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Effecting of Steel Fibers and Fly Ash on the Properties of Concrete

Mazin B. Abdul-Rahman[1, *]

Alya'a A. Ali [2]

Amenah M. Younus [1]

[1] Department of Civil Engineering
College of Engineering
Tikrit University
Tikrit, Iraq

[2] Department of Survey Engineering
Technical College / Kirkuk
North Technical University
Kirkuk, Iraq

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A B S T R A C T

In this research, the effect of the addition of fly ash particles with different weight ratios of 15%, 20%, and 25% as well as the addition steel fibers with different volume fractions of 0.25%, 0.75%, and 1.25% on the mechanical properties of concrete (compressive strength and modulus of rupture) was studied. To carry out this research, ten concrete mixes were prepared, one of which is the reference normal concrete (without any additives), the others contain steel fibers and fly ash as additives with the mentioned volumetric and weight proportions. For each type of concrete mix, three standard 150×300 mm cylinders and three standard prisms 100×100×500 mm were casted, water to cementing material ratio was fixed for all concrete mixes (W/cm = 0.435) and the superplasticizer was used with ratio of 0.98%-1.22% by weight of the cementitious material in mixtures that contain steel fibers and fly ash particles as a partial replacement of cement weight. The results showed that the addition of fly ash particles had little effect on the mechanical properties of normal concrete, while the steel fibers had the greatest effect. The highest increase in compressive strength and flexural strength compared with reference concrete was 61.60% and 78.84%, respectively in the volume fractions 1.25% of steel fiber.

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تأثير الألياف الحديدية والرماد المتطاير على خصائص الخرسانة

الخلاصة

في هذا البحث تم دراسة تأثير إضافة جزيئات الرماد المتطاير بنسب وزنية مختلفة (15% ،20% ،25%) وكذلك إضافة الألياف الحديدية بنسب حجمية مختلفة (0.25% ، 0.75% ، 1.25%) على الخصائص الميكانيكية للخرسانة الإعتيادية في الانضغاط والانثناء . ولإجراء هذه الدراسة تم تحضير عشر خلطات خرسانية، واحدة منها للخرسانة الاعتيادية المرجعية (الخالية من المضافات)، والاخرى تحتوي على مضافات الألياف الحديدية والرماد المتطاير وبالنسب الحجمية والوزنية المذكورة أعلاه. لكل نوع من انواع الخلطات الخرسانية تم صب ثلاثة اسطوانات قياسية (150×300) ملم، وثلاثة مواشير قياسية أيضاً (100×100×500) ملم، وكانت نسبة الماء الى السمنت ثابتة في الخلطات الخرسانية كافة ومساوية الى (0.435)، وأُستخدمَ الملدن الفائق بنسبة (0.98-22.1%) من وزن المواد السمنتية للخلطات المعززة بالألياف الحديدية والتي تحتوي على جزيئات الرماد المتطاير كاستبدال جزئي من وزن السمنت. وقد أظهرت النتائج بان اضافة جزيئات الرماد المتطاير لها تأثير قليل على الخواص الميكانيكية للخرسانة الاعتيادية ، في حين كان للالياف الحديدية التأثير الأكبر، إذ كانت أعلى نسبة زيادة في مقاومة الانضغاط ، ومقاومة الانثناء بالمقارنة مع الخرسانة المرجعية هي (61.60%) و (78.84%) على التوالي عند النسبة الحجمية (1.25%) للالياف الحديدية.

1. INTRODUCTION

1.1. General

Concrete is a popular construction material commonly used in the construction of most construction projects, so, most of the theoretical and practical researches and studies are concentrated in the deeper insights to determine its mechanical properties under the influence of applied structural loads. However, concrete has a weak tensile strength compared to its compressive strength, with little resistance to cracking (because of its low ductility), as a result, an additives are used to the improve the mechanical properties and structural performance of normal concrete. The construction industry has shown great interest in the use of fiber reinforced concrete due to the improvements in structural performance that can be produced compared to conventional concrete. The fibers improve ductility and durability of the concrete, it also reduces the expansion of cracking resulting from shrinkage of concrete, especially resulting from plastic shrinkage and redistribution it, as

* *Corresponding author: E-mail* : dr.mazinburhan@tu.edu.iq

well as reduce the creep of concrete but with ratio less than that for shrinkage. Consequence, the mechanical fracture of the concrete is transformed from fracturing a sudden brittle and a danger to a ductile fracture. It also has the ability to improve concrete resistance in shear, tensile, bending, shock and fire resistance [1]. Pozzolanic materials are also added to the concrete to improve their mechanical properties, such as silica dust, fly ash and others. Fly ash is one of the most widely used pozzolanic materials in the world. It is composed of silica, silica and alumina together, which do not have concrete properties in themselves, but with water reacting with calcium hydroxide at normal temperature to give a cement compound (C-S-H), which is one of the most important components of concrete .When these materials are added to the concrete properly, they improve the concrete resistance in a very manner, give high performance to the concrete , increase the durability of the concrete , reduce concrete shrinkage during the treatment , reduce the amount of water required during the mixing process and has the importance of improving workability and in the reduction of heat hydration because of the pozzolanic reaction between lime and fly ash and thus prevent cracking or thermal cracking [2].

