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Influence of Adding Different Amounts of Super Plasticizers on the Mechanical Properties of Concrete (Impact and Abrasion)

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ABSTRACT

Trial laboratory batches were used to study the effect of adding different amounts of superp lasticizers on the mechanical properties (Compressive strength, abrasion resistance, and impact resistance) of concrete. A series of five different concrete mixtures including: Normal concrete mixture C1 (without superp lasticizers) as a reference mix and four concrete mixtures (C2, C3, C4, and C5) with different amounts of superp lasticizers (0.25, 0.50, 0.75, and 1.00) % as a percentage of cement content, respectively. Results show that the (1.00)% addition of superp lasticizers in the concrete mixture leads to (19.84)% increasing in the compressive strength and records an improvement in the abrasion resistance by (38.06)% and recorded an improvement in the impact resistance by (386.67)% as compared with the reference mixture. On the other hand, increasing the percentages of superp lasticizers lead to increase in compressive strength, abrasion resistance and impact resistance for all concrete mixtures.

Key words: Impact Resistance, Compressive Strength, Abrasion Resistance, Super Plasticizers, ACI 544, First-crack strength, Failure strength, ASTM C 944, Depth of Wear.

تأثير إضافة مقادير مختلفة من الملدنات الفائقة على الخواص الميكانيكية للخرسانة (الصدم والاحتكاك)

الخلاصة

تم عمل خلطات تجريبية لدراسة تأثير الكميات المختلفة من الملدنات الفائقة على الخواص الميكانيكية (مقاومة الانضغاط, مقاومة التآكل, ومقاومة الصدم) للخرسانة. تم إنتاج خمس خلطات خرسانية متضمنة: خرسانة اعتيادية C1 (بدون مضافات) كخلطة مرجعية، وأربعة خلطات (C2, C3, C4, C5) بنسب مختلفة من الملدنات الفائقة (0.25 , 0.50 , 0.75 , 1.00)% كنسب وزنيه من وزن السمنت على التوالي. النتائج بينت أن إضافة الملدنات الفائقة في الخلطة الخرسانية بنسبة (1.00)% أدى

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إلـى زيـادة فـي مقاومـة الانضـغاط بنسـبة (19.84)% و تحسـين فـي مقاومـة التآكـل و البـري بنسـبة (38.06)% و تحسين في مقاومـة الصـدم بنسبة (386.67)% عنـد مقارنتهـا بالخلطـة المرجعيـة. و مـن ناحية أخرى, فقد أدت زيادة نسب الملدنات الفائقة إلى زيادة في كل من مقاومة الانضغاط ومقاومة البـري ومقاومة الصدم لجميع الخلطات الخرسانية.

INTRODUCTION

Concrete has an excellent impact resistance in comparison with other construction materials. Nevertheless, existing concrete structures designed without consideration of impact or blast load can be vulnerable under unexpected extreme loads. Accordingly, to improve the resistance of concrete structures under the extreme loads, additional strengthening methods are required (Krauthammer, 2008; Malvar et al., 2007).

Concrete is the most commonly used construction material worldwide, which, during its working process, is frequently subjected to quasi-static loadings of magnitudes that change slowly. Designs of such large structures as nuclear power plant protection devices, airport runways and military facilities must however account for the impact of dynamic loadings of drastically changing magnitudes [1]. The compressive strength of concrete can be increased by increasing the strength of the cement paste and improving the interfacial zone, reducing the potential stress concentration between the aggregate and the cement paste. Such an increase can be achieved by reducing the water-to-cement ratio, using fine pozzolanic materials and reducing the coarse aggregate size[1].

Cement based materials are quasi-brittle and are known to exhibit a highly stress rate sensitive behavior. In structures that are subjected to impact forces this causes concern in two ways, first the brittleness may result in catastrophic failure without warning, and second the properties of concrete during such events may be very different from those measured in standardized quasi static test. There are no standardized tests available for testing concrete under impact loading and there is significant confusion as to what constitutes an appropriate test [2].

Concrete generally registers low tensile strain capacity and brittle nature, and therefore, develops susceptibility to the presence and development of cracks in plastic as well as hardened state [3]. Concrete structures may be required to withstand impact loads which can result, for example, from kinetic energy weapons, turbine blade fragments, and tornado generated projectiles [4]. Local damage can lead to concrete fragmentation from the front surface, projectile penetration into the target, scabbing of concrete from the back face, and finally, perforation through the target. The extent of damage depends on a variety of factors, such as impact velocity, mass, geometry, material properties, and thickness of the target [5].

Literature Review

Researchers and designers are not able to use impact resistance as a design parameter, simply because it cannot be fully quantified due to the lack of a standard impact test for concrete [6]. In spite this is a standard impact test, researchers had proposed their own impact tests to estimate the impact resistance of concrete. Some of these tests are relatively difficult to perform and require complicated equipment. None of these tests, however, have been claimed to be a standard test due to the lack of statistical data on the variation of the results [7]. In this regard, ACI Committee 544[8] has proposed a drop weight impact test to demonstrate the relative brittleness and to quantify the impact resistance of fiber-reinforced concrete (FRC). The test is widely used because it is simple and economical. The results obtained from this test are often noticeably scattered.

The large variation in impact resistance as determined from this test is reported in the literature for different types of FRC. Large variation is a common problem in impact testing, and it is difficult to devise systems that give reproducible results. This might be attributed to the nature of the impact process itself and the number of factors controlling the impact resistance compared with other mechanical properties[7, 9].

