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Effect of Matrix Composition on Steel Fiber Reinforced Concrete Properties

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Abstract. The main objectives of this study are to determine the influence of concrete mix composition on steel fiber reinforced concrete SFRC properties.

For the range of aggregate maximum size used (1/4″ – 1″), the ultimate flexural strength was found to be independent of maximum aggregate size. The fine aggregate needed in the mix is a function of the volume and type of fibers. Mixes with medium and high fine aggregate content (55 to 75%) showed the best results with respect to workability and strength. The influence of fibers in increasing ultimate flexural strength was the greatest when low or medium water cement ratio was used (0.42 or 0.51). The ultimate flexural strength was found to be approximately proportional to the fiber concentration in the concrete.

Introduction

The contribution of fibers toward concrete strength has been acknowledged by laboratory and field applications in the last few decades. As the cost of construction materials continues to increase, steel fiber reinforced concrete SFRC very likely will have the potential to be the economic choice of the future. Because of SFRC high flexural strength and its high cracking resistance, two economic advantages, over plain concrete, can be gained. First, saving the material cost due to the use of thinner SFRC section, second, saving the maintenance cost due to the ability of SFRC to resist and limit cracking.

Since SFRC is a composite made out of two materials, namely steel fibers and concrete, the optimization of the ingredients for both components is essential to get the best composite at the lowest cost.

Romauldi *et al.* [1] studied the behavior of concrete reinforced with closely spaced wire reinforcement. They showed that the ultimate strength is related to the wire spacing. Romauldi and Mandel [2] later found out that the tensile strength of concrete reinforced with uniformly distributed fibers is inversely proportional to fiber spacing. However, the general consensus is that the strength is closely proportional to the fiber concentration as a percentage by volume or weight of the concrete.

Schnutgen [3] found that tensile strength of SFRC is dependent on the fiber aspect ratio. Using one volume content and one size of fibers, he also reported that the increase in strength, over that of plain concrete is nearly constant with different sizes and shapes of aggregate. Nanni [4] investigated the load deformation response of fiber reinforced concrete subjected to standard flexural (ASTM C-1018) [5] and split tension (ASTM C-496) tests. He concluded that the split-tension test can not substitute for the standard flexural test in determining the postcrack performance of fiber reinforced concrete. Barab and Hanson [6] reported that changing the aggregate maximum size from 3/4″ to 1-1/2″ did not result in large reductions in flexural strength. Parameswaran and Rajagoplan [7] found that the aggregate fiber interaction is negligible in fiber reinforced concrete with maximum size aggregate 3/8″ or less. Kesler [8] reported inconclusively that flexural strength is influenced by the aggregate fineness modulus. Tests by Ritchie and Ruhman [9] indicate that inclusion of fibers has a significant effect on the rheological properties of fresh concrete. Fiber balling and inadequate mix workability impose an upper limit on fiber inclusion beyond which increase in strength and other properties are not fully realized.

SFRC properties, in both fresh and hardened state, depend on the following:

1. Fiber type, content, and fiber aspect ratio
2. Maximum coarse aggregate size and content
3. Fine aggregate content
4. Water-cement ratio
5. Cement content
6. Additives

In this paper the effect of the first four variables on steel fiber reinforced concrete is presented.

Research Significance

The influence of concrete mix composition on SFRC properties is investigated thoroughly along with the influence of fiber type and content [10]. It is significant to show that 3for the range of aggregate studied (1/4″ - 1″), the ultimate flexural strength was practically unaffected by the aggregate maximum size. Medium and low fine aggregate content with low and medium water/cement ratios produced the strongest SFRC. It is also significant to present strength prediction equations for different concrete composition.

In addition, this research provides important data that will help in understanding and utilizing SFRC.

Experimental Program

Table 1 shows the plain and SFRC mix design variables. They can be summarized as follows:

1. Round gravel maximum size (MSA)
   a) 1″ b) 1/2″ c) 1/4″

2. Percentage fine aggregate by weight (% FA)
   a) 35″ b) 55% c) 75%

3. Water/cement ratio (W/C)
   a) 0.42 b) 0.51 c) 0.60

4. Fiber concentration by volume (V_f)
   a) 0.00% b) 0.75% c) 1.5%

5. Fiber type
   a) Brass-coated steel fiber with round cross sectional area (.016″ × 1″)

   b) Brass-coated deformed steel fibers (.010 × 1″)

To achieve the goals of the study 27 plain concrete mixes and 108 fibers SFRC mixes were made. Cement factor was fixed at 650 1bs./cu.yd of Type I cement.

Flexural Strength

Three hundred and ten flexural beams 4 × 4 × 14 in. were prepared for third-point loading tests. Table 1 gives the number of beams prepared and tested from each mix design. All the beams were cured in 100 percent relative humidity for twenty-eight days prior to testing.

