EFFECT OF USING FIBERS ON SOME MECHANICAL PROPERTIES OF SELF COMPACTING CONCRETE

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Abstract

The aim of this study is to find the influence of different fibers parameters such as volume, aspect ratio, type, and shape of fibers on the workability of the fresh concrete and some of the mechanical properties of selfcompacting concrete made from locally available materials. One reference concrete mix, which all other mixes develop from, has been designed in this work. The results indicate that the addition of fibers decreases the slump flow, increases T50., decreases L-box flow and increases Tv. The effect of fibers on the fresh properties of SCC depends on the content, length, type and shape of fibers. Steel fibers had a marginal effect on compressive strength of FRSCC, the higher percent of increase in compressive strength was (2.38 %). All fiber mixes demonstrated higher splitting tensile strength, flexural strength and impact strength relative to plain mix at all curing ages. The strengths increased as the fiber content and/or the aspect ratio increased and it increased by using crimped fibers. The fibers slightly decrease the U.P.V at 28 days.

تأثير استخدام الألياف على بعض الخواص الميكانيكية للكونكريت الذاتي الانضغاط

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الخلاصة

أن الهدف الرئيسي من هذه الدراسة هو إيجاد تأثير العوامل المختلفة للألياف مثل النسبة الحجمية، النسبة الباعية، تأثير النوع وشكل الألياف على قابلية تشغيل الخرسانة الطرية وبعض الخصائص الميكانيكية للخرسانة ذاتية الرص المنتجة من المواد المتوفرة محليا. تم تصميم خلطة مرجعية واحدة في هذا البحث والتي تم اعتمادها كأساس لتطوير الخلطات الأخرى . لقد أشارت النتائج المستحصلة إلى نقصان قيم انسياب الهطول، زيادة زمن الوصول لقطر 500 ملم، انخفاض نسب الانسداد و زيادة زمن فحص القمع عند إضافة الألياف إلى الخرسانة . إن تأثير الألياف على الخصائص الطرية للخرسانة ذاتية الرص يعتمد على محتوى الألياف وطولها ونوع الألياف وشكل الألياف. إن ألياف الفولاذ لها تأثير محدود على مقاومة الانضغاط، حيث وصلت أعلى نسبة زيادة إلى (2.38 %).لقد أبدت الخرسانات المسلحة بالألياف مقاومات شد وانحناء وصدم أعلى من الخرسانة المرجعية ولكل أعمار الإنضاج. وتزداد المقاومة بزيادة المحتوى والنسب الباعية للألياف وتزداد المقاومات كذلك باستخدام الألياف الملتوية. إن استخدام الألياف يؤدي إلى انخفاض طفيف بقيم سرع انتقال الموجات فوق الصوتية بعمر 28 يوما.

1. Introduction

Because plain concrete is a brittle material with low tensile strength and poor fracture toughness, it imposes numerous design constraints and often leads to long term durability problems. Therefore, discrete fibers with adequate mechanical properties can be added in fiber reinforced concrete (FRC) to improve toughness; increase resistance to impact; reduce spalling of the reinforcement cover; and improve abrasion resistance and flexural and shear strength***(Johnston, 2001)***. On the other hand, self compacting concrete (SCC) was developed to respond to the need for concrete that can improve durability while eliminating the need for compaction and vibration work. The technologies of FRC and SCC have evolved separately. A new area of research has recently evolved, which investigates the potential of developing concrete that combines the benefits of both fiber reinforcement and self compacting,leading to fiber reinforced self compacting concrete (FRSCC).It is possible to mix fibers of different sizes, from micro to macro, or of different mechanical properties, or both together. It has been shown recently that by using the concept of hybridization with two different fibers incorporated in a common cement matrix, the hybrid composite can offer more attractive engineering properties.

2. Materials

2-1: Cement

Ordinary Portland Cement conforms to***(IQS No.5/1984)*** was used in this research.The chemical composition and physical properties of this OPC are given in Tables (1) and (2).

2.2 Fine Aggregate

Natural sand from Al-Ekhaider region is used as a fine aggregate in this research. Results indicate that the fine aggregate grading and the sulfate content are within the requirements of ***(IQS No.45/1984)*** as shown in Tables (3) and (4).

2.3 Coarse Aggregate

Rounded gravel of maximum size 10 mm from Al-Nibaee region is used. Table (5) shows the grading of this aggregate, which conforms to the ***(IQS No.45/1984)***. The specific gravity, sulfate content and absorption of coarse aggregate are illustrated in Table (6).

2.4Water&Super-plasticizer

The tap water has been used for both mixing and curing of concrete.A chemical admixture based on modified polycarboxylicether, (Glenium 51) was used in producing SCC as a superplasticizeradmixture.Table (7) shows the typical properties of Glenium 51.