Aim of research

In this investigation, the impact and abrasion resistance and compressive strength of concrete incorporating with super plasticizers will be discussed.

Experimental investigation

Apparatus:

Drop weight machine

The drop weight test conducted followed from the test technique suggested by the ACI committee 544 on fiber reinforced concrete [8].Figure (1) shows a photo of the apparatus designed according to ACI 544.

Figure (1) Drop weight machine.

Abrasion machine

Abrasion resistance was measured through the standard test method described in ASTM C 944[17], this test determines abrasion resistance by measuring the amount of concrete abraded of a surface by a rotating cutter in a given time period, the cutter consist of a series of dressing wheels mounted on rod that is attached to drill press, the drill press is used to apply a constant force through the cutter into the specimen and to rotate a cutter at 200 revolution/minute. Figure (2) shows a photo of the apparatus designed according to ASTM C 944.

Figure (2) Rotating-cutter drill press.

Materials

Cement:

Sulfate–resisting Portland cement (Type V) obtained from Hammam-Al-Alil was used. Physical and chemical properties of the used cement were done in accordance to Iraqi specifications No. 5 / 1984**[10]**, test results are given in Tables (1 and 2).

Table (1) Physical properties of sulfate–resisting Portland cement.

Physical properties	Test results of sulfate-resisting cement	Iraqi specifications No. 5 / 1984[10]
Specific surface area by Blain method, m^2/kg	280	≥ 230
Initial setting time (hrs : min)	1 : 30	≥ 45 minute
Final setting time (hrs: min)	3 : 18	≤ 10 hours
Compressive strength, MPa 3 days 7 days	 21 29	 ≥ 15 ≥ 23

Table (2) Chemical compositions of sulfate–resisting Portland cement.

Chemical analysis Oxides and componds	Test results of sulfate-resisting cement(%)	Iraqi specifications No. 5/1984 (by weight%)[10]
MgO	1.9	≤ 5.0
SO_3	2.3	≤ 2.5
CaO	62.92	-
SiO_2	20.3	-
Fe_2O_3	5.4	-
Loss on Ignition	1.1	≤ 4.0
Insoluble Residue	0.85	≤ 1.5
C_3A	2.3	≤ 3.5
C_3S	58.9	-
C_2S	13.6	-
C_4AF	25.2	-

Coarse aggregate:

Coarse aggregate with MAS (10) mm. obtained from Mosul city was used. Its sieve analysis was shown in Table (3).

Table (3) Sieve analysis of the used coarse aggregate.

Sieve size (mm)	Cumulative passing (%)	Limits of Iraqi specification No. 45/1984[11]
14	100	100
10	94.6	85-100
5	4.8	0-25
2.36	0	0-5

Fine aggregate:

Fine aggregate (Zone No.3) obtained from Mosul city was used. Its sieve analysis was shown in Table (4).

Table (4) Sieve analysis of the used fine aggregate.

Sieve size (mm)	Cumulative passing (%)	Limits of Iraqi specification No. 45/1984[11]
4.75	98.4	90-100
2.36	94.6	85-100
1.18	92	75-100
0.60	66	60-79
0.30	40	12-40
0.15	10	0-10

The main properties of the used coarse and fine aggregates are shown in Table (5).

Table (5) Main properties of coarse and fine aggregates.

Property	Coarse aggregate	Fine aggregate
Dry sp. Gravity	2.63	2.59
S.S.D. sp. Gravity	2.64	2.65
App. sp. Gravity	2.66	2.79
Absorption capacity (%)	0.5	2.9
Rodded unit weight (kg/m^3)	1716	1765
Fineness modulus	6.55	2.61
SO_3 content(%)	0.1	0.45

Super plasticizers:

Sika Visco Crete -5930, is a third generation of super plasticizers for concrete and mortar, was used. It meets the requirements for super plasticizers according to ASTM C 494 Types G and F and BS EN 934 Part 2 : 2001[12]. Main properties of the used super plasticizers were shown in Table (6).

Table (6) Typical properties of superplasticizers (Sika Visco Crete -5930).

Form	Aqueous solution of modified Polycarboxylate
Colour	Turbid liquid
Density	1.08 Kg/lt. ± 0.005
Odor	None
Boiling	100 ^{o}c
pH value	7 - 9

Mixing water:

Tap water was used in preparing all mixtures in accordance with ASTM C1602[13].

Mix proportioning:

Mix proportions used in this investigation were obtained using three methods (ACI, British, and Road Note No. 4 "RN4" methods)[14], as shown in Table (7).

Table (7): Mix proportions.

Mix design method	Mix proportions	(A/C) Ratio
ACI	1 : 2.2 : 2.0 , w/c= 0.61	4.2
British	1 : 1.8 : 1.8 , w/c= 0.5	3.6
Road Note No. 4	1 : 1.9 : 2.4 , w/c= 0.45	4.3

Since all methods of concrete mix design shown in Table (7) give the same compressive strength 25 MPa (fix on design), therefore, the mix proportions obtained by the (Road Note No.4) was chosen because it gives (A/C) ratio higher than the other two methods and this will be the best mix design method from economic as point of view.

