Addition of conductive screws to improve the mechanical properties of concrete

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ABSTRACT

In the present paper, experimental investigations were conducted to improve the properties of concrete by using conductive screws as a fibre. Screws of two different lengths were used (1/2 inch and 1 inch). These screws were made of iron coated with Zinc-Aluminium alloy (called Al-Clad), which is resistant to corrosion and rust. This coating gives the screw strength and flexibility. The water/cement ratio used was w/c = 0.55 and the volume fractions of the conductive screw were 0%, 0.5%, 1%, and 1.5% by volume of concrete mix. The results show that the use of the conductive screw enhanced the mechanical properties of concrete. The compressive strength increases with increasing the volume fraction of the screw with a length of 1 inch. For 1.5% fibre content, the strength was increased by 24.28%, 23.66%, and 20.91% for 7, 28, and 90 curing days respectively compared to the reference mix. The same trend was observed with the modulus of rupture results. For the same length and with the 1.5% volume fraction of fibre, the modulus of rupture increased by 19.44% and 32.26% for 7 and 28 days of curing respectively. The splitting tensile strength also increased by 27.05% and 33.17% for 7 and 28 curing days respectively for 1.0% fibre content.

KEYWORDS: Fibres, conductive screw, compressive strength, modulus of rupture, splitting tensile strength.

إضافة الصواميل الموصلة لتحسين الخواص الميكانيكية للخرسانة

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الخلاصة

في البحث الحالي تم اجراء تحريات عملية لتحسين خواص الخرسانة باستخدام الصواميل الموصلة كألياف. تم استخدام نوعين من الصواميل الموصلة, النوع الاول بطول (0.5 انج) اما النوع الاخر بطول (1- انج). هذه الصواميل الموصلة مصنوعة من الحديد المطلي بسبيكة زنك-المنيوم والمسماة الكلاد المقاومة للتآكل والصدأ والتي تعطي القوة والمرونة للصواميل. نسبة الماء الى سمنت التي استخدمت كانت (w/c=0.55) والنسبة الحجمية للصواميل الموصلة التي اضيفت للخرسانة كانت (0%, 0.5%, 1%, and 1.5%) من حجم الخلطة الخرسانية). النتائج بينت ان الخواص الميكانيكية للخرسانة تحسنت بوجود الصواميل حيث ان مقاومة الانضغاط قد ازدادت بزيادة نسبة اضافة الصواميل (طول 1- انج) وصولا الى (20.91%,23.66%,24.28) وللأعمار (7,28,90) يوم انضاج

على التوالي ولنسبة اضافة 1.5% , كذلك زاد معامل الكسر للخرسانة بزيادة نسبة اضافة الصواميل (طول 1- انج) وصولا الى(19.44% و 32.26%) لعمر7و28 يوم انضاج على التوالي ولنسبة اضافة 1.5%, بينما اعلى نسبة زيادة لمقاومة الشد كانت (27.05%, 33.17%) لعمر7و28 يوم انضاج على التوالي ولنسبة اضافة 1.0% للصواميل ذات طول 1- انج.

1 Introduction

Cracks can form in concrete as a result of several factors, such as structural, environmental or economic reasons. The reason for cracks forming is that concrete shrinks when it is restrained. Most cracks are formed due to the inherent weakness of the material to tensile forces. Using fibres to reinforce concrete offers a solution for this problem by making concrete tougher and more ductile. The fibre works to delay the growth of cracks and allows smaller cracks to form instead, after the application of load on the member, thus increasing the tensile strength. This leads to the possibility of fibre-reinforced concrete to deform larger, beyond-the-peak stress, compared to conventional concrete (Figure 1) (Neville and Brooks 2010).