Third-point testing procedures outlined in ASTM C 78 standard were followed. Every beam was rotated 90° from the casting position and placed on the third-point loading apparatus. The distance between the support points for the concrete beams were kept at 12 inches.

Table 1. **Plain and steel fiber reinforced concrete mix design variables**

		Plain concrete			Straight fibers (0.016×1″)						Deformed fibers (0.01×1″)					
					$V_f = 0.75\%$			$V_f = 1.50\%$			$V_f = 0.75\%$			$V_f = 1.50\%$		
		w/c			w/c						w/c					
MSA	%FA	0.42	0.51	0.60	0.42	0.51	0.60	0.42	0.51	0.60	0.42	0.51	0.60	0.42	0.51	0.60
1″	35				×						×				×	
	55									×						
	75				×							×	×			
1/2″	35				×		×									
	55					×									×	×
	75									×						
1/4″	35			×			×						×			
	55						×						×			
	75							×					×			

(×) = 4 flexural specimens

( ) = 2 flexural specimens

Flexural test results

Figure 1 shows a typical load-deflection diagram. Using first degree regression analysis on the enlarged flexural load-deflection diagrams, the first crack loads, defined as the load level at which the curve deviates from linearity, were obtained for all beams. The first crack and ultimate loads were used in combination with the concrete section properties to evaluate the first crack and ultimate modulus of ruptures according to the general flexural formula:

$$\sigma = M \frac{C}{I} \qquad (1)$$

where

σ = First or ultimate modulus of rupture depending on the load level used, psi.

M = Applied moment in. lbs.
= (2 in.) × P for third-point loading on beams having a 12 in. clear span.

P = Applied load in lbs.

C = Half the beam height, in.

I = Concrete moment of Inertia, in.^{4}

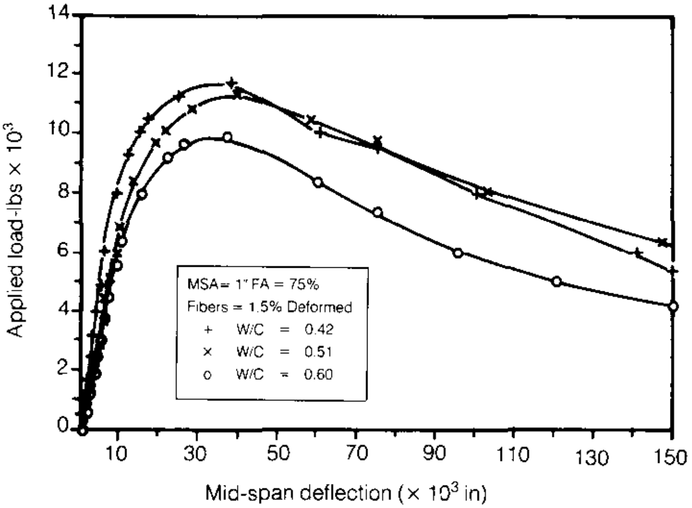

Fig. 1. **Load-deflection diagram**

Plain concrete

Table 2 summarizes the average flexural modulus of rupture for all plain concrete mixes. The modulus of rupture decreases as the amount of fine aggregate was increased in concrete mixes having a low water-cement ratio. Stronger concrete was produced when high water-cement ratio and high fine aggregate content were used. This was due to the fact that the concrete was easy to compact and had less air voids. Plain concrete flexural test results suggest that maximum aggregate size between 1/4″ to 1″ had little or no influence on modulus of rupture.

Steel fiber reinforced concrete

a) Tables 3-5 are summaries of the flexural tests results and relative gains obtained by adding 0.75% straight fibers (l/d = 63). Using these fibers for reinforcing plain concrete did not result in an appreciable increase in the first crack modulus of rupture. In addition, the ultimate strength was increased by an average of only 10 percent. Addition of this volume of fibers mainly gave the concrete some ductility after the first crack occurred.

b) The first crack strength and ultimate flexural strength results for concrete reinforced with 1.50% straight steel fibers (l/d = 63) are presented in Tables 3-5. For this fiber content, the first crack strength showed an average increase of 11 percent above that of plain concrete and the ultimate flexural modulus of rupture increased by up to 92 percent. Despite changing the maximum aggregate size in the mixes, the ultimate flexural strength was mainly influenced by water-cement ratio and fine aggregate content. High reduction in flexural strength was very apparent in cases where high water-cement ratio and low fine aggregate content were used. This was a result of non-uniform mix due to some aggregate and fiber settling which was aggravated by using vibratory compaction.