Preparation and casting of specimens:

All batches of concrete were cast in the laboratory using a drum mixer. Mixing, casting, and curing were conformed to ASTM C192 [15]. Each batch was used to cast the 6 cubes of (100*100*100) mm. and 6 cylinders of (150*63.5) mm, and 6 cylinders of (150*75) mm. to perform the compressive strength, impact resistance and abrasion resistance tests, respectively. The mixing procedures were performed according to the following sequences:

(a) The fine and coarse aggregates were placed in the mixer, mixed for two minutes.

(b) The cement was added to the mixed aggregate, and mixed for two minutes also.

(c) Two-third of the mixing water was mixed with half quantity of the superplasticizers and added to the mixer, mixed for two minutes.

(d) The rest quantity of water and superplasticizers were added to the mixer and mixing till there are no dry balls of cement[14].

(e) Molds were oiled and placed on the vibration table while the concrete was poured the cylindrical specimens were cast in three layers and each layers compacted by the vibrator until no further air bubbles appeared on its surface, while the cubes specimens were casted in two layers and compacted as the same manner.

(f) After completing the compaction operation, the top of the specimen was smooth finished by means of a trowel. Then,

(g)The specimens were demolded after (24±2) hrs, and subjected to the standard moist curing by immersing them in curing tank at 23 ^{o}C and relative humidity more than 90% till testing at 28 days.

Test procedure of specimens

Compressive strength test

The specimens were taken out from the curing tank, and the compressive strength of the specimens was tested in accordance with BS 1881: Part 116: 2003[16].

Impact resistance test

Surface of the cylindrical specimens were grinding [14], and the impact resistance of concrete were measured in compliance with ACI 544. The testing procedure was done as follows:

1. Rests a specimen on the base plate within positioning lugs.
2. The specimen bottom has received a thin layer of heavy grease to reduce the friction between the specimen and the base plate.
3. The positioning bracket of the base plate is bolted in place. Then, A 4.54 kg hammer consecutively falls from a 457 mm height onto a 63.5 mm diameter steel ball standing at the center of the disc, subjecting the disc to repeated impact blows.

4. The number of blows developing the first visible crack on the disc top record as the first-crack strength.
5. The falling operation continues to trigger the ultimate failure of the disc containing cracks. The ultimate failure is the opening-up of the disc to touch three of the four lugs. The number of blows triggering the ultimate failure is the failure strength.

Abrasion resistance test

The abrasion resistance of concrete were measured in compliance with ASTM C 944**[17].**Readings were taken every two minutes for 30 minutes or 1.0 mm. depth of wear, whichever occurred first.

The abrasion testing procedure was done as follows:

1. Determine the mass of the specimen to the nearest 0.1 gram.
2. Fasten the specimen securely in the abrasion device so that the bottom face of the concrete cylinder is placed upwards and normal to the drill press shaft.
3. Mount the special rotating cutter device in the drill press shaft.
4. Start the motor and lower the cutter slowly until just in contact with the surface of the concrete cylinder.
5. Continue abrasion with a normal load (10 kg) on the specimen for two minutes after contact between the cutter and the surface. At the end of each two-minute abrasion period, remove the test specimen from the device and clean surfaces with air. Determine the specimen mass to the nearest 0.1 gram.
6. The depth of wear shall be checked up with the average thickness loss of specimen obtained by the following formula [18]:

$$t = \frac{(W_1 - W_2)V_1}{W_1 * A} \quad \dots (1)$$

where:

t = loss in thickness, mm.,
W_1 = initial mass of the specimen, gm,
W_2 = final mass of the abraded specimen, gm,
V_1 = initial volume of the specimen, mm^3,
A = surface area of the specimen, mm^2.

Test results and discussions:

Results of the existing investigation were tabulated in Tables (1 to 4), and diagrammatically illustrated in Figs. (1 to 8).

Table(8) Slump test results.

Mixture code	Slump.(mm)	28-day Compressive strength. (MPa)
C1	60	33.0
C2	90	33.3
C3	120	34.9
C4	170	36.6
C5	190	39.6

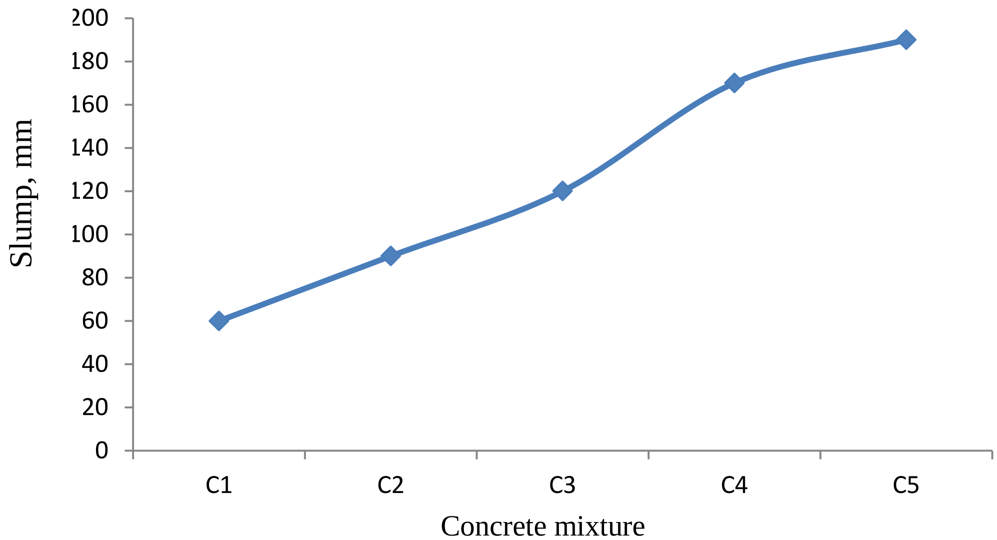

Figure (3) Slump test results for concrete mixtures.