Fibres made from materials such as steel, glass, synthetic materials and natural products help to improve various properties of concrete (Irine 2014). A significant number of researchers have proved that the addition of steel fibres to conventional plain or reinforced and pre-stressed concrete members led to the enhancement of several properties of concrete, particularly those related to strength, performance and durability. The effect of using steel fibres on the behaviour of concrete has been studied by many researchers. The results obtained by Aoude (2008) showed that the addition of steel fibres to concrete results in several enhancements, including the improvement of the tensile resistance, post-cracking strength, and toughness, as well as improving post-peak strength and ductility. In structural members, concrete reinforced with fibres has better shear resistance than conventional concrete; this enhancement in shear resistance is due to the improvements in the diagonal tension capacity of the concrete. Steel fibres can be used to replace traditional shear reinforcement and promote flexural failure and ductility if added in sufficient quantity (Cohen 2012). In columns, the addition of steel fibres enhances confinement and cover spalling (Aoude et al. 2009). Research has also shown that steel fibres can improve energy dissipation capacity at joints and shear walls (Parra-Montesinos 2005).

Numerous factors influence the properties of fibre-reinforced concrete, such as the type, shape and amount of fibres used. A convenient parameter to describe a fibre is its aspect ratio (L/D), defined as the fibre length divided by an equivalent fibre diameter (Wafa 1990). Steel fibre is expensive in the local area market, as well as being difficult to obtain. Using conductive screws made from iron coated with Zinc-Aluminium alloy (called Al-Clad), which is resistant to corrosion and rust, instead of conventional steel fibre will reduce the cost of concrete. In this study, conductive screws were used as a short fibre to reinforce conventional concrete. The screws were used in different volume fractions and lengths. Experimental investigations were conducted to study the effect of this type of fibre on the fundamental mechanical properties of concrete.

2 Experimental program

The experimental program was designed to understand the behaviour of concrete reinforced with conductive screws in different volume fractions and lengths. The compressive strength, modulus of rupture, and tensile strength of the concrete mixers were investigated at different ages.

2.1 Materials used

2.1.1 Cement

Sulphate-resistant Portland cement (Type V) was used, in line with Iraqi standard specifications (No.5/1984). The physical and chemical properties of the cement used are given in Table 1.

2.1.2 Fine aggregate

Local river sand was used as a fine aggregate. Natural sand from the Al Najaf sea region was used. Grading and some physical properties of the sand are given in Table 2. Its grading conformed to the Iraqi specifications (IQS) (No. 45/1984) Zone 2.

2.1.3 Coarse aggregate

The coarse aggregate used complies with IQS No.45/1984. Table 3 shows the grading and some physical properties of the coarse aggregate.

2.1.4 Fibres

Conductive screws were used throughout the experimental program, as shown in Figure 2-a. These screws were made from iron coated with Zinc-Aluminium alloy, which is resistant to corrosion and rust. The conductive screws were used in two different lengths: 0.5 inch and 1 inch, as shown in Figures 2-b and 2-c. The screws used have a density of 7500 kg/m^3 and a modulus of elasticity of 200 Gpa. Some properties of the screws are listed in Table 4.

2.2 Mix proportions

A water/cement ratio (w/c) = 0.55 and a volumetric mixing ratio of (1: 2: 4) (cement: sand: gravel) were considered necessary to give the concrete mix the required workability, with a specific slump (8-12 cm) for concrete reinforced with conductive screws. The fibres were added in volume fractions of 0%, 0.5%, 1%, and 1.5% by volume of the total mix for each test . The mix with no fibre was considered as a reference mix.

3 Testing of concrete

3.1 Compressive strength test

The compressive strength test was conducted according to the standard specifications BS EN 12390-3:2002. The program consisted of casting and testing a total of 72 cubic specimens of 150 x 150 x 150 mm. The volume fractions of the conductive screws added to the concrete were 0%, 0.5%, 1%, and 1.5% by volume of the total mix for each length of screw and for three curing ages (7, 28, and 90 days). The average of the compressive strength results of three cubes was recorded for each testing age.

3.2 Flexural strength test

A total of 18 concrete prisms of 100×100×500 mm were cast during this study. The test was carried out using the two-point load method according to ASTM C78-02. The volume fractions of the fibre (conductive screw) were 0%, 1%, and 1.5% by volume of concrete mix for length of 1.0 inch only and for the ages of 7 and 28 days. 0.5% of fibre was not considered as it is very small compared to the size of the concrete prism. The average of three prisms was recorded for each testing age.