c) Tables 6, 7 and 5 give summaries of first crack and ultimate modulus of rupture values, and relative strength increase for concrete reinforced with 0.75% deformed steel fibers (l/d = 100). The inclusion of this type and percentage of fibers in concrete resulted in a moderate increase in first crack strength, an average of 8 percent. The increase in ultimate strength was similar to that obtained by using 1.50% straight steel fibers (l/d = 63). The ultimate flexural strengths were improved by an average of 44 percent with a maximum of 84 percent. The increase in first crack flexural strength in (a) and (b) compares well with those reported by Snyder and Lankard [11], ACI Committee 544 [12], Mangat [13], and Ward and Li [14].

d) Detailed tests results and a summary are given in Tables 6-7 for concrete reinforced with 1.50% deformed steel fibers. By adding 1.50% of deformed steel fiber (l/d = 100) to plain concrete mixes, two quite different results were obtained. On one hand, irrespective of aggregate maximum size and water-cement ratio, there was only a limited increase in both first crack and ultimate flexural strength of con-

Table 2. 28-day average flexural strength of plain concrete (σ_m), psi

		Flexural strength 4 × 4 × 14 water-cement ratio		
MSA	**%FA**	**0.42**	**0.51**	**0.60**
1.0″	35	1112	844	716
	55	1000	980	910
	75	961	958	924
1/2″	35	1106	878	936
	55	1099	1011	867
	75	927	947	917
1/4″	35	1125	913	499
	55	985	966	897
	75	988	897	932

Table 3. First crack flexural strength (σ_{mf}) for concrete reinforced with straight steel fibers (0.016 × 1″), psi

		Volume of fibers = 0.75% water-cement ratio			Volume of fibers = 1.50% water-cement ratio		
MSA	**%FA**	**0.42**	**0.51**	**0.60**	**0.42**	**0.51**	**0.60**
1.0″	35	896	946	812	960	1056	842
	55	1042	1056	946	1181	973	914
	75	1029	857	867	1308	1022	1020
1/2″	35	1165	731	831	1038	1088	771
	55	1199	1029	918	1088	1088	988
	75	1002	1053	917	1162	1061	935
1/4″	35	961	875	683	1029	990	717
	55	1117	949	794	1170	1199	975
	75	1168	1078	858	1211	1204	965

Table 4. **Ultimate flexural strength (σ_{cu}) for concrete reinforced with straight steel fibers (0.016 × 1″), psi**

		Volume of fibers = 0.75% water-cement ratio			Volume of fibers = 1.50% water-cement ratio		
MSA	%FA	0.42	0.51	0.60	0.42	0.51	0.60
1.0″	35	1044	974	850	1276	1266	970
	55	1065	1085	1020	1532	1320	1061
	75	1115	894	1104	1711	1410	1468
1/2″	35	1212	803	855	1259	1210	867
	55	1227	1075	965	1381	1345	1306
	75	1075	1066	946	1673	1304	1142
1/4″	35	1167	969	830	1311	1165	960
	55	1126	1006	875	1451	1389	1265
	75	1237	1096	864	1554	1385	1188

Table 5. **Summary of the average concrete strength improvements due to steel fiber addition**

	Ratio	Volume of fibers %	No. of spec.
Flexural strength σ_{mf}/σ_m	1.03	0.75% (straight)	124
	1.11	1.50% (straight)	116
	1.08	0.75% (deformed)	122
	1.20	1.50% (deformed)	116
Flexural strength σ_{cu}/σ_{mf}	1.07	0.75% (straight)	124
	1.26	1.50% (straight)	116
	1.33	0.75% (deformed)	122
	1.50	1.50% (deformed)	116
Flexural strength σ_{cu}/σ_m	1.10	0.75% (straight)	124
	1.41	1.50% (straight)	116
	1.44	0.75% (deformed)	122
	1.81	1.50% (deformed)	116

Table 6. First crack flexural strength (σ_{mf}) for concrete reinforced with deformed steel fibers (0.01 × 1″), psi

MSA	%FA	Volume of fibers = 0.75% water-cement ratio 0.42	0.51	0.60	Volume of fibers = 1.50% water-cement ratio 0.42	0.51	0.60
1.0″	35	1149	1002	860	826	709	771
	55	1110	999	821	1238	1044	976
	75	1208	997	974	1317	1289	1210
1/2″	35	1067	810	709	1132	900	743
	55	1186	1034	987	1382	1201	827
	75	1231	1143	960	1622	1113	1282
1/4″	35	875	1001	686	1636	1271	746
	55	1042	1114	902	1282	978	707
	75	1248	1023	962	1557	1297	1173

Table 7. Ultimate flexural strength (σ_{cu}) for concrete reinforced with deformed steel fibers (0.01 × 1″), psi