Figure(4) Slump test for mixture C1

Figure(5) Slump test for mixture C5.

Table (9): Compressive strength test results

Mixture code	7-day Compressive strength(MPa)	28-day Compressive strength(MPa)	56-day Compressive strength(MPa)
C1	28.4	33.0	40.7
C2	28.5	33.3	41.2
C3	29.1	34.9	42.6
C4	30.7	36.6	46.2
C5	33.0	39.6	58.7

Table (10) Test results for each concrete mixture.

Mixture code	28-day compressive strength (MPa)	Depth of abrasion (mm)
C1	33.0	0.500
C2	33.3	0.435
C3	34.9	0.429
C4	36.6	0.397
C5	39.6	0.365

Table (11) Test results for each concrete mixture.

Mixture code	Compressive strength (MPa)	Loss on abrasion (gm)	Percentage increase in compressive strength	Percentage increase in abrasion resistance
C1	33.0	12.15	Reference	Reference
C2	33.3	10.50	0.85%	15.71%
C3	34.9	10.00	5.78%	21.5%
C4	36.6	9.50	10.74%	27.89%
C5	39.6	8.80	19.84%	38.06%

Table (12) Impact test results for specimens with different amounts of superplasticizers.

Mixture code	Specimen number	Number of blows		First crack impact energy (kN mm)	Failure impact energy (kN mm)	Average failure impact energy (kN mm)
		First crack	Failure			
C1	1	19	19	392.73	392.73	620.1
	2	25	25	516.75	516.75	
	3	43	46	888.81	950.82	
C2	1	25	27	516.75	558.09	647.66
	2	27	29	558.09	599.43	
	3	35	38	723.45	785.46	
C3	1	30	33	620.1	682.11	861.25
	2	35	41	723.45	847.47	
	3	47	51	971.49	1054.17	
C4	1	50	54	1033.5	1116.18	1502.02
	2	65	67	1343.55	1384.89	
	3	91	97	1880.97	2005	
C5	1	70	76	1446.9	1570.92	3017.82
	2	86	91	1777.62	1880.97	
	3	235	271	4857.45	5601.57	

Table (13) Test results for each concrete mixture.

Mixture code	Compressive strength (MPa)	Average Number of blows for failure crack	Percentage increase in compressive strength	Percentage increase in abrasion resistance
C1	33.060	30	Reference	Reference
C2	33.340	31.3	0.85%	4.4%
C3	34.970	41.66	5.78%	38.88%
C4	36.612	72.66	10.74%	142.2%
C5	39.620	146	19.84%	386.67%

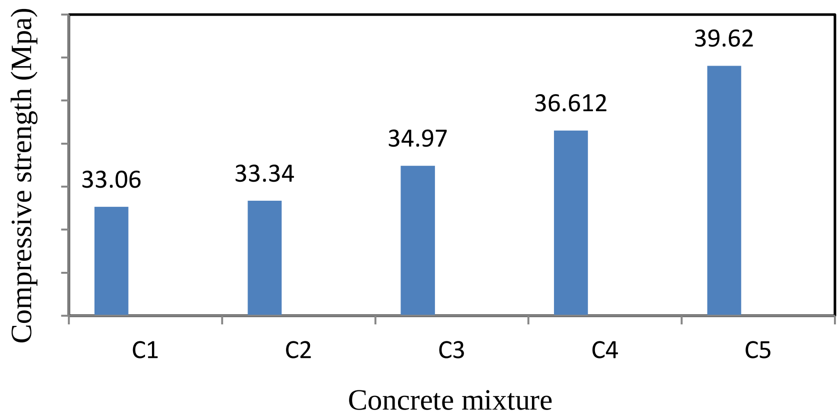

Figure (6) 28-day compressive strength results.

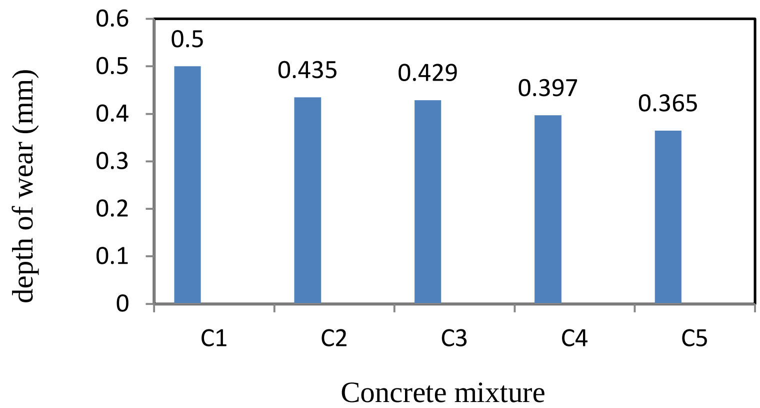

Figure (7) Depth of wear results.