3.3 Splitting Tensile Strength

The splitting tensile strength was determined according to ASTM C496-04. A total number of 18 cylinders (100 × 200 mm) were cast and tested. The volume fractions of the fibre were 0%, 1%, and 1.5% by volume of concrete for the length of 1.0 inch only. The average of the splitting tensile strength results of three cylinders was recorded for each testing age (7 and 28 days).

4 Discussion of the results

4.1 Compressive strength and density

The results of the compression test are summarised in Tables 5 - 9 and plotted in Figures 3 - 6. From the test results, it can be seen that the compressive strength increases gradually with increasing the fibre content for three curing ages (7, 28, and 90 days). The increase in compressive strength appears more clearly with fibre contents of 1.0 and 1.5% compared to the reference mix. For 1.5% fibre content (1-inch long screws), the compressive strength increased by 24.28%, 23.66%, and 20.91% for 7, 28, and 90 curing days respectively. For the fibre-length (1inch), the increase in compressive strength was more than that of the fibre length of 0.5 inch.

From Figure 7 it can be observed that there is a reduction in the width of the cracks and an increase in the number of cracks (under the influence of compressive stresses) with increasing the volume fraction of the fibre compared to the reference mix with zero fibre content. Most of these cracks were inclined at different angles from the direction of loading. This is attributed to the fact that the load path is intercepted by the conductive screw, which leads to a change in its direction.

The increase in the density of the concrete containing conductive screws is small, therefore the concrete remained within the limits of normal concrete weight (as shown in Table 11). Even though the density of these screws is greater than the density of concrete, the quantity of screws compared with the amount of concrete makes the effect of these screws on the density negligible.

4.2 Flexural Strength (Modulus of Rupture)

The results of the flexural strength test shown in Tables 10 and 11 and Figures 8 and 9 show that the modulus of rupture of concrete increases with increasing the fibre content for all curing ages. For 1.5% fibre content, the modulus of rupture increased by 19.44% and 32.26% for 7 and 28 curing days respectively compared to the reference mix. This can be attributed to the fact that the fibre will enable the concrete to resist the tensile stresses.

From Figure 10-a for the reference mix prism, it can be noted that the width of the crack is large, singular and extends in a straight line from the top to the bottom. In this case, the failure was sudden. The conductive screw-reinforced concrete prism was more ductile. The crack is not straight and it tends towards the middle of the prism, which suggests that the screw intercepts the path of the crack, resulting in a small crack accompanied by other small cracks. The prism in the latter case will fail gradually (Figure 10-b).

4.3 Tensile Strength

The tensile strength test results are illustrated in Tables 12 and 13 and Figures 11-12. Generally, the tensile strength increased in the concrete containing conductive screws as expected. For 1% fibre content (1-inch length), the splitting tensile strength increased by 27.05% and 33.17% for 7 and 28 curing days respectively. The strength begins to decrease at a ratio of 1.5%; however, this is still higher than that of the reference mix cylinders. This indicates that the optimum percentage of this type of fibre is 1% for this type of concrete.

The benefit obtained from adding conductive screws is the reduction in the width of cracks in the concrete cylinder. The cracks are not extended throughout the length of the cylinder; instead, multiple cracks with inclined angles were observed (Figure 13).

5 Conclusions

After analysing the results of the investigations, the following conclusions can be drawn:

1. The use of conductive screws works to improve the mechanical properties of concrete by increasing the compressive strength, flexural strength, and splitting tensile strength. This is due to the ability of this type of fibre to control and redistribute the stresses after cracking.
2. The increase in the mechanical properties of concrete when using 1-inch screws is greater than when using 0.5-inch screws.
3. The compressive strength, splitting tensile strength, and modulus of rupture of concrete increased with increasing the slenderness ratio of the screw (L/D).
4. The strength of concrete increased with increasing the fibre content.
5. The width of the cracks formed in the concrete decreased with increasing the fibre content; instead, there was an increase in the number of cracks.
6. The concrete remained within the limits of the normal weight of concrete.