2.5 Limestone Powder (LSP)

This material is locally named as "Al-Gubra“. LSP has been brought from local market. The chemical composition of LSP is shown in Table (8).

2.6. *Fibers*

In this work two types of fibers are used; polymer microfibers and two shapes of steel macro fibers (crimped and straight fibers) in different combinations. The characteristics of these fibers are detailed in Table (9) and (10).

Table (1) Chemical composition and main compounds of cement

Compound composition	*Chemical composition*	*Percentage by weight*	*Limits of (IQS NO.5/1984)*
Lime	CaO	60.19	/
Silica	SiO_2	21.0	/
Alumina	Al_2O_3	5.68	/
Iron oxide	Fe_2O_3	3.16	/
Sulphate	SO_3	2.41	≤2.8%
Magnesia	MgO	2.35	≤5%
Free lime	Free CaO	1.23	/
Loss on ignition	L.O.I.	3.15	≤4%
Insoluble residue	I.R	0.82	≤1.5%
Lime saturation factor	L.S.F	0.86	0.66-1.02
Main compounds (Bogue'sequs.)		*Percent by weight of cement*	
Tricalcium silicate (C_3S)		35.82	
Dicalcium silicate (C_2S)		33.26	
Tricalcium aluminate (C_3A)		9.71	
Tetracalciumaluminoferrite (C_4AF)		9.61	

Table (2) Physical properties of cement

properties	*Test results*	*Limits of (IQS NO.5 /1984)*
Setting time (Vicat's Method) Initial, min Final, hrs:min	 140 4:083	 ≥ 45 min ≤ 10 hrs
Fineness (Blaine Method) ,m^2/kg	346	≥ 230 m^2/kg
Compressive strength, MPa 3 days 7 days	 20.1 29.0	 ≥ 15, MPa ≥ 23, MPa

Table (3) Grading of fine aggregate

Sieve size (mm)	*Cumulative passing %*	*Limits of Iraqi specification No.45/1984 /zone (3)*
10	100	100
4.75	94	90-100
2.36	90	85-100
1.18	85	75-100
0.6	65	60-79
0.3	20	12-40
0.15	3	0-10

Table (4)Physical properties of fine aggregate

Physical properties	*Test result*	*Limits of Iraqi specification No.45/1984*
Specific gravity	2.60	/
Sulfate content %	0.09	≤0.5%
Absorption	1.86	/
Fineness modulus	2.43	/

Table (5) Grading of coarse aggregate

Sieve size (mm)	*Cumulative passing%*	*Limits of Iraqi specification No.45/1984*
14	100	100
10	89	85-100
5	14	0-25
2.36	2.3	0-5

Table (6) Physical properties of coarse aggregate

Physical properties	*Test result*	*Limits of Iraqi specification No.45/1984*
Specific gravity	2.62	/
Sulfate content %	0.04	≤0.1%
Absorption %	1.51	/

*Table (7) Typical properties of Glenium 51**

Main action	*Concrete super plasticizer*
Color	Light brown
pH Value	6.6
Form	Viscous liquid
Relative density	1.1 at 20°C
Viscosity	128 ± 30 cps at 20°C
Normal dosage	(0.5-0.8) l/100 kg of cement
Transport	Not classified as dangerous
Labeling	No hazard label required

*Table (8) Chemical analysis of LSP**

Oxide	*Content %*
CaO	52.76
Fe_2O_3	0.69
Al_2O_3	1.10
SiO_2	1.62
MgO	0.1
SO_3	2.91
L.O.I	40.60

Table (9) Properties of polymer microfibers

Chemical Base	100 % Polypropylene fiber
Specific Gravity	0.91
Length	12 mm
Diameter	18 micron-nominal
Water Absorption	Nill
Specific Surface Area of Fibers	250 m^2/kg
Tensile strength	(300-400) N/mm^2

Table (10) Properties of the steel fibers

Fiber type	Straight metal		Crimped metal
Length	40 mm	50 mm	30 mm
diameter	0.5 mm		0.3 mm
Aspect ratio (L/D)	80	100	100
Tensile strength	850 N/mm2		1050 N/mm2
Specific Gravity	7.20		7.20

3. Experimental Work

3.1 Concrete mixes

In order to achieve the scopes of this study, a total of 16 FRSCC mixtures were made, all based on the same control mixture. The concrete was designed according to the ***(EFNARC, 2002)*** method. Table (11) provides the proportions of the reference mixture, from which all other mixtures were developed. A w/p of 0.33 was maintained for all mixtures, and the dosage of high-range water-reducing admixture was also kept constant. By keeping mixture variables constant and varying only the fiber parameters, the goal was to evaluate the effect of including fibers with different contents on characteristics of SCC. The optimum dosage of HRWRA of 1.4 l/100 kg of cement was determined by using slump flow test. The dosage of HRWRA was increased to 1.5

l/100 kg of cement for mixes incorporated polymer microfibers. Fibers were added in quantities ranging from 0 to 1.25 % by volume of the total mixture. Fiber content in FRSCC mixtures are detailed in Table (12).