MSA	%FA	Volume of fibers = 0.75% Water-cement ratio 0.42	0.51	0.60	Volume of fibers = 1.50% Water-cement ratio 0.42	0.51	0.60
1.0″	35	1276	1182	926	1108	923	1092
	55	1599	1321	1113	2016	1674	1211
	75	1736	1303	1377	2236	2114	2087
1/2″	35	1615	1103	816	1530	1161	1042
	55	1750	1301	1269	2210	1534	1277
	75	1613	1590	1238	2543	1964	2079
1/4″	35	969	1379	922	2032	1598	1025
	55	1498	1346	1112	1922	1569	1237
	75	1817	1403	1601	2384	2206	1798

crete mixes having a low fine aggregate content. The main reasons for that were fiber balling and aggregate segregation and greater restriction on fiber orientation. On the other hand, a great improvement in both first crack and ultimate strengths were observed in mixes where medium and high fine aggregate content were used. The reduction in fiber influence on ultimate flexural strength by changing water-cement ratio from 0.42 to 0.51 was much less than the reduction encountered when the water-cement ratio increased to 60. This was probably due to fibers settling in the bottom of the mould at casting time and thus creating a non-uniform concrete mix. This settling effect produced higher apparent first crack flexural strengths due to the presence of larger number of fibers in the immediate vicinity of the crack; thus the contribution of fibers in improving the composite flexural strength after the first crack occurred were less than when low and medium water-cement ratios were used.

Analysis of flexural tests results

The flexural tests results were statistically analyzed based on the Law of mixtures approach. The general form of the formula used is:

$$\sigma_c = A\,\sigma_m\,(1 - V_f) + B\,V_f\,(l/d) \tag{2}$$

where

σ_c = Composite flexural strength, psi,
σ_m = Concrete matrix flexural strength, psi
V_f = Volume fraction of fibers in concrete,
l = Fiber length, in.,
d = Fiber diameter, in.,
A = constant which depends primarily on the concrete matrix properties, and
B = Constant which depends on the fibers distribution and efficiency in the mix and the bond strength between fibers and concrete mix.

Equation 2 is dependent only on the properties and volume fractions of composite. It is independent of the state of stresses to which the composite is subjected. Even if composite failure occurs by fiber pull-out, the concrete matrix contributes fully to the load carrying capacity of the composite [13].

Combined effect on first crack modulus of rupture. Figure 2 shows steel fiber reinforced concrete SFRC normalized first crack strength plotted against the normalized first crack of plain concrete. The following regression equation was established to predict the first crack modulus of SFRC from that of plain concrete:

$$\sigma_{mf} = 0.90\,\sigma_m\,(1-V_f) + 204\,V_f\,(l/d) \tag{3}$$

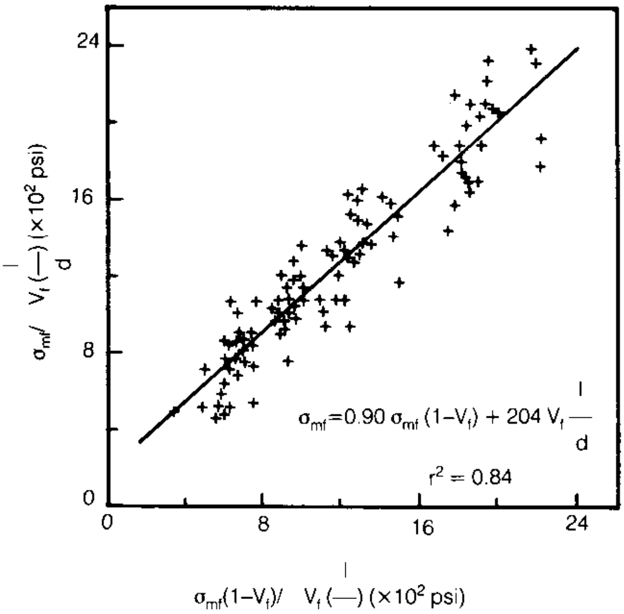

Fig. 2. SFRC normalized first crack strength vs. normalized modulus of rupture of plain concrete (all mixes)

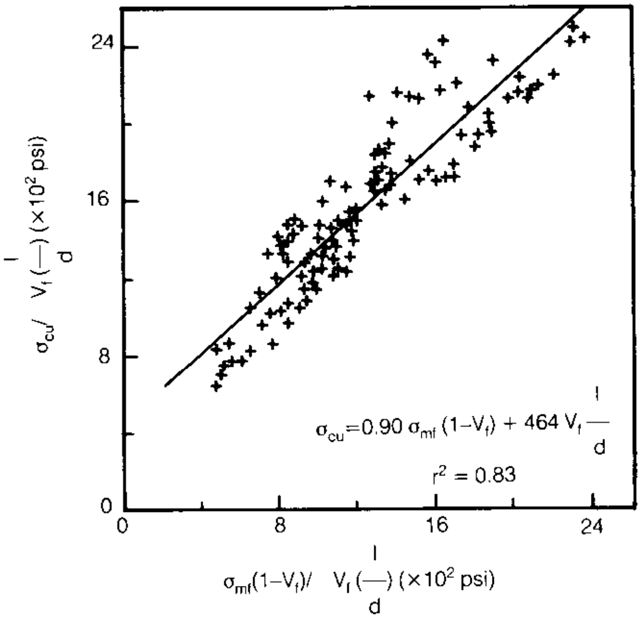

Fig. 3. Normalized ultimate flexural strength vs. normalized first crack strength for SFRC (all mixes)

where

σ_{mf} = First crack modulus of rupture of SFRC, psi
σ_m = First crack modulus of rupture for plain concrete, psi.