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Table (1): Properties of the sulphate resistance Portland cement (Type V)

Oxide composition	**Oxide content %**	**Limits of IQS (5-1984)**
SiO2	22.5	____
Al2O3	4.2	____
Fe2O3	5.7	____
CaO	63.1	____
MgO	1.3	≤ 5.0
SO3	2.41	≤ 2.5
Free CaO	1.5	____
L.O.I	1.6	≤ 4.0
I.R	0.4	≤ 1.5
L.S.F	0.84	0.66-1.02
The main components (using Bogue's formulae)		
C3S	39.6	____
C2S	27.8	____
C3A	1.3	
C4AF	17.3	____
Physical properties		
Fineness (Blaine) cm2/gm	367	≥250
Initial setting time (Vicat) (min)	120	≥ 45
Final setting time (Vicat) (Hrs:min)	3:40	≤ 10
Soundness (Autoclave method) %	0.02	≤ 0.8

Table (2): Grading and physical properties of the sand

Sieve size (mm)	Passing %	I.Q.S.45:1984 Limits Zone (2)
10	100	100
4.75	97.6	100-90
2.36	81.33	100-75
1.18	63.66	90-55
0.6	47.19	59-35
0.25	16.27	30-8
0.15	7.81	10-0
Fineness modulus = 2.9		
Sulphate content (SO3) = 0.24 % **(Iraqi specification requirement ≤ 0.5%)**		

Table (3): Grading and physical properties of the coarse aggregate

Sieve size (mm)	Passing %	I.Q.S.45:1984 Limits (5-40)
75	100	100
63	100	-
37.5	100	95-100
20	54.53	35-70
14	8.63	-
10	13.7	10-40
5	0.04	0 -5
Sulphate content (SO3) = 0.0457 % **(Iraqi specification requirement ≤ 0.09%)**		

Table (4): Geometrical Properties of conductive screws

Fibre type	Average Diameter (mm)	Head Diameter (mm)	Length (mm)
1	3	7	12.7 **(0.5 inch)**
2	3	6.5	25.4 **(1 inch)**

Table (5): Compressive strength and the fibre content relationship at different ages of the screw (for length 0.5 inch)

Fibre content %	Compressive Strength (MPa)		
	7 days	28 days	90 days
0.0	14.77	19.15	21.65
0.5	14.94	21.93	24.53
1.0	15.54	22.10	24.65
1.5	17.59	22.50	25.05

Table (6): Compressive strength increase rate and the fibre content relationship at different ages of the screw (for length 0.5 inch)

Curing age (day)	Increase rate for compressive strength with reference mix %		
	0.5	1.0	1.5
7	1.15	5.21	19.09
28	14.51	15.40	17.49
90	13.30	13.85	15.70

Table (7): Compressive strength and the fibre content relationship at different ages of the screw (for length 1 inch)

Fibre content %	Compressive Strength (MPa)		
	7 days	28 days	90 days
0.0	14.37	18.97	21.47
0.5	15.13	19.22	22.52
1.0	16.15	21.73	24.63
1.5	17.86	23.46	25.96

Table (8): Compressive strength increase rate and the fibre content relationship at different ages of the screw (for length 1 inch)

Curing age (day)	Increase rate for compressive strength with reference mix %		
	0.5	1.0	1.5
7	5.28	12.38	24.28
28	1.32	14.54	23.66
90	4.89	14.72	20. 91

Table (9): Density versus fibre content

Fibre content %	Density (0.5 inch) (kg/m^3)	Increase rate of Density (for length 0.5 inch) %	% Density (1 inch) (kg/m^3)	Increase rate of Density (length-1 inch) %
0.0	2516.0	0.00	2472.6	0.00
0.5	2542.2	1.04	2486.3	0.55
1.0	2534.8	0.75	2488.2	0.63
1.5	2579.7	2.53	2493.8	0.86

Table (10): The results of the modulus of rupture (screw length 1.0 inch)