Table (11) Proportions of reference mixture

Material	Cement (kg/m^3)	Water (L/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	LSP (kg/m^3)	SP (L/m^3)	W/C	W/P
Amount	450	190	805	780	120	6.3	0.422	0.333

Note: LSP= limestone powder; SP= superplasticizer; W= water; P= cement + limestone powder

Table (12) Fiber content in FRSCC mixtures

Mix No.	*Mix Symbol*	*Fiber Content (vol.%)*
1	R	Reference mix with no fiber
2	ST1	0.75 % steel straight fiber of 40 mm length
3	ST2	1.0 % steel straight fiber of 40 mm length
4	ST3	1.25 % steel straight fiber of 40 mm length
5	ST4	0.75 % steel straight fiber of 50 mm length
6	ST5	1.0 % steel straight fiber of 50 mm length
7	ST6	1.25 % steel straight fiber of 50 mm length
8	ST7	.5 % steel straight fiber of 40 mm length + 0.5 % steel straight fiber of 50 mm lengt
9	SC	1.0 % crimped steel fiber
10	PO	0.15 % polymer fiber
11	PS1	0.6 % steel straight fiber of 40 mm length + 0.15 % polymer fiber
12	PS2	0.85 % steel straight fiber of 40 mm length + 0.15 % polymer fiber
13	PS3	0.5 % steel straight fiber of 40 mm length + 0.25 % polymer fiber
14	PS4	0.6 % steel straight fiber of 50 mm length + 0.15 % polymer fiber
15	PS5	0.85 % steel straight fiber of 50 mm length + 0.15 % polymer fiber
16	HF1	35 % steel straight fiber of 40 mm length + 0.5 % steel straight fiber of 50 mm leng + 0.15 % polymer fiber
17	HF2	.5 % steel straight fiber of 40 mm length + 0.6 % steel straight fiber of 50 mm lengt + 0.15 % polymer fiber

3.2 Fresh Concrete Tests

The fresh properties of SCC were tested by the procedures of ***(European Guidelines for self compacting concrete)***. In this work three tests were used slump flow test, L-box test and V-funnel test. The Visual Stability Index (VSI) value was obtained during the slump flow test. The VSI test ranks the stability of the SCC on a scale of 0-3, with 0 indicating highly stable SCC and 3 indicating unacceptable SCC.

3.3 Hardened Concrete properties

The mechanical properties studied are compressive strength, splitting tensile strength, flexural strength and impact strength. Furthermore, the non-destructive test method, ultra-sonic pulse velocity test are used. The compressive strength test was performed in accordance with ***(BS. 1881: Part 116: 1983)*** using 100 mm cubespecimens. The splitting tensile strength test was carried out according to ***(ASTM C496-2004)*** using Ø100 × 200 mm cylinder specimens. The test procedure given in ***(ASTM C-78, 2005)*** was used to determine the flexural strength using 100 × 100 × 400 mm prisms. In this study, the repeated drop weight impact testing apparatuswhich was developed by ***(Barr***

&Baghli, 1988)is used. The test specimens are (100×100×400 mm) beams. The notch depth of 20 mm is introduced on specimen tensile face. The impact apparatus consists of three main components: the base, the drop weight guide system, and the impact masses or strikers. The drop weight guide system consists of two vertical steel rods 2500 mm and 18 mm in diameter along which the impact mass dropped freely onto the test specimens. The front end of the impact masses have a rounded surface in order to create a line contact between the impact mass and the test specimen. In this study, a mass of order 1 kg drops through 1 m is used only. The impact resistance of the test samples is determined in terms of the number of blows required to cause complete failure of the specimens. The energy produced by each blow is given by the product of the drop height and weight of the striker, then the total impact energy is determined by multiplying the energy per blow by the number of blows. The average of five prisms is adopted at each test.