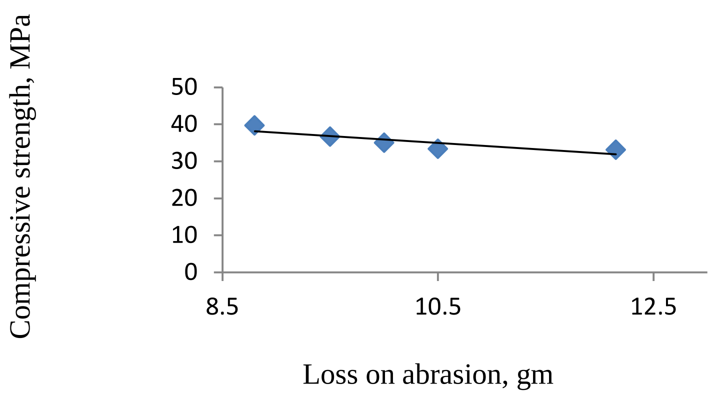

Figure (8) Effect of compressive strength on abrasion resistance of concrete.

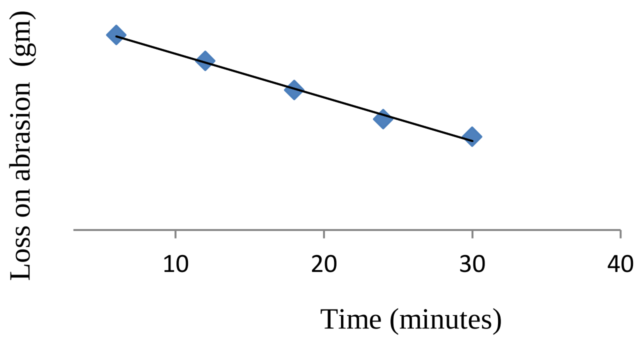

Figure (9) Loss on abrasion versus time for reference mixture C1.

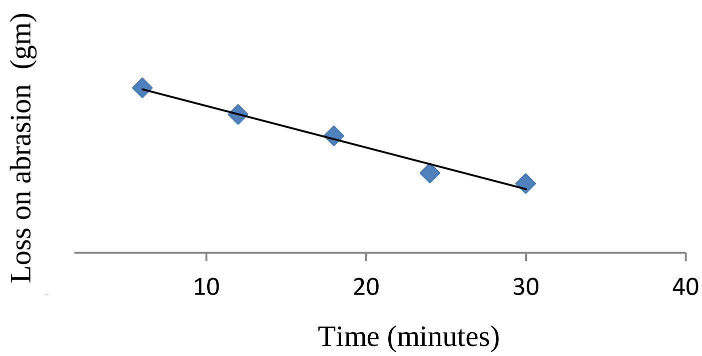

Figure (10) Loss on abrasion versus time for reference mixture C2.

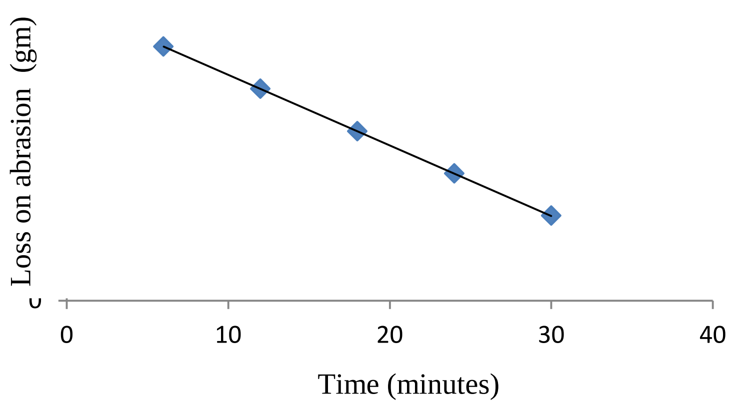

Figure (11) Loss on abrasion versus time for reference mixture C3.

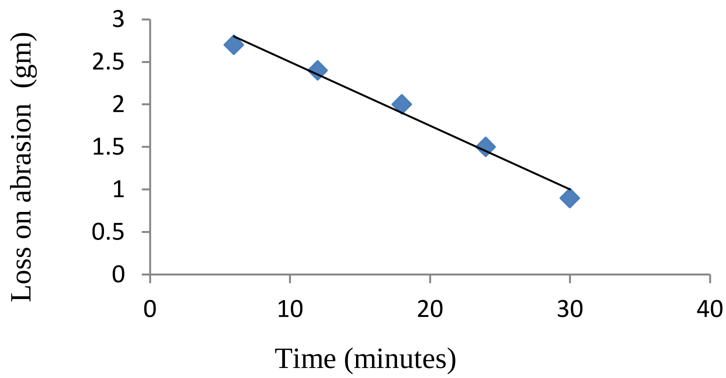

Figure (12) Loss on abrasion versus time for reference mixture C4.

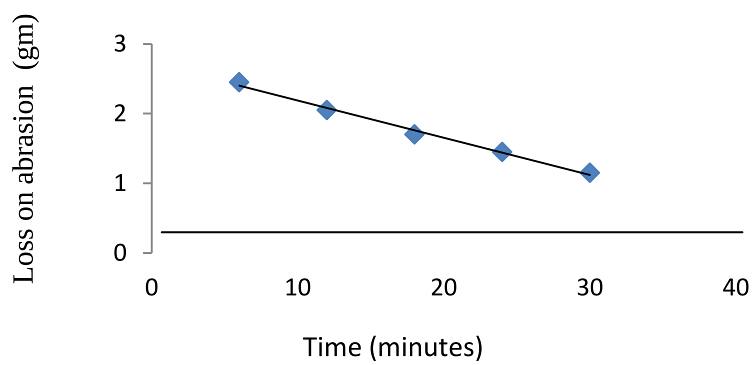

Figure (13) loss on abrasion (gm) versus time for mixture C5.