The rest of the terms are previously defined.

Equation 3 shows that adding steel fibers generally increased the first crack modulus of rupture. That improvement is expressed by the second term on the right hand side of the equation. The increase of first crack modulus of rupture depended on the amount of fibers in the area where the first crack initially started and their alignment.

Combined effect on ultimate flexure strength. Figure 3 shows the normalized SFRC ultimate flexural strength plotted against the normalized SFRC first crack modulus of rupture. Using regression analysis on SFRC first crack and ultimate strength, the following equation was produced:

$$\sigma_{cu} = 0.90\,\sigma_{mf}\,(1-V_f) + 464\,V_f\,(l/d) \tag{4}$$

where

σ_{cu} = Ultimate modulus of rupture of SFRC, psi and other terms as previously defined.

Comparing Eqs. 3 and 4, the fibers contribution to the composite is very clear. The last two terms in the right hand side of both equations represent the increase in strength properties resulting from the addition of steel fibers to plain concrete. Equation 2 represents a crack arrest-composite mechanism and can be used to predict both first crack strength and ultimate crack strength. The second term in Equations 3 and 4 represents the contribution of the average and the ultimate interfacial bond stresses at first crack strength and ultimate strength respectively. Lim and Paramasivam [15]. and Nammur and Naamann [16] reported that bond stress at ultimate differs from bond stress at first crack. Assuming linear bond stress distribution, the ultimate bond stress is twice the average bond stress. Bearing in mind the inherent variabilities in concrete properties and fiber orientation, the numerical values of the second term in Equations 3 and 4 (204 and 464) support the foregoing discussions.

Effects of maximum size aggregate on SFRC flexural strength properties. Three maximum aggregate sizes were used in this study: 1″, 1/2″, and 1/4″. Using tests results of both first crack and ultimate strength of SFRC for all the mixes having the same maximum size aggregate (MSA), Figs 4-6 were plotted. The regression equations are printed in those figures. Comparisons of those graphs and equations coefficients for all the three MSA, show that there are practically no differences in SFRC flexural strength properties resulting from using concrete mixes having MSA equal or less fiber length. This was expected since fine aggregate is the media in which the fibers can effectively improve the flexural ultimate strength and not the MSA provided that MSA does not exceed the fiber length. The fiber spacing concept presented by Romauldi and Mandel [2] assumes that fiber spacing is influenced by fiber diameter and fiber volume fraction in the mix. The introduction of large aggregate sizes obstruct the fiber distribution and fiber orientation in the concrete mix effecting fiber spacing. The actual fiber spacing in mortar differs from that of concrete containing coarse aggregates, yet they will be the same if fiber spacing concept is applied. The fiber spacing concept is purely a geometrical factor statistically obtained by considering the number of fibers crossing an arbitrary plane cross-section of the composite. If the spacing concept is valid then the strength of SFRC containing smaller aggregate size will be superior to those containing larger aggregate size. The presence of large aggregate size increases fiber spacing by obstructing their proper distribution and orientation and in turn reduces the flexural strength. This was not the case as can be seen from Figs 4-6. Soroushian and Lee [17] presented correlations of SFRC tensile strength with some measures of fiber spacing. The correlation coefficients ranged from 0.193 to 0.419 which is another proof of the unsuitability of fiber spacing concept to describe the strength of SFRC.

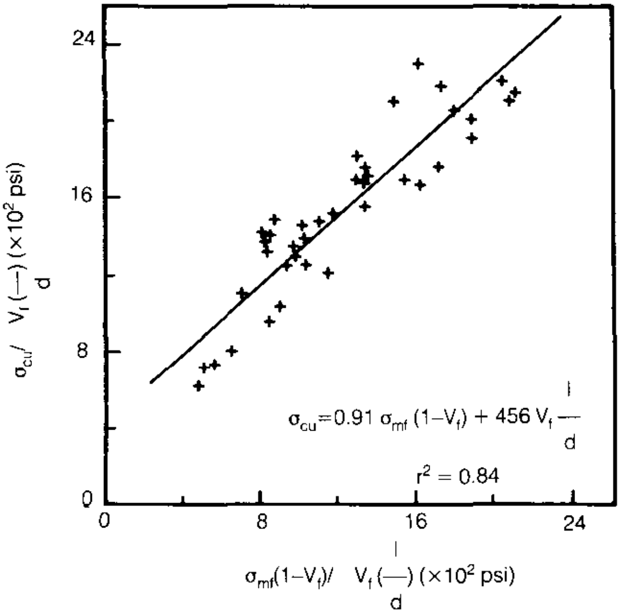

Fig. 4. **Normalized ultimate flexural strength vs. normalized first crack strength for SFRC (all SFRC with MSA = 1")**