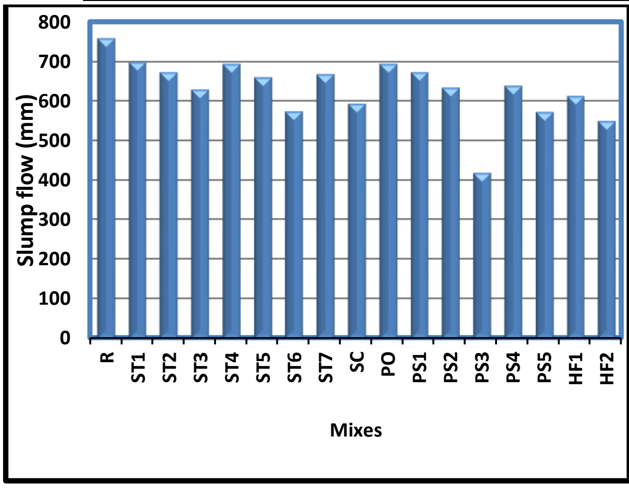
4. Results of Tests

4.1 Fresh Concrete Properties

4.1.1 Slump Flow Test

Table (13) and Fig. (1) show the results of slump flow tests together with the Visual Stability Index (VSI) values. The values of (D) represent the maximum spread (slump flow final diameter), while the values of T50 represent the time required for the concrete flow to reach a circle with 50 cm diameter. Reference mixture (R) is proportioned at the upper level of self compactability, in order to remain within the given limits after the addition of the fibers. The results of the slump flow range between (420-760) mm, the results of T50cm range between (2.3-5.9) seconds as shown in Fig. (2). It is very clear from the results that not all of the mixes satisfy the requirements of SCC. None of the mixes show segregation, bleeding or halo-formation, giving a satisfactory VSI, within the targeted value of 0 to 1except of SC mix.

As steel fibers were added (ST mixtures), slump flow values generally became lower. The reduction percents in slump flow values was found to be increase with the increase in steel fibers aspect ratio and with the increase in fiber content. For the same fiber content and aspect ratio, the mixes with crimped steel fibers had lower slump flow than mixes with straight steel fibers.These fibers tended to become entangled together and formed clusters at the center of the flow spreadwhich jeopardize the ability of concrete to flow. It can be seen that the flowability is better for ST mixtures than for PS and HF mixtures (for the same fiber vol.) which containing polymer microfibers due to the high specific surface area for this fibers.The flow time was higher for PS & HF mixes than for ST mixes since the polymer fibers increased the viscosity of the mixes. Some of these mixes had T50 exceeded thelimits of ***EFNARC*** due to the cumulative negative effect for polymer fibers and higher fiber factor (PS5, HF1 and HF2).



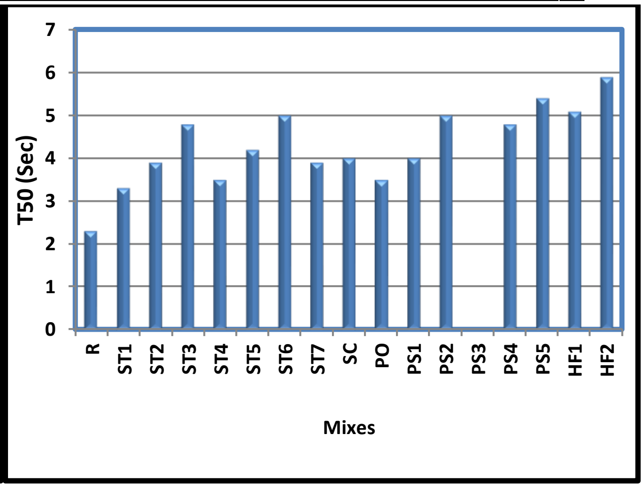


Fig. (1) Slump flow diameter D (mm)Fig. (2) Time requiredto reach a circlewith 50cm diameter

4.1.2L-box Test

The Blocking Ratios results (BR=H2/H1) of the tests are summarized in Table (13) & Fig. (3). The reference mixture (R) achieved the highest L-box results (0.99). The reduction percents in BR was found to be increased with the increase in steel fibers aspect ratio and with the increase in fiber content. As shown from the results that for the same fiber content, better L-box flow was achieved at lower aspect ratios.For the same fiber content and aspect ratio, the mixes with crimped steel fibers had lower L-box flow than mixes with straight steel fibers.Also, the reduction percents were affected by the fibers type;for the same fiber volume, the PS mixes had lower L-box flow than ST mixes.