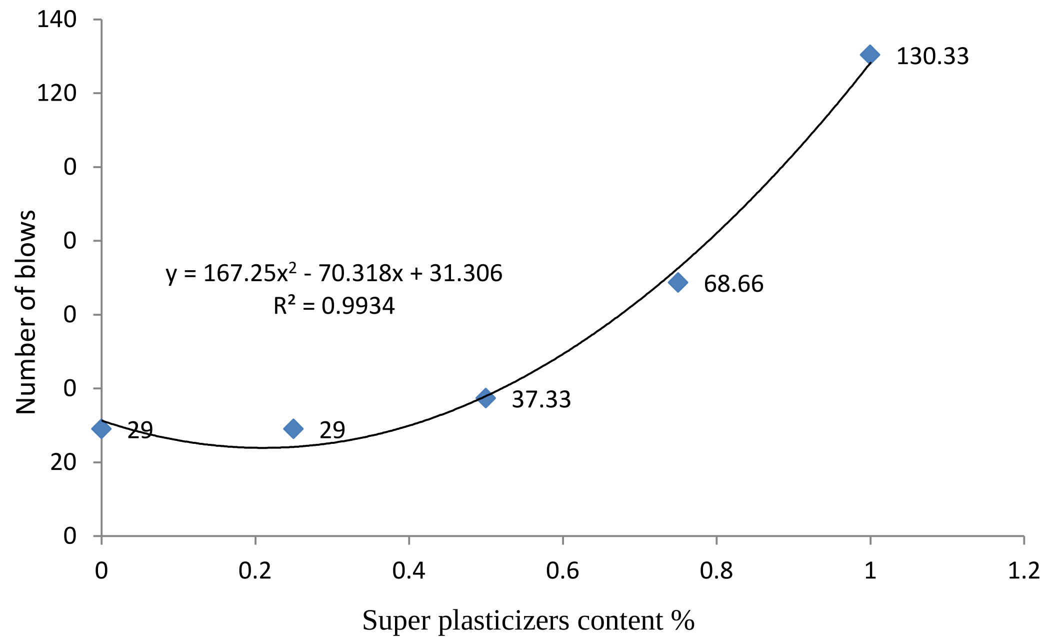

Figure (14) Number of blows to first crack in concrete mixtures.

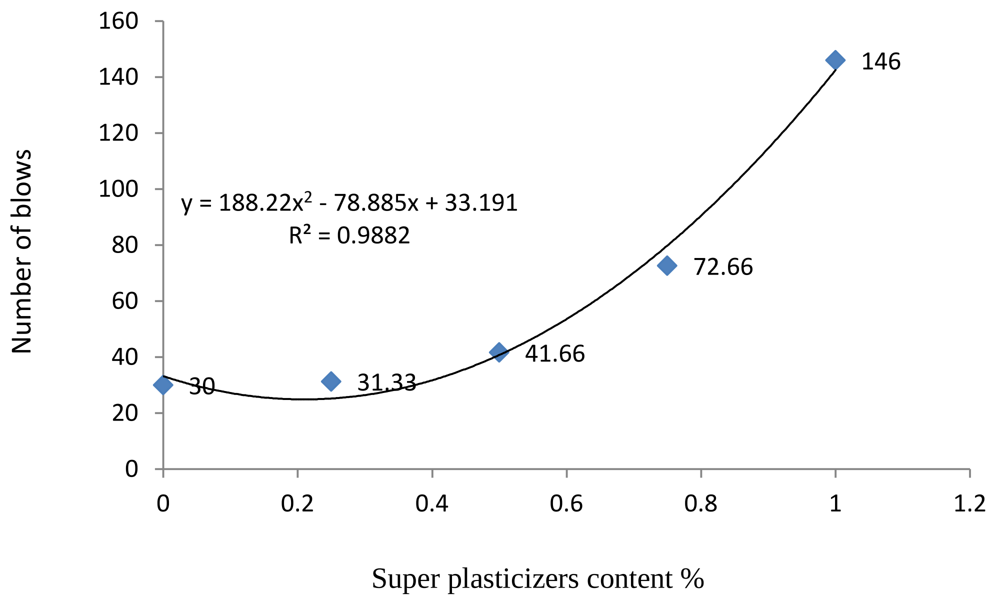

Figure (15) Number of blows to failure crack in concrete mixtures.