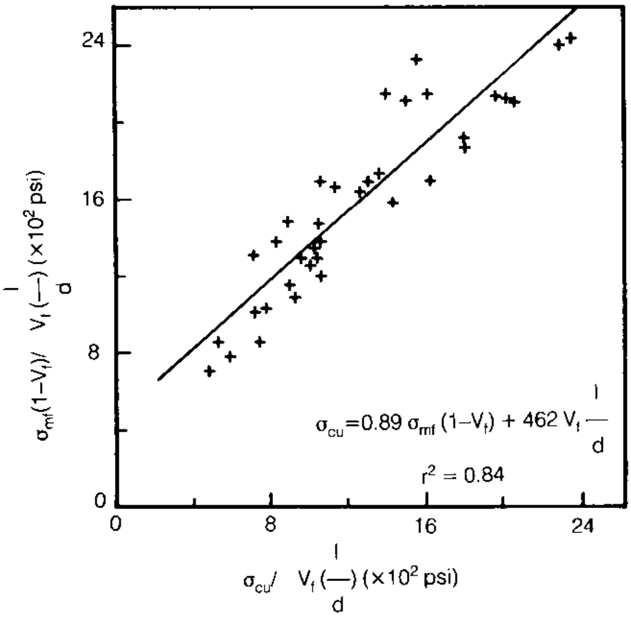

Fig. 5. **Normalized ultimate flexural strength vs. normalized first crack strength for SFRC (all SFRC with MSA = 1/2 ")**

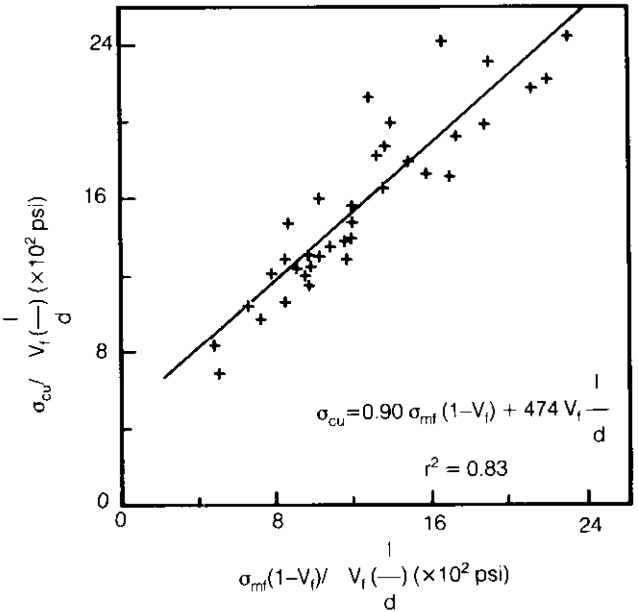

Fig. 6. **Normalized ultimate flexural strength vs. normalized first crack strength for SFRC (all SFRC with MSA = 1/4 ")**

Effect of water-cement ratio on SFRC flexural strength. Three different water-cement ratios: 0.42, 0.51, and 0.60 were used in preparing all concrete mixes for this study. The influence of the water-cement ratios on SFRC flexural strength properties is shown in Figs. 7-9. Also an example of the effect of water-cement ratios on flexural strength is given in Fig. 10. the curves in Fig. 10 show trends of the effect of water-cement ratio on flexure strength different from the trends normally observed for plain concrete. This new curve characteristic was not typical for all SFRC tested in the present study. The main reason for the higher reduction in the fiber influence on SFRC ultimate flexural strength at a high water-cement ratio was the fiber and aggregate settling in the bottom of the mould due to the high fluidity of the mix and thus making it more difficult to produce concrete mixes with uniform fiber and aggregate distributions. This settling effect results in higher apparent first crack load due to the presence of larger number of fibers in the area where the first crack was initiated and thus the contribution of the concrete matrix to the ultimate flexural strength was higher at high water-cement ratio.