1.2. Literature Review

In 2015, Sood [3] conducted a practical study on the effect of the addition of fly ash on ordinary concrete using three replacement ratios (20%, 40%, 60%) of cement weight. The optimum replacement content was found to be 20% of the cement content. Its results showed that the maximum compressive resistance was recorded at the lowest content of fly ash (by 20%) compared to reference concrete at all ages (56.28) days, therefor, he used replacement rates (15% to 25%) of cement content in fly ash for the casting of one-way concrete slabs. It was concluded that the flexure resistance of fly-ash concrete continued to increase with increased fly ash replacement rates at all ages.

In 2017, Attiya [4] conducted a practical study to improve the mechanical properties of concrete by using micro-steel fiber to improve mechanical behavior of concrete such as increasing spalling resistance and reducing cracking. The researcher used these fibers at different volume fractions from 0.1% to 2% with (W/Cm = 0.45). It was found that increased steel fibers content had a pronounced effect on increased compressive strength, tensile strength and flexibility, as well as increased elasticity coefficient values and improved stress-strain relationship. The elasticity coefficient was also improved by 77% compared to the reference mix.

In 2011, Almottiri [5] conducted a practical study to investigate the mechanical behavior of concrete contain fly ash and steel fibers in compression, tensile and flexure. According to its results, the use of steel fibers with fly ash improves concrete mechanical properties (especially tensile and flexural strength) by increasing the ratio of fly ash to 30% and the ratio of steel fibers to 1.5% in concrete.

1.3. The Objective of the Research

The objective of the research is to study the effect of addition of steel fibers and fly ash on the mechanical properties (compressive strength and modulus of rapture) of concrete and compare them with the mechanical properties of the reference concrete (without any additi-ves).

2. EXPERIMENTAL PROGRAM

The concrete mix used is designed according to the ACI 211.1-91 [6] with a compressive strength of the cylinder (f'_c= 30 MPa) at 28 days. Table 1 shows the materials and mixing ratios of the materials used.

The experimental program in this research included conduct a series of tests to study the mechanical properties of concrete. The studied properties are compressive strength (by testing cylinders of dimensions {150×300}) and modulus of rupture (by testing a prisms of dimensions {100×100×500}). The variables adopted in this study includes the fly ash adding percentage (by cement weight) and the steel fibers percentage (by content volume).

The slump test for each mixture was tested to ensure that the mix was achieved for the required workability. The ratio of (W/cm) was fixed and the ratio of the SuperPlasticizer (SP) for each mixture was adjusted as shown in the Table 2.

2.1. Materials

2.1.1. Cement

An Ordinary Portland Cement Type I was used. The results of the test were in identically with Iraqi Standards [7]. The chemical and physical properties for this cement is shown in Tables 3 and 4, respectively.

2.1.2. Fine Aggregate

The fine aggregate used is river sand from the Al-Tawz area of Salah Al-Din Governorate, which was sieved on the sieve (4.75 mm), it's tests results were conformed to Iraqi Standards [8]. The results of the tests are shown in Tables 5 and 6.

2.1.3. Coarse Aggregate

The coarse aggregate used is Rounded Gravel, which is available in Al-Dibs area of Kirkuk province, with a maximum size of 12.5 mm, it's tests results were conformed to Iraqi Standards [8]. The results of the tests are shown in Tables 7 and 8, indicating their conformity with the above specification.

2.2. Admixtures

2.2.1. SuperPlasticizer

(GLENIUM 54) was used in the present research as a high water-reducing additive (HAWRA) shown in Fig. 1 to enhance early and end resistance, and as a high performance to produce a well workability and easy to flow concrete. This (HAWRA) is conformed to American Standard (ASTM C494 Types A and F) [12]. Table 9 shows the technical specifications of this additive.

Table 1

Ratios of concrete mixing with test results.

Water (kg/m^3)	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Compressive strength at 7 Day (MPa)	Compressive strength at 28 Day (MPa)	Slump (mm)
174	400	705	1015	29.973	34.58	75

Table 2
Ratios of SuperPlasticizer (SP) with slump test results.