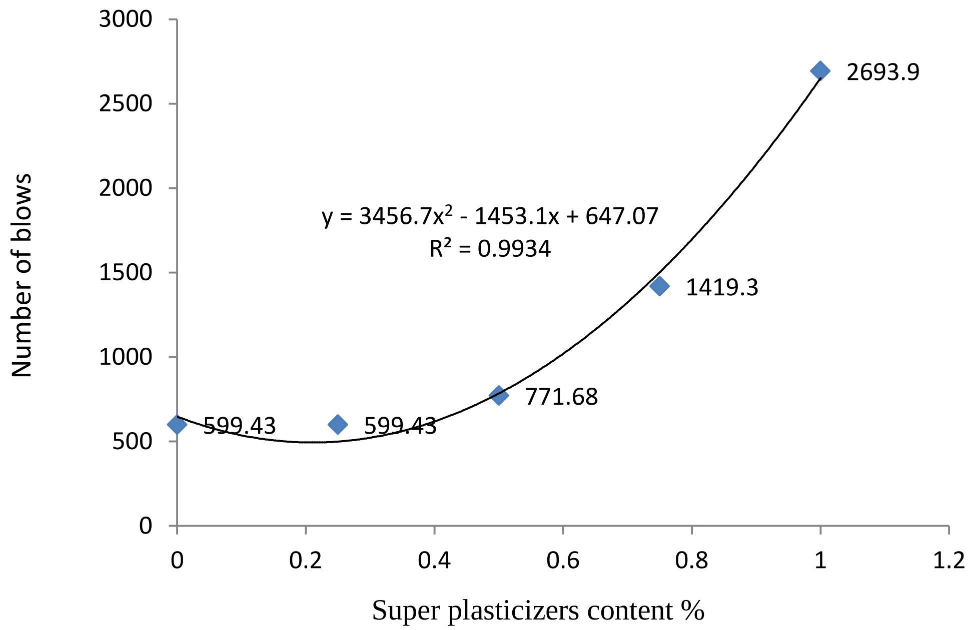

Figure (16) Number of blows to first crack impact energy in concrete mixtures.

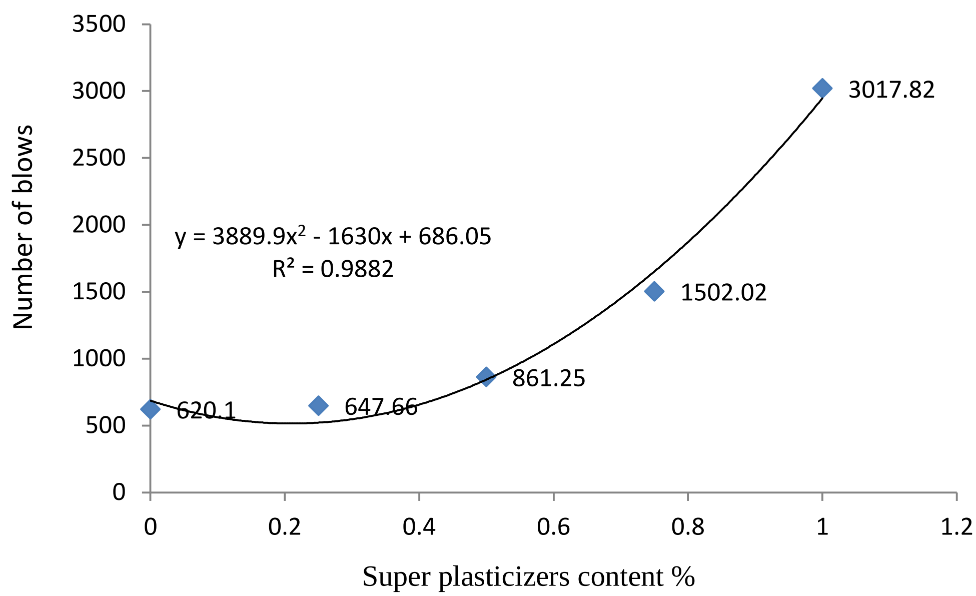

Figure (17) Number of blows to failure crack impact energy in concrete mixtures.

The following parameters may be discussed, as follows:

Effect of superplasticizers on slump:

It was clear from Table (1) and Figure (1) that, for concrete mixtures (C2, C3, C4, and C5) that, increasing of the percentages of superplasticizers lead to improve the workability and increase in compressive strength for all mixes, as compared with reference mixture C1.

The slump results in Table (1) show that mixture C3 had the best consistency When in its fresh state be plastic and generally capable of being molded by hand.

Effect of superplasticizers on the compressive strength:

It was clear from Tables (2 and 4) and Figure. (4) that, the addition of different amounts of superplasticizers gain average compressive strength values range from (33.34 to 39.62) MPa as compared with the reference mixture.

The maximum compressive strength value 39.62 MPa (19.84% increasing), was recorded in mixture C5 with 1.0 % of superplasticizers, whilst the minimum compressive strength value 33.34 MPa (0.85% increasing), was obtained with the 0.25% superplasticizers in mixture C2.

Compressive strength increases for all dosage of superplasticizers than normal concrete. This is due to confinement provided by superplasticizers bonding characteristics of concrete increases and improving the interfacial zone, reducing the potential stress concentration between the aggregate and the cement paste. Such an increase can be achieved by reducing the water-to-cement ratio hence compressive strength increases with the increases in superplasticizers content.

Effect of super plasticizers on the impact resistance:

It may be noted that from Tables (5 , 6) the appearance of first visible crack and ultimate failure took place simultaneously. A significant variation in the number of blows required for causing the first crack and failure among the test samples of the same mix was observed for mixture concrete samples. (Swamy and Jajagha) [19] and (Gopalaratnam and Shah)[21] have also reported a wide spread in the results of their impact tests.

The sources of large variations in results obtained from the ACI impact test may be attributed to the following reasons [22]:

– The subjectivity of the test due to the visual identification of the first crack, which may occur in any direction.