Effect of fine aggregate content on SFRC flexural strength. Figure 11 shows an example of the effect of fine aggregate content on the ultimate flexural strength of plain and steel fiber reinforced concrete. Figure 12 shows an example of normalized ultimate flexural strength plotted against the normalized first crack flexural strength. Higher fine aggregate content in the mix results in higher ultimate flexural strength. The fine aggregate is the media in which fibers can orient themselves. The amount of fine aggregate needed for proper orientation depends primarily on the fiber concentration by volume in concrete. Higher concentration of fiber requires higher fine aggregate content for proper workability and strength.

Effects of fiber type and content on SFRC flexural strength. Figure 13 shows that the increase in ultimate flexural strength of SFRC is approximately directly proportional to the fiber concentration expressed as a percentage by volume of the total concrete. The average increase in SFRC ultimate flexural due to the addition of 0.75% and 1.50% straight steel fibers (l/d = 63) were 11 percent and 41 percent, respectively. The effect of deformed steel fibers on ultimate flexural strength of SFRC averaged 44 percent and 81 percent for fiber concentration of 0.75% and 1.50%.

The concretes made with medium fine aggregate content (55%) were the most workable mixes except when the 1.50% deformed fibers were added. Except for concrete made with a high content of deformed fibers (1.50%; l/d = 100) and low fine aggregate content, workability was improved by increasing the water-content ratio.

Conclusions

Equations were established to predict both the first crack and ultimate flexural strength of steel fiber reinforced concrete. The influence of aggregate maximum size,

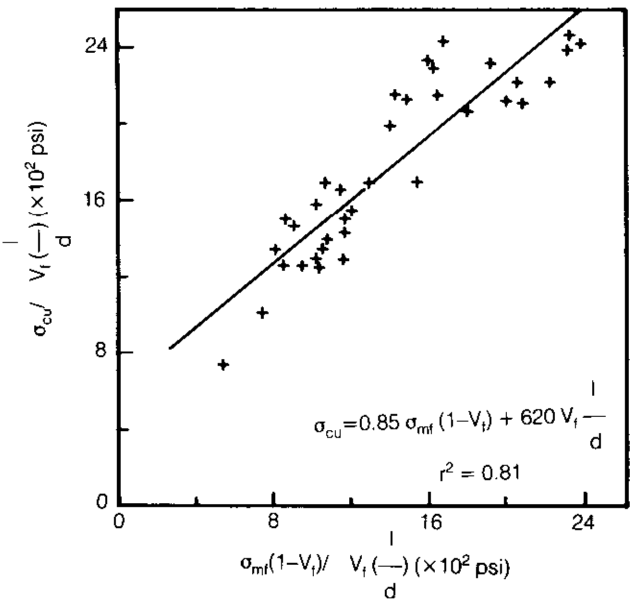

Fig. 7. Normalized ultimate flexural strength vs. normalized first crack strength for SFRC (all SFRC with w/c = 0.42)

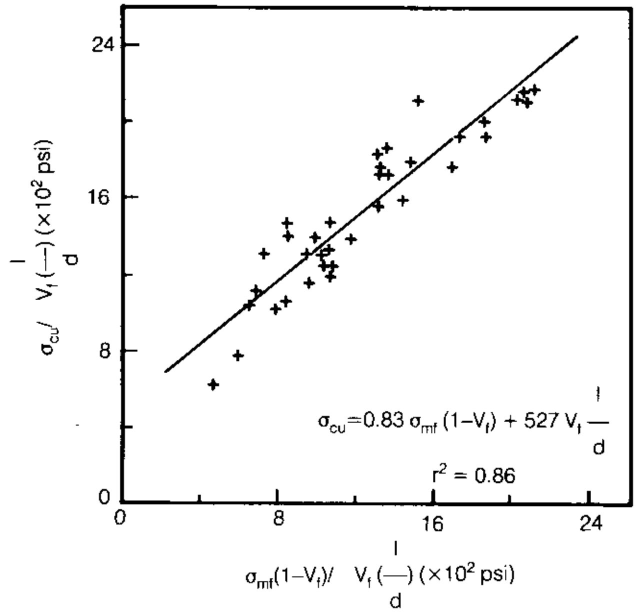

Fig. 8. Normalized ultimate flexural strength vs. normalized first crack strength for SFRC (all SFRC with w/c = 0.51)