Added percentage %	Modulus of Rupture (Mpa)	
	7 days	28 days
0.0	1.80	3.10
1.0	1.95	3.55
1.5	2.15	4.10

Table (11): The rate of change in the modulus of rupture when increasing the fibre content (screw length 1.0 inch)

Added percentage %	Change in Modulus of Rupture (7 days) %	Change in Modulus of Rupture (28 days) %
0.0	0.00	0.00
1.0	+8.33	+14.52
1.5	+19.44	+32.26

Table (12): The results of the splitting tensile strength with different fibre content for ages o7 and 28 days

Fibre content %	Tensile Strength (Mpa)	
	7 days	28 days
0.0	2.05	2.44
1.0	2.73	3.10
1.5	2.60	2.95

Table (13): The rate of change in the tensile strength with an increase in the fibre content (screw length 1.0 inch)

Fibre content %	Rate of change in tensile strength (7 days) %	Rate of change in tensile strength (28 days) %
0.0	0.00	0.00
1.0	27.05	33.17
1.5	20.90	+26.83

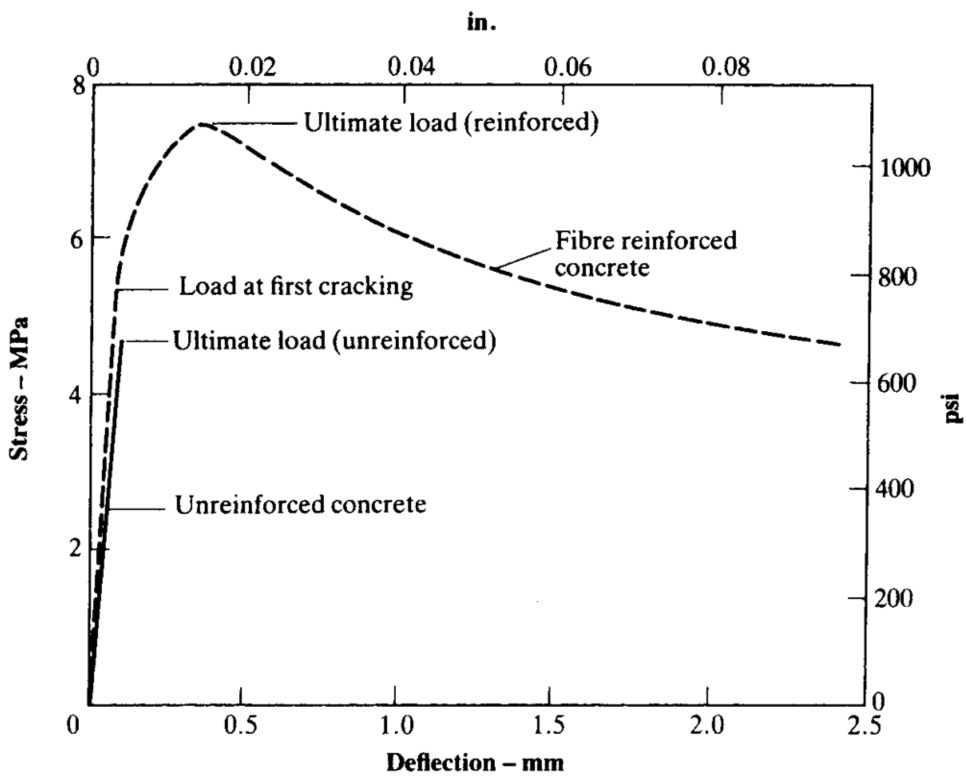


Figure (1): Typical stress deformation behaviour of fibre-reinforced concrete and unreinforced concrete (Neville and Brooks 2010)

(a) Screws used

(b)

(c)

Figure (2): (a) Screws used, (b) length (1.0 inch), (c) length (0.5 inch)