– The impact resistance of concrete is based on a single point of impact, which might happen to be on a hard particle of coarse aggregate or on a soft area of mortar.

– The absence of criteria for preparing test specimens allows trawled, cut or smooth mould-faced surfaces to be tested, adding another source of variability.

– No criteria are stated for accepted or rejected failure mode.

These tables also indicate the calculated impact energy required for first visible crack and at failure for different specimens tested in this investigation. The impact energy imparted by the hammer per blow can be calculated by the following expressions:

$$H = \frac{g*t^2}{2} \quad \text{..................} \quad (2)$$

$$V = g*t \quad \text{..................} \quad (3)$$

$$\text{Impact energy } U = \frac{M*V^2}{2} \quad \text{..................} \quad (4)$$

$$m = \frac{W}{g} \quad \text{..................} \quad (5)$$

where

U = impact energy per blow of the hammer ,
V = velocity of the hammer at impact ,
g = acceleration due to gravity ,
t = time taken by the hammer to fall a height of 457 mm ,
H = height of fall ,
m = mass of the hammer ,and
W = the weight of hammer.

Substituting the relevant values in Equation. (2)

$$457 = \frac{9810\, t^2}{2}$$

t = 0.305 s and
V = 9810 * 0.305 = 2992.05 mm / s.
Impact energy per blow U ,of the hammer can be obtained by substituting the values in Equation.(3)

$$U = \frac{4.53 *(2992.05)^2}{2*9810}$$

$$= 2067 \text{kg.mm} \quad \text{or} \quad 20.67 \text{ KN.mm}$$

The results, in terms of number of blows for first crack and for ultimate failure are plotted against super plasticizers content in Figures.(12) and (13),respectively whereas, Figures.(14) and (15) present the results in terms of first crack and failure energy, respectively, plotted against super plasticizers content.

It can be observed in general from the tables and figures that for a particular super plasticizers mix proportion, the best performance in terms of first crack as well as failure impact resistance of the super plasticizers concrete is given by concrete having 1.00 % super plasticizers content followed by concrete containing 0.75 % super plasticizers content and 0.50 % super plasticizers content Reason is that due to confinement provided by super plasticizers bonding characteristics of concrete increases and improving the interfacial zone, reducing the potential stress concentration between the aggregate and the cement paste.

In general, it can be concluded that on increasing the percentage superplasticizers content, the impact resistance at first crack as well as at ultimate failure increases. Further, it can also be concluded that incorporation of superplasticizers content in the plain concrete has significantly improved the impact resistance of concrete.

Effect of super plasticizers on the abrasion resistance:

It was clear from Tables (3.3 and 3.4) that, the addition of (0.25%) of super plasticizers leads to an increasing in the abrasion resistance by (15.71%), while the increasing in the abrasion resistance was (38.06%) with the addition of (1.0%) super plasticizers.

On the other hand, Figure. (5) shows that the depth of wear was decreased as the amounts of super plasticizers increased. Figure. (6) shows that the compressive strength was an important factor affecting the abrasion resistance of concrete mixture. Loss on abrasion decreased linearly as compressive strength increased.

Figures. (7 to 11) show that, the loss on abrasion of concrete mixtures decreased with time.

However, all mixtures with and without super plasticizers exhibited high resistance to abrasion under the actions of applied abrasive forces (i.e., much less than 1.0 mm. depth of wear).

CONCLUSIONS

The data collected in this investigation led to the following conclusions:

1. The addition of different amounts of super plasticizers gave average compressive strength values range from (33.34 to 39.62) MPa as compared with the reference mixture.
2. The addition of (0.25%) of super plasticizers leads to an increasing in the abrasion resistance by (15.71%), while the increasing in the abrasion resistance was (38.06%) with the addition of (1.0%) super plasticizers as compared with the reference mixture.
3. Mixture C5 containing 1.0% super plasticizers shows the highest compressive strength (39.62 MPa), and increasing in the abrasion resistance (38.06%) as compared with the reference mixture.
4. All super plasticizers mixtures exhibited substantially higher rates of abrasion resistance gain as compared with the reference mixture.
5. All mixtures with and without super plasticizers show a high abrasion resistance.
6. Generally, depth of wear decreases with time and super plasticizers content.

7. Concrete abrasion resistance was proportional to compressive strength, i.e, abrasion resistance increase with the increasing in the compressive strength.
8. The effects of amount of super plasticizers on abrasion resistance of concrete followed the same general trend as that observed for compressive strength.
9. The effect of super plasticizers on hardened concrete properties were significant.
10. Impact tests have been conducted on plain concrete and concrete containing different amount of super plasticizers , Drop weight type impact tests have been conducted and number of blows of the impact hammer to produce first crack and ultimate failure were recorded for each specimen tested. The results have been presented in the form of tables and figures.
11. The incorporation of super plasticizers in concrete has significantly improved its impact resistance as compared to reference concrete.
12. The best performance under impact loading has been given by the concrete containing 1.00 % of super plasticizers content followed by concrete containing 0.75% super plasticizers content and 0.5% super plasticizers content.

Recommended for future work:

1. In this study sulfate resistance cement (Type V) was used, the effect of other types of cement may be also studied.
2. Influence of different water/cement ratios & different amounts of super plasticizers on the impact resistance of concrete.

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