Group no.	Mix no.	SF %	FA%	W/cm	SP%	Slump (mm)
Ref.	M1	0	0	0.435	0	75
G1	M2	0.25	15	0.435	1	57
	M3	0.25	20	0.435	0.98	61
	M4	0.25	25	0.435	0.98	73
G2	M5	0.75	15	0.435	1.04	65
	M6	0.75	20	0.435	1.02	71
	M7	0.75	25	0.435	1.01	67
G3	M8	1.25	15	0.435	1.22	59
	M9	1.25	20	0.435	1.2	61
	M10	1.25	25	0.435	1.2	65

Table 3
Chemical properties of cement.

Oxides Composition	Content %	Limit of Iraqi Specification No. 5/1984 [7]
CaO	58.887	-
Al_2O_3	4.370	-
SiO_2	20.100	-
Fe_2O_3	4.845	-
MgO	3.668	5 % Max
SO_3	2.100	2.5 %Max
Loss on ignition, (L.O.I)	3.620	4 %Max
Insoluble material	1.330	1.5 %Max
Lime saturation factor (L.S.F)	0.888	(0.66-1.02)
C_3S	44.630	-
C_2S	24.036	-
C_3A	3.392	< 5 %
C_4AF	14.729	-

Table 4
Physical properties of cement.

Physical Properties	Test results	Limit of Iraqi specification No. 5/1984 [7]
Specific surface area (Blaine method)‹(m^2/kg)	293	(230 m^2/kg) lower limit
Setting time (vacate apparatus)		
Initial setting‹(hrs : min)	2 hrs 24 min	Not less than 45min
Final setting‹(hrs : min)	4 hrs 45 min	Not more than 10 hrs
Compressive strength (MPa)		
For 3-day	22.13	Not less than 15 MPa
For 7-day	29.57	Not less than 23 MPa

Table 5
Grading of fine aggregate.

Sieve size	Cumulative retained (%)	Cumulative passing (%)	Limit of IQS no. 45/1984 for zone no. (2)
4.75-mm (no.4)	2.00	98.00	90-100
2.36-mm (no.8)	9.93	90.07	75-100
1.18-mm (no.16)	24.45	75.55	55-90
600-µm (no.30)	42.83	57.17	35-59
300-µm (no.50)	73.48	26.52	8-30
150-µm (no.100)	94.68	5.32	0-10
		Fineness modulus = 2.47	

Table 6
Physical and chemical properties of fine aggregates.

Properties	Specification	Test results	Limits of specification
Specific gravity	ASTM C128-01/04 [9]	2.710	-
Absorption (%)	ASTM C128-01/04 [9]	2.460	-
Dry loose unit weight kg/m^3	ASTM C29/C29M/97 [10]	1482	-
Sulfate content (as SO_3)(%)	(IQS) no. 45-84 [8]	0.052	0.5 (max. value)
Material finer than 0.075mm (%)	(IQS) no. 45-84 [8]	1.300	5 (max. value)

Table 7
Grading of coarse aggregate.

Sieve size (mm)	Cumulative retained (%)	Cumulative passing (%)	Limit of IQS no. 45/1984 for zone no. (2) [8]
14	0.00	100.00	90-100
10	36.70	63.30	50-85
5	97.93	2.07	0-10

Table 8
Physical and chemical properties of coarse aggregates.

Properties	Specification	Test results	Limits of specification
Specific gravity	ASTM C127-01 [11]	2.600	-
Absorption (%)	ASTM C127-01 [11]	0.664	-
Dry loose unit weight kg/m^3	ASTM C29/C29M/97 [10]	1585	-
Sulfate content (as SO_3)(%)	(IQS) No. 45-84 [8]	0.028	0.1 (max. value)

Table 9
Main properties of GLENIUM 54.

Main Action	Concrete Superplasticizer
Form	Whitish to straw coloured liquid
Relative density	1.07 kg/ltr, at 20°C
PH Value	5-8

Table 10
Chemical analysis and Pozzolanic effect of fly Ash.

Parameter	Unit	Average	Standard deviation	Limit value according to EN 450 [14]
Loss on ignition	%	2.6	0.51	≤ 5
Fineness > 0.045 mm	%	15.1	4.52	≤ 40
Free lime (CaOfree)	%	0.06	0.042	≤ 1.0
Sulfate (SO3)	%	0.4	0.03	≤ 3.0
Chloride (Cl)	%	0.012	0.0129	≤ 0.1
Cross density	g/cm^3	2.33	0.04	-
Activity index				
28 day	%	84.4	4.29	≥ 75
90 day	%	96.9	6.49	≥ 85

Table 11

The specifications of the steel fibers.