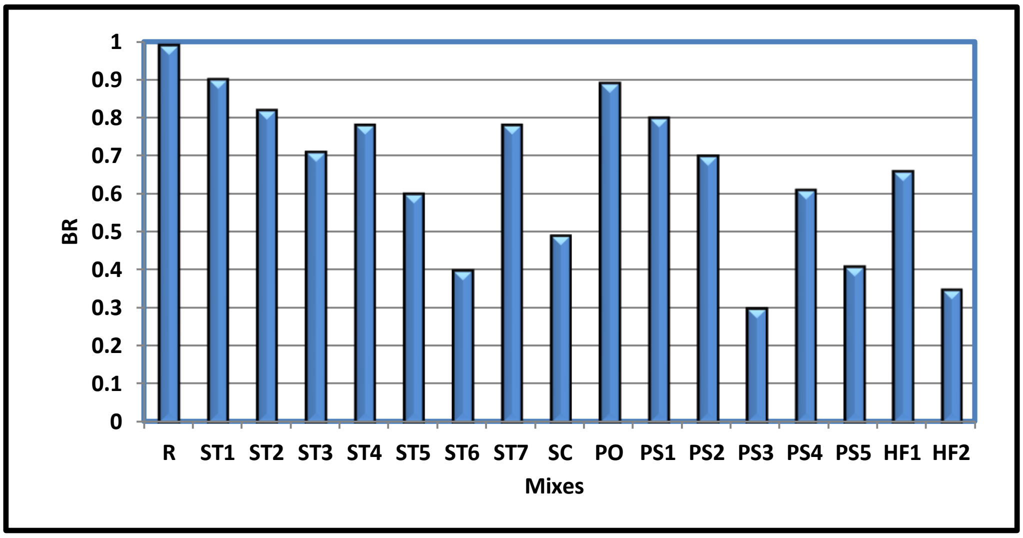


Fig. (3) Blocking Ratios for L-box tests

4.1.3 V-funnel Test

The time values of discharging concrete from the under gate of the funnel (Tv) are summarized in Table (13)& Fig. (4).The reference mixture achieved the lowest Tv value. It is clear from the results that the flow time increases with the addition of fibers in the mixes and also with increase of their aspect ratios and fiber content. The mixes with crimped steel fibers had comparable flow time to mixes with straight steel fibers. The polymer fibers increase the viscosity of the concrete mixes, this explained the increasing in flow time for mixtures containing polymer fibers compared withthe ST mixtures having the same fiberscontent.

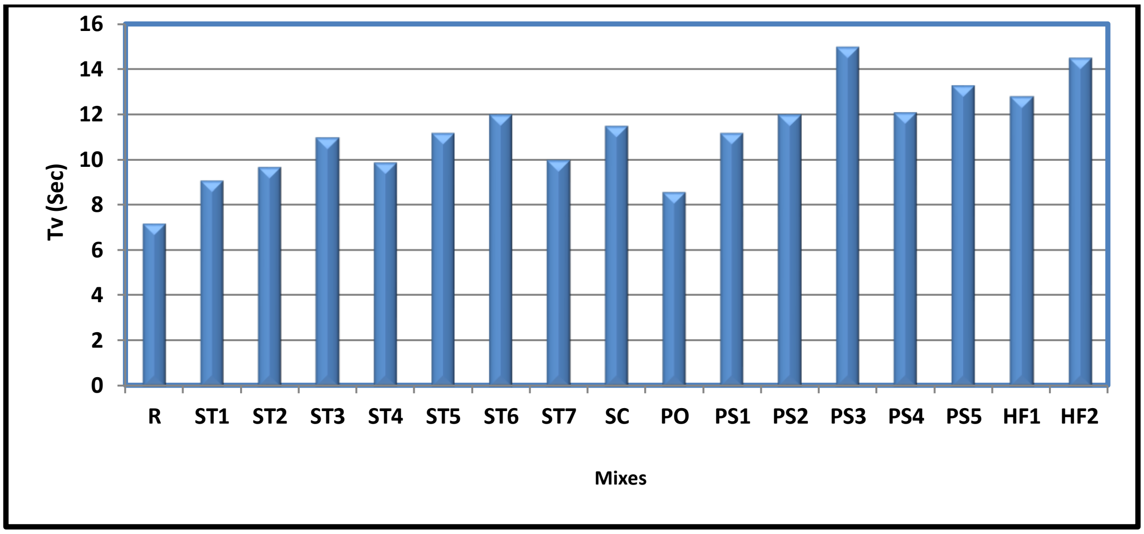


Fig.(4) Tv (Sec) for V-funnel

Table (13) Results of fresh concrete tests

Mix	*D (mm)*	*T50 (Sec)*	*VSI rating*	*Blocking Ratio (BR)*	*Tv (sec)*
R	760	2.3	0	0.99	7.2
ST1	700	3.3	0	0.9	9.1
ST2	675	3.9	1	0.82	9.7
ST3	630	4.8	0	0.71	11
ST4	695	3.5	0	0.78	9.9
ST5	662	4.2	0	0.6	11.2
ST6	575	5	0	0.4	12
ST7	670	3.9	1	0.78	10
SC	595	4	2	0.49	11.5
PO	695	3.5	1	0.89	8.6
PS1	675	4	0	0.8	11.2
PS2	635	5	0	0.7	12
PS3	420	____	0	0.3	15
PS4	640	4.8	0	0.61	12.1
PS5	574	5.4	0	0.41	13.3
HF1	615	5.1	0	0.66	12.8
HF2	551	5.9	0	0.35	14.5

