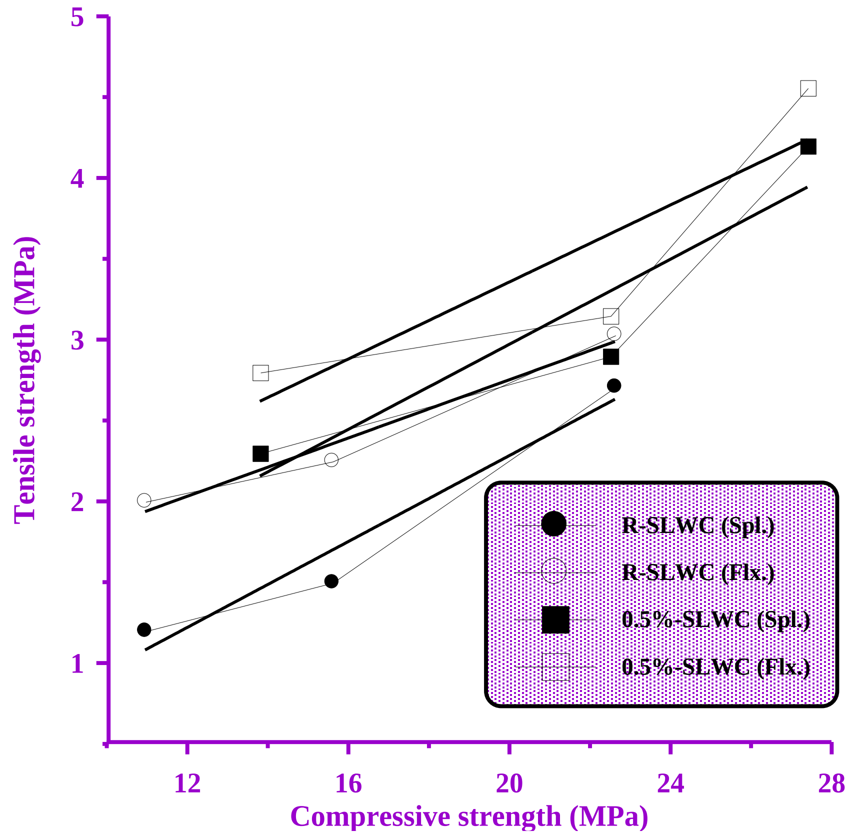
4-1-3 The relationship between compressive and tensile strength of R,0.5% and 1%-SLWC.

Figs (6) and (7) show the relationship between compressive and tensile strength for R ,0.5% and 1%-SLWC where the tensile strength tested in two indirect tests (splitting tensile and flexural strength).Results indicate that the tensile strength of all LWC mixes increases with the increase of compressive strength .In Fig (6)and (7) it is apparent that the R-SLWC showed lower values and slope in such relation corresponding to 0.5% and 1 % SLWC. The higher slope was observed in 1%-SLWC .On the other hand ,the effect of steel fibers was more clearly in flexural strength than splitting tensile strength of all SLWC mixes .This may be due to significant bond improvement gained by using steel fibers .

It was found by Soroushian and Bayasi [27]that the local bond resistance increased by 55 % and fractional resistance increased by 140 % by using steel fibers of length 50.8 mm and 57 as aspect ratio in NWC.



Fig(6)Relationship between compressive and tensile strengths for R-SLWC and 1%-SLWC



Fig(7)Relationship between compressive and tensile strengths for R-SLWC and 0.5%-SLWC

CONCLUSIONS

Based on the results of present study the following conclusions can be drawn :

1- The produced R-LWC using crushed bricks as a LWA was confirmed to the requirements of SLWC .

2- The addition of steel fiber increased the compressive strength of R- SLWC at all ages up to 28 days

3-The addition of steel fiber provided clear increment in the tensile strength more than compressive strength especially flexural strength.

4-The use of 0.5% steel fiber in SLWC increase the compressive ,splitting tensile and flexural strength 22.1 ,54.98 and 50.5 % respectively at 28 days while the use of

1% showed superior performance .The corresponding increment was 38.8 , 77.12 and 111.2 %.

5-The rate of compressive strength gain was approximately constant between 3 and 28 days (49.6-54%) for all SLWC mixes .The using of 0.5% and 1% steel fiber demonstrated clear increase in tensile strength gain especially flexural strength gain .

6-Adition of 0.5% steel fibers increase the slope of relationship between compressive and tensile strength .Superior increase of such slope was observed in 1%- SLWC.

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