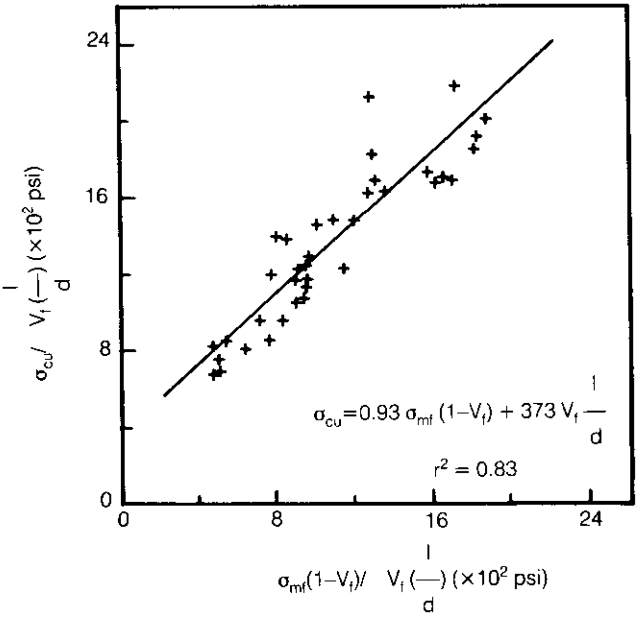

Fig. 9. Normalized ultimate flexural strength vs. normalized first crack strength for SFRC (all SFRC with w/c = 0.60)

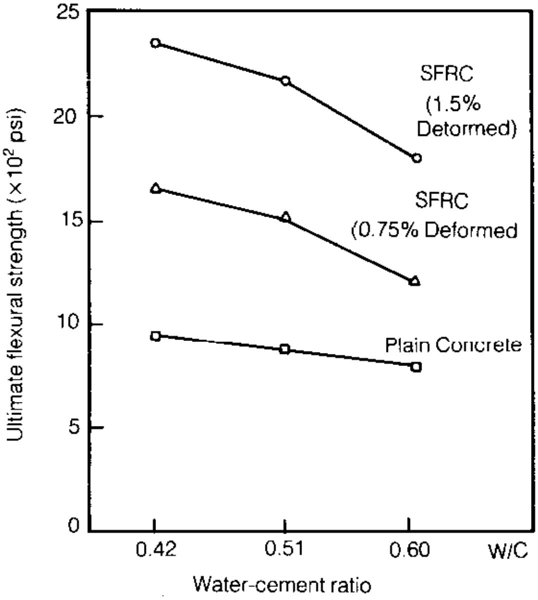

Fig. 10. Ultimate flexural strength vs. water-cement ratio

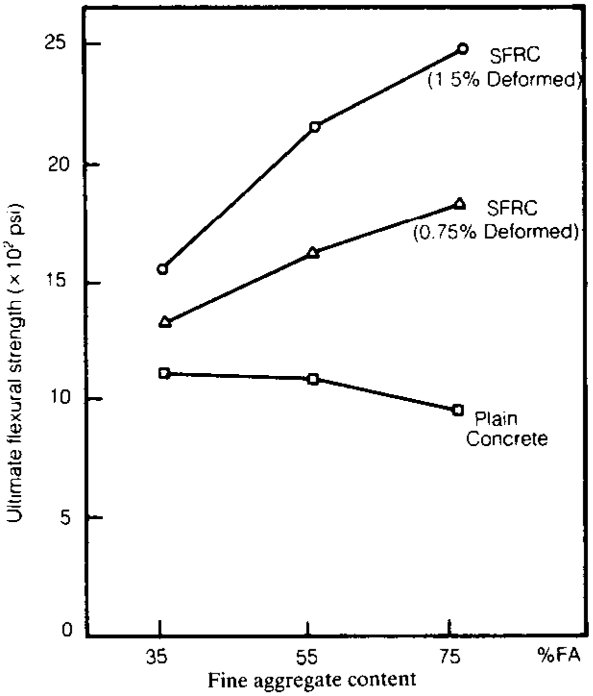

Fig. 11. Ultimate flexural strength vs. fine aggregate content

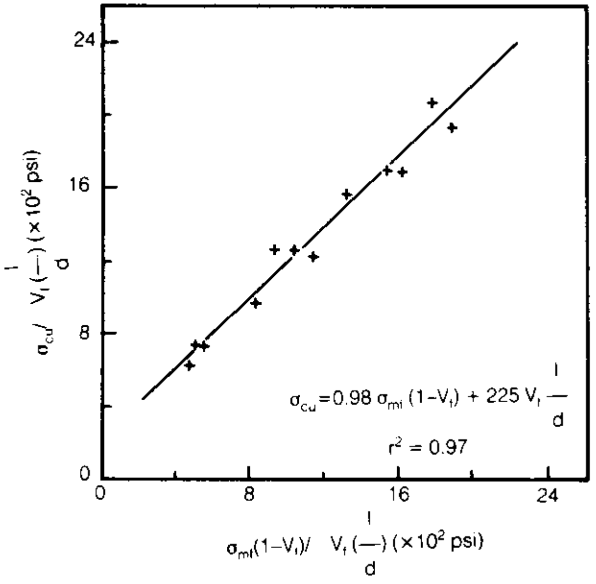

Fig. 12. Normalized ultimate flexural strength vs. normalized first crack strength for SFRC (MSA = 1″ FA = 35% Fibers = All)