5. HardenedConcreteProperties

5.1Compressive Strength Test

Table (14) shows the average of the results of compressive strength test at 7, 28, and 90 days gained from cubes.As observed from results, there were early age developments in compressive strength (reach to 11 %) for steel mixes. It was reported that the addition of steel fibers has a slightly negative effect on the compressive strengths of concrete at early ages (7 days), ***(Al-Jabri, 2005***), but this effect was likely due to increasing the dosage of superplasticizer, which has a retardation effect, in the reported study compared with that of the reference mixture when fibers were added in SCC.Among all steel mixes, the concrete specimens incorporated crimped steel fibers (SC mix) achieved the lowest compressive strength.Thepercents of decrease in compressive strength were (7.28, 7.79 and 8.06) % for reference concrete reinforced with 1% crimped steel fibers relative to the corresponding plain concrete at 7, 28 and 90 days curing respectively. While, the percents of the decrease in compressive strength were (11.78, 9.54 and 7.69) % for reference concretes reinforced with 1% crimped steel fibers relative to reference concrete reinforced with 1% straight steel fibers have the same fiber content and aspect ratio at 7, 28 and 90 days curing respectively.This is probably due to the increment of the air entrained, with the addition of crimped fibers, which introduced because of clustering of the fibers with each other. This adversely affected the stability of the mix, resulting in strength reduction.It can be seen that the higher aspect ratio had a negative effect on compressive strength, the longer fibers demonstrated comparatively lower strength than shorter fibers for the same fiber volume at all test ages.

5.2 Splitting Tensile Strength Test

Table (14) shows the average of the results of tensile strength test at 7, 28 and 90 days gained from cylinders. By contrast to the compressive strength, the results of the splitting tensile strength tests clearly showed the benefit of fibers.The trends illustrated a definite increase in tensile capacity attributable to higher fiber concentrations. The tested cylinders for plain concrete failed suddenly and split into two separate parts, while the cylinders with fibers is cracked at failure withoutseparation.All fibrous mixes demonstrated higher splitting tensile strength relative to plain mix at all curing ages. The percent of increase in splitting tensile strength was found to be increased with the increase in steel fiber aspect ratioandwith the increase in fiber content. With an increase in fiber content, the fibers become more densely spaced, and they may hinder growth of microcracks within the brittle matrix and increase the splitting tensile strength of the fiber reinforced concrete.Thepercents of increase in tensile strength at 90 curing days were (20.15, 35.32 and 47.76) % for reference concrete reinforced with 0.75 %, 1 % and 1.25 % steel fibers had aspect ratio equals 80 with respect to plain concrete. While, the percents of increase in tensile strength at 90 curing days were (33.83, 46.52 and 59.45) % for reference concrete reinforced with 0.75 %, 1 % and 1.25 % steel fibers had aspect ratio equals 100 with respect to plain concrete.The SC mix demonstrated, comparatively, higher splitting tensile strength relative to both reference and ST mix, the percent of increase in splitting tensile strength for SC mix relative to corresponding plain mix was (58.46) % at 90 days.

5. 3 Flexural Strength Test

The flexural strength results for the different mixes are shown in Table (14). It is worthwhile to note that the fibrous concrete mixes really stand out higher in the flexural strength when compared to the non-fibrous concrete mixes. Concrete mixes reinforced with steel fibers showed significant improvement in flexural strength at all ages relative to the reference concrete without fibers. This is mainly due to the increase in crack resistance of the composite and to the ability of fibers to resist forces after the concrete matrix has failed. The percents of increase in flexural strength was found to be increase with the increase in steel fiber aspect ratioandwiththe increase in fiber content. For (80) aspect ratio, the percents of increase in flexural strength at 90 days curing were (28.94, 43.23 and 49.17) % for reference concretes reinforced with 0.75 %, 1% and 1.25 % steel fibers respectively relative to the corresponding plain concrete. While for (100) aspect ratio, the percents of increase in flexural strength at 90 days curing were (35.62, 44.16, 54.36) % for reference concretes reinforced with 0.75 %, 1% and 1.25 % steel fibers respectively relative to the corresponding plain concrete.This might be due to comparatively higher bond strength of the longer fibers.For the same fiber content, the concrete specimens incorporated crimped steel fibers demonstrated higher flexural strength than specimens with straight steel fibers. The percent of increase in flexural strength at 90 days curing was (50.65) % for reference concretes reinforced with 1% crimped steel fibers relative to the corresponding plain concrete.This is due to the better mechanical anchorage because of the corrugated shape along the length of fibers.Concrete mixes reinforced with hybrid fibers exhibited superior performance in flexural strength compared to the plain concrete. The concrete mixes incorporated hybrid fibers had comparable flexural strength results or even better than that of mixes with single type fibers only. This is probably because fibers with different lengths could better control the micromechanics of crack formation at different strain levels than single type fibers.