Commercial name	Configuration	Property	Specifications
		Density	7840 kg/m^3
		Ultimate strength	2850 MPa
		Raw Material	Steel
Dramix®	straight	Color	Yellow (coated with brass)
		Standard	ASTM
		Average length	13 mm
		Nominal diameter	0.2 mm
		Aspect ratio (L_f/D_f)	65

Fig. 1. SuperPlasticizer (GLENIUM 54).

2.2.2. Fly Ash

Fly Ash is manufactured by the Turkish Company (ISKENMENT-TR). Fly ash shall be added to concrete according to US and British standard [13] and [14]. Table 10 shows the results of the chemical analysis and Pozzolanic activity of this type of ash.

2.2.3. Steel Fibers

The steel fibers used in this research are Ultra Steel Fibers type (Dramix®) made by Bekaert of Belgium. Steel fibers are straight fibers made of steel and copper plated as shown in Fig. 2. Table 11 shows the specifications of the steel fibers used in the current research.

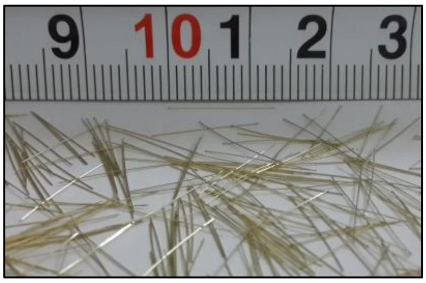

Fig. 2. Ultra Steel Fibers used.

2.3. Mechanical Properties of Hardened Concrete

2.3.1. Compressive Strength (f'_c)

Compressive strength in concrete is one of the most important mechanical properties of concrete in most structural applications. In the present study, the compressive strength was tasted at 28 days for all concrete mixtures by taking the rate of three cylinders of dimensions (150×300) mm for each mixture as shown in Table 12 and Figs. 3-5.

The results showed that the concrete mix (M8) containing (1.25) of steel fibers and (15%) of fly ash recorded the highest compressive strength for all mixtures with an increase of (61.6%) compared to the reference mixture (M1), This increase is due to the regular distribution of fiber within the concrete textures , which makes it cohesive and more hard to resist cracking in the tensile area and resist the resulting side strains , as well as the good reaction of fly ash with calcium hydroxide resulting from the cement hydration process which resulted in denser , stronger and less permeable concrete .

In concrete mixtures containing different volume ratios of steel fibers and different weight ratios of fly ash, it is observed an increased reduction in compressive strength by increasing fly ash content to the same ratio of fibers for all mixtures except M7 and M10. This is due to the slow Pozzolan reaction which causes to delay the acquisition of resistance in the early ages but give exceptional results at the long extent, while offset by a significant increase in compressive strength by increasing the volume ratios of steel fibers in the concrete mix because of the fact that the coefficient of elasticity of steel fibers is higher than the coefficient for the elasticity of concrete and these results correspond to the results of other researchers [1,15].

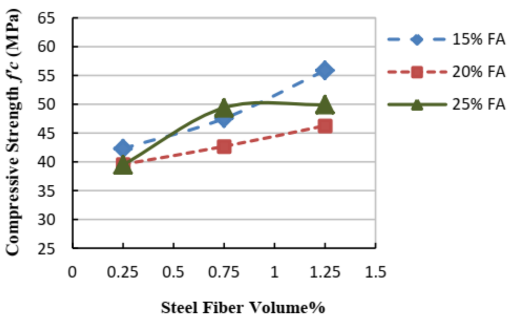

Fig. 3. Effect of steel fibers on the compressive strength at 28 days.

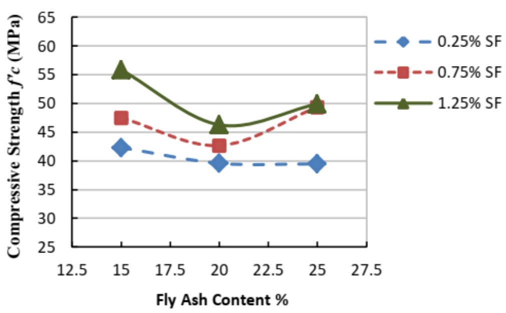

Fig. 4 Effect of fly ash on the compressive strength at 28 days.

(a) With additives SF & FA **(b)** Without additives

Fig. 5. Compression failure mode of concrete cylinders at 28 days.