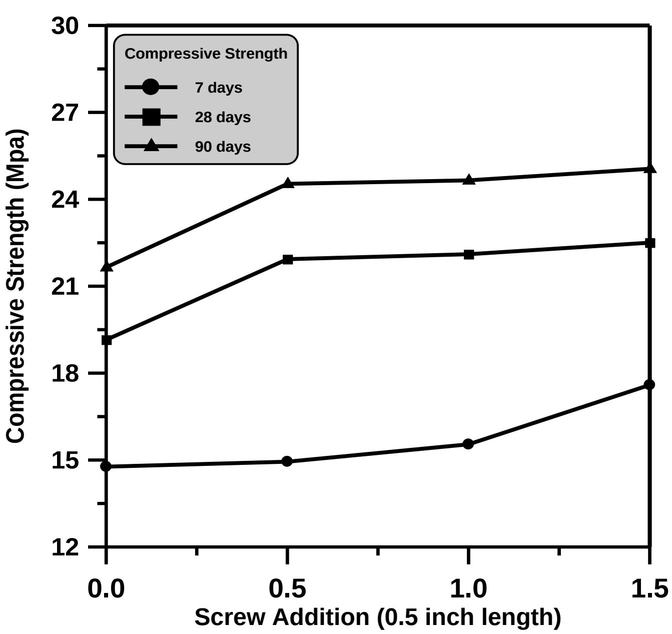


Figure (3): The relationship between the compressive strength and fibre content (screw length 0.5 inch)

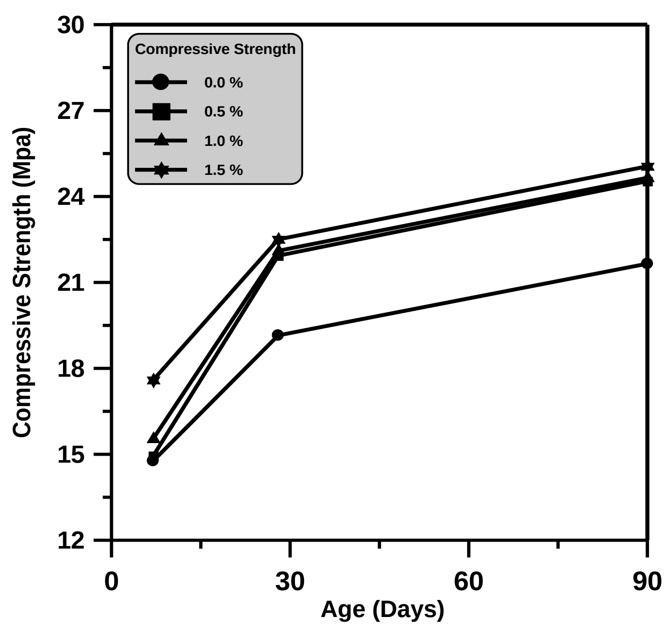


Figure (4): The relationship between the compressive strength and curing age (screw length 0.5 inch)

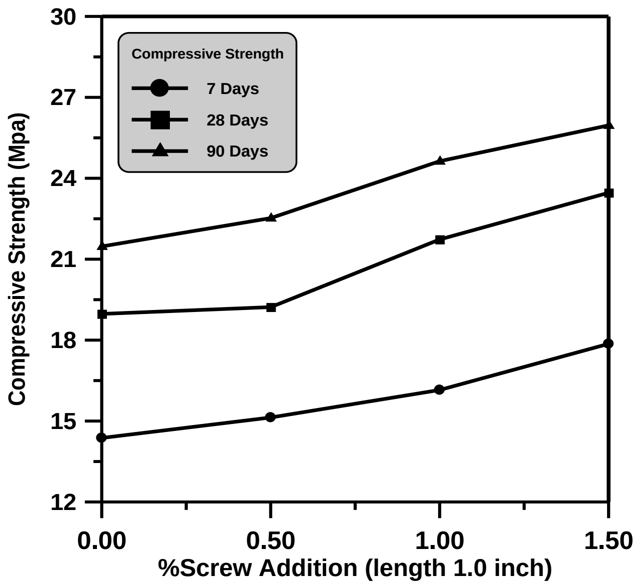


Figure (5): The relationship between the compressive strength and fibre content (screw length 1.0 inch)