5.4 Impact Strength Test

The ACI recommendations for impact testing have not readily accepted and a great deal of research has been carried out to improve or develop alternative tests for investigating impact resistance ***(Barr &Baghli, 1988).*** The results obtained from this test are often noticeably scattered ***(Schrader, 1981)***. The sources of large variations in results obtained from the current ACI impact test are allowing cracks to occur anywhere and in any direction: this increases the subjectivity of the test and also makes the visual identification of the first crack very difficult; using a single point of impact: this increases the possibility of false results, as it might happen that this point is a hard particle of coarse aggregate or a soft area of mortar and absence of criteria for accepted or rejected failure mode: this increases the scatter of the results. The repeated drop-weight impact testing apparatus used in this study is developed by ***(Barr &Baghli, 1988)***. The suggested modifications are proposed to reduce the sources of variations are; forcing cracks to occur in a predefined path by using a notched specimen. The variation of the results is reduced relative to other testing arrangements that proposed by ***ACI*** Committee 544. The impacting mass had a rounded surface in order to create a line contact between the impacting mass and the test specimen. Using a 100 mm line of impact instead of a single point reduces the possibility of false results, as it will probably act upon more representative area of concrete that contains hard particles of coarse aggregate as well as soft areas of mortar. Ultimate failure should be declared if the upper surface of specimen has been shattered or the specimen touches the basement of the apparatus (the touch will happen if the deflection equals 2 cm), whichever takes place first. Only specimens failed by cracking through the notch are accepted; any other pattern of cracking should be rejected. The results of the impact resistance test in terms of the number of blows required to cause first crack, failure and the impact energy for the various types of concrete at 90 days curing are presented in Table (14).

The addition of steel fiber to concrete increases the impact resistance of the composite significantly. This behavior may be attributed to the ability of steel fibers in absorbing the energy required to produce failure, where the fiber addition results in more closely-spaced cracks, reduced the crack width and bridges cracks, leading to the absorption of large energy ***(Gopalaratnam& Shah, 1986)***.Fiber reinforced self compacting concretes demonstrated considerably higher impact resistance at first crack and at ultimate failure compared to plain self compactingconcrete.This is mainly ascribed to the high capacity of fiber reinforced concrete to absorb large amount of energy prior to failure. At 90 days curing the percents of increase in impact resistance to failure for reference mixes reinforced with 0.75 %, 1 % and 1.25 % steel fibers of 40 mm were 583.33 %, 733.33 % and 1166.67 % respectively relative to the corresponding plain reference concrete. While, the percents of increase in impact resistance to failure for reference mixes reinforced with 0.75 %, 1 % and 1.25 % steel fibers of 50 mm were 816.67 %, 1016.67 % and 1383.33 % respectively relative to the corresponding plain reference concrete. The crimped fibers demonstrated a discernable effect on impact strength. The percents of increase in impact resistance to failure for reference mixes reinforced with 1 % crimped steel fibers was 1350 %, relative to the corresponding plain concrete at 90 days curing. This is due to improving fiber - matrix bond by deformations, which would increase the adsorbing energy required to pullout crimped fibers.

6. Non Destructive Tests

The values of ultrasonic pulse velocity for the various types of concrete at 28 days are presented in Table (14).The results indicated that all fiber reinforced mixes had lower ultrasonic pulse velocity as compared to plain concrete.This may be attributed to the increase of the amount of entrapped air voids due to incorporation of fibers into the mix. It is noticed that the reduction in the ultrasonic pulse velocity increases with the increase of fiber content. The percents of reduction in ultrasonic pulse velocity for reference concretes reinforced with 0.75 %, 1 % and 1.25 % steel fibers of 40 mm at 28 days curing was 0.311 %,1.948 % and 4.104 % respectively relative to the plain reference concrete. While, the percents of reduction in ultrasonic pulse velocity for reference concretes reinforced with 0.75 %, 1 % and 1.25 % steel fibers of 50 mm at 90 days curing was 0.725 %,1.762 % and 6.528 % respectively relative to the plain reference concrete. It can be seen from the results that the aspect ratio has no clear effect on the ultrasonic pulse velocity. The ultrasonic pulse velocity increased as the aspect ratio increased for some mixtures and decreased for others.