2.3.2. Modulus of Rupture (f_r)

Modulus of rupture of concrete is affected by the quality and quantity of materials involved in the production of concrete. The results of the Modulus of rupture test for all concrete mixtures at 28 days are shown in Table 13 and Figs. 6-8.

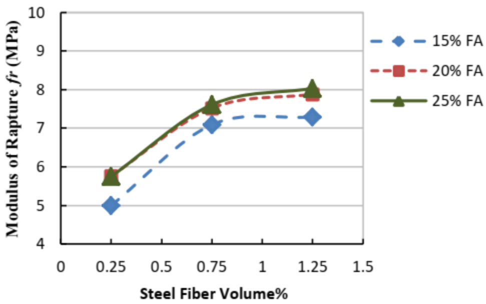

Fig. 6. Effect of steel fibers on the flexural strength at 28 days.

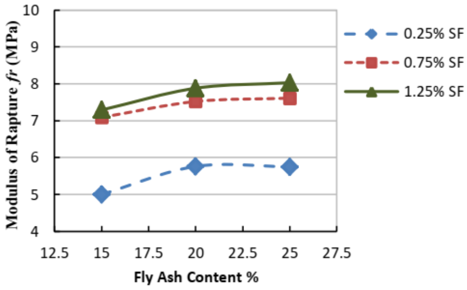

Fig. 7. Effect of fly ash on the flexural strength at 28 days.

From Table 13, it can be observed the increase of the flexural resistance of the concrete by increasing the weight ratio of fly ash. This is due to the reaction of fly ash particles with the calcium hydroxide resulting from cement hydration process form additional calcium silicate during the reaction process which produce a dense, less permeability concrete and increase the strength of bonding between the concrete and steel fibers. Also it can be seen that the flexural resistance is increased by increasing the steel fibers percentage which produces a high flexibility coefficient of steel fibers (higher than the normal concrete elasticity coefficient) which makes them contribute with the concrete mixture in resistance of tensile stresses, delay the appearance of bending cracks, improves ductility and resistance to bending. This finding is correspond with other researchers [1,5].

(a) Without additives.

(b) With additives SF & FA.

Fig. 8. Flexural failure mode of concrete prisms at 28 days.

Table 12
rate of compressive strength (f_c') for all concrete mixtures

Group no.	Mix no.	SF %	FA%	Compressive strength (28) day (f_c') MPa	Increasing %
Ref.	M1	0	0	34.58	—
G1	M2	0.25	15	42.32	22.38
	M3	0.25	20	39.58	14.50
	M4	0.25	25	39.47	14.14
G2	M5	0.75	15	47.52	37.42
	M6	0.75	20	42.68	23.42
	M7	0.75	25	49.39	42.83
G3	M8	1.25	15	55.88	61.60
	M9	1.25	20	46.28	33.83
	M10	1.25	25	49.93	44.39

Table 13
rate of flexural strength (f_r) for all concrete mixtures.

Group no.	Mix no.	SF %	FA %	Flexural strength (28) day (f_r) MPa	Increasing %
Ref.	M1	0	0	4.49	—
G1	M2	0.25	15	5.00	11.36
	M3	0.25	20	5.76	28.29
	M4	0.25	25	5.75	28.06
G2	M5	0.75	15	7.09	57.91
	M6	0.75	20	7.52	67.48
	M7	0.75	25	7.61	69.49
G3	M8	1.25	15	7. 29	62.36
	M9	1.25	20	7.88	75.50
	M10	1.25	25	8.03	78.84

3. CONCLUSIONS

- The replacement of fly ash particles with different ratios of the cement improves the compression resistance of concrete compared to the reference concrete (without fly ash), but the increased replacement rates of fly ash caused a reduction in compressive strength of concrete cylinders. The addition of steel fibers performs to a significant improvement in the resistance of compression of concrete cylinders, and this improvement is increased by increasing the volume ratios of steel fibers. The highest increase in compressive strength of the concrete cylinders compared to the reference concrete (without additives) was (61.60%) at the weight ratio of (15%) for the fly ash particles and the volume ratio of (1.25%) for the steel fibers. The lowest increase in the resistance of compression of concrete cylinders was (14.14%) at the weight ratio of (25%) for fly ash particles and the volume ratio of (0.25%) for steel fibers.
- The flexural strength of concrete prisms increases with the increase of percentages fly ash particles and steel fibers, respectively. The highest increase in the flexural strength of concrete prisms compared to the reference concrete (without additives) was 78.84% in the weight ratio of (25%) for the fly ash and for volumetric ratio (1.25%) for the steel fibers. The lowest increase in the flexural strength of concrete prisms was (11.36%) at the weight ratio of (15%) for fly ash and for volume ratio of (0.25%) of steel fibers.

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