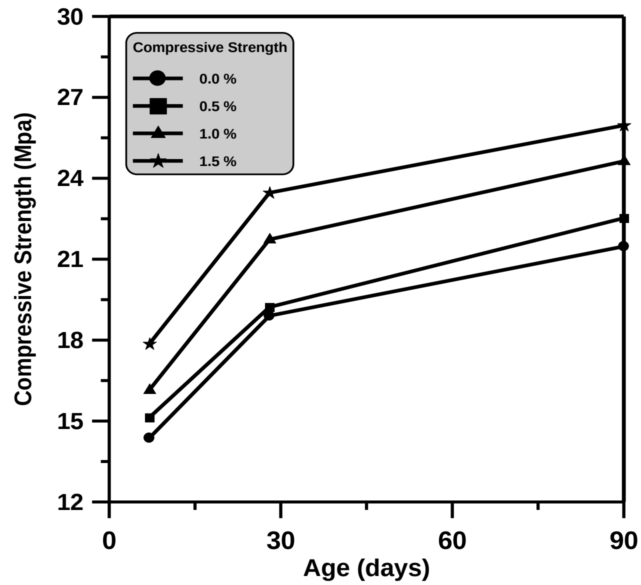


Figure (6): The relationship between the compressive strength and curing age (screw length 1.0 inch)

(a) Reference concrete cube

(b) Concrete cube with fibre

Figure (7): Failure patterns of concrete cubes

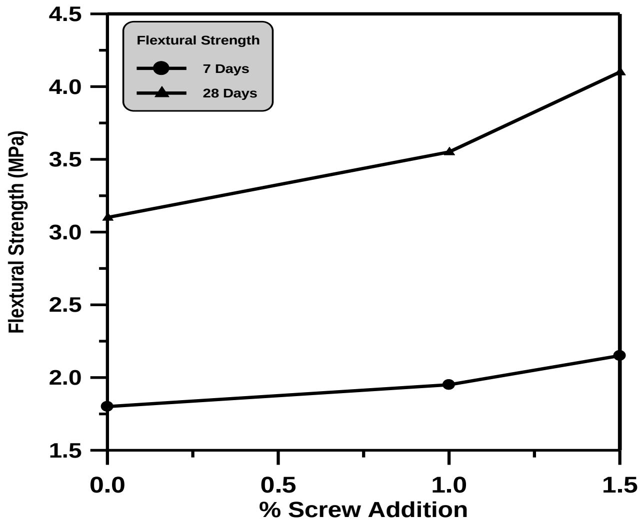


Figure (8): The relationship between the modulus of rupture and the fibre content (screw length 1.0 inch)

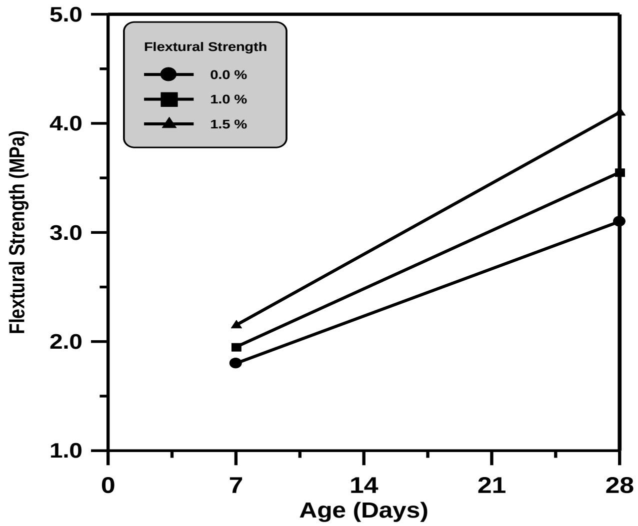
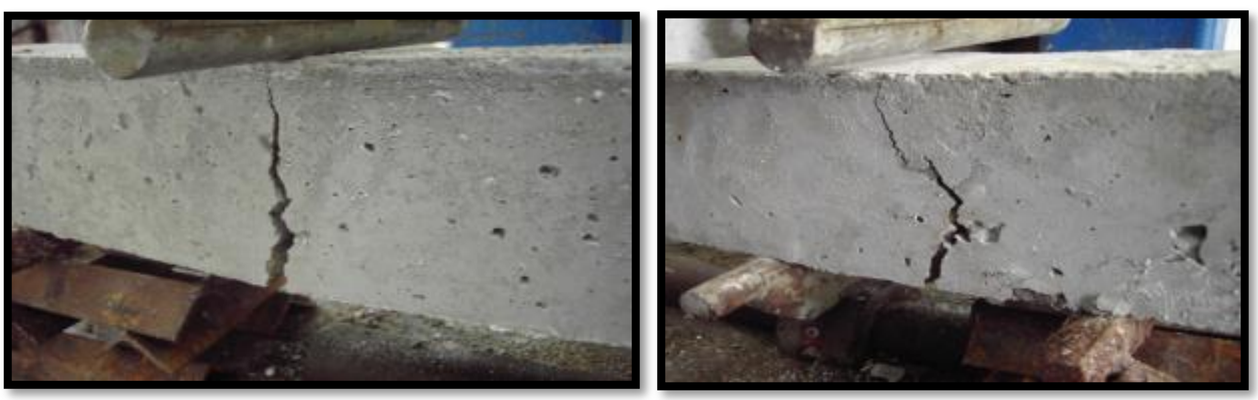