Table (14) Results of hardened concrete tests

Mix	Compressive strength (MPa)			Tensile strength test (MPa)			Flexural strength test (MPa)			Impact strength		***UPV***
	7 days	***28 days***	***90 days***	***7 days***	***28 days***	***90 days***	***7 days***	***28 days***	***90 days***	***No. of blows at failure***	***Energy (N.m)***	***V (Km/sec)***
R	31.02	47	51.67	2.78	3.85	4.02	3.94	5.13	5.39	6	58.86	4.83
ST1	33.51	48.21	52.11	3.81	4.69	4.83	5.54	6.76	6.95	41	402.21	4.81
ST2	34.53	48.72	52.90	4.4	5.26	5.44	5.78	7.25	7.72	50	490.5	4.73
ST3	31.76	47.30	51.70	4.92	5.8	5.94	6.42	7.83	8.04	76	745.56	4.63
ST4	32.82	48	51.95	4.3	5.11	5.38	5.83	7.15	7.31	55	539.55	4.79
ST5	32.33	47.91	51.90	4.81	5.73	5.89	6.20	7.61	7.77	67	657.27	4.74
ST6	30.78	46.52	51.11	5.27	6.2	6.41	6.72	8.29	8.32	89	873.09	4.51
ST7	33.53	48.50	52.91	4.77	5.68	5.79	6.31	7.6	7.91	67	657.27	4.81
SC	28.52	43.34	47.91	5.09	6.15	6.37	6.53	8.01	8.12	87	853.47	4.45
PO	29.12	43.11	47.20	3.20	4.2	4.27	4.23	5.41	5.67	16	156.96	4.41
PS1	30.01	46.11	51.02	3.66	4.57	4.65	5.6	6.79	6.99	38	372.78	4.38
PS2	29.96	45.87	50.66	4.1	5.11	5.3	5.8	7.31	7.92	48	470.88	4.38
PS3	25.63	38.11	40.22	3.56	4.57	4.7	5.5	6.82	6.99	35	343.35	4.24
PS4	28.86	45.30	48.10	3.97	4.9	5.1	5.9	7.17	7.36	52	510.12	4.49
PS5	28.53	45.12	47.19	4.54	5.61	5.78	6.7	7.80	8.05	62	608.22	4.5
HF1	31.61	47.05	52.03	4.49	5.6	5.73	6.71	7.74	7.90	63	618.03	4.74
HF2	28.12	40.15	43.23	5.23	6.22	6.43	6.82	8.33	8.42	91	892.71	4.50

UPV= Ultrasonic pulse velocity, V= The pulse velocity in km/sec

6. Conclusions

a) The more fibers are added and the higher is their aspect ratio, the more the slump flow decreases compared to a reference SCC without fibers.

b) For the same fiber content and aspect ratio, the crimped fibers affected the flowability of the concrete more than straight fibers.

c) The polymer microfibers had a detrimental effect on the flowability of FRSCC. So, the fiber type is deemed more influential on the slump flow and T50 than the total fiber volume.

d) It was found that the L-box flow decreased when the fiber volume increased.

e) Longer fibers bridged the L-box bars, causing intensive blocking of fibers that degraded its restricted flowability. For the same fiber content, better L-box flow was achieved at lower aspect ratios.

f) For the same aspect ratio, the mixes with crimped steel fibers had lower L- box flow than mixes with straight steel fibers.

g) The flow time increases with the addition of fibers in the mixes and also with increase of their volume fractions and aspect ratios.

h) Among all steel mixes, the mix that incorporated crimped steel fibers achieved the lower compressive.

i) The aspect ratio had a negative effect on compressive strength, the longer fibers demonstrated comparatively lower strength than shorter fibers for the same fiber volume at all test ages.

j) All mixes that incorporated single type straight steel fiber and polymer microfibers had lower strength than reference mix. The lowest compressive strength corresponding to mixtures with the highest polymer fiber concentrations (0.25% polymer fibers).

k) All fiber mixes demonstrated higher splitting tensile strength relative to plain mix at all curing age. The tensile strength increased as the fiber content and/or the aspect ratio increased.

l) The mix containing crimped fibers (SC) demonstrated, comparatively, higher splitting tensile strength relative to both reference and straight steel fibers mix at the same fiber aspect ratio and fiber content.

m) Concrete mixes reinforced with steel fibers showed significant improvement in flexural strength at all ages relative to the reference concrete without fibers. The percent of increase in flexural strength was found to be increased with the increase in steel fiber aspect ratio and in fiber content.

n) For the same fiber content, the concrete specimens incorporated crimped steel fibers demonstrated higher flexural strength than specimens with straight steel fibers.

o)Concrete mixes reinforced with hybrid fiber exhibited superior performance in flexural strength compared to the plain concrete.

p) It has been verified that the used impact test in this research succeed to differentiate between the impact resistance of fibrous concretes with different fiber contents and aspect ratios.

q) Fiber reinforced self compacting concretes demonstrated considerably higher impact resistance at first crack and at ultimate failure compared to plain self compacting concrete.

r) The increase in the steel fibers volume fraction and aspect ratio led to a good increase in the impact resistance of the SCC specimens.

s) The crimped fibers demonstrated a discernable effect on impact strength.

t) All fiber reinforced mixes had lower ultrasonic pulse velocity as compared to plain concreteat 28 days.

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