Figure (9): The relationship between the modulus of rupture and the curing age for different fibre contents (screw length 1.0 inch)



a) Reference concrete prism

b) Concrete prism with fibre

Figure (10): Failure patterns of concrete prisms

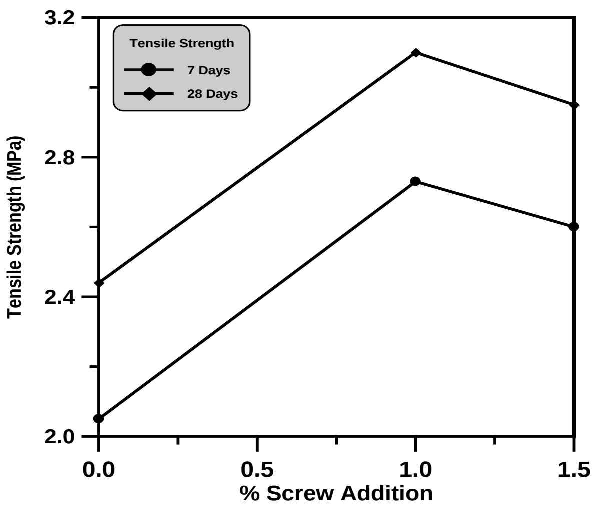


Figure (11): The relationship between the splitting tensile strength and the fibre content (screw length 1.0 inch)

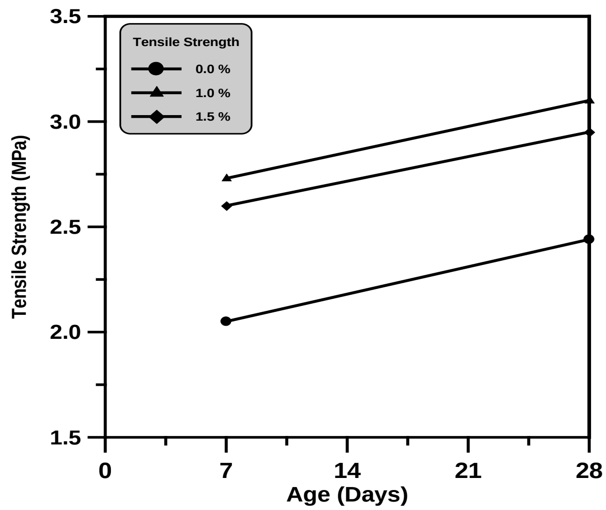


Figure (12): The relationship between the splitting tensile strength and the curing age with different fibre contents (screw length 1.0 inch)

a) Reference concrete

b) Concrete with fibre

Figure (13): Failure patterns of concrete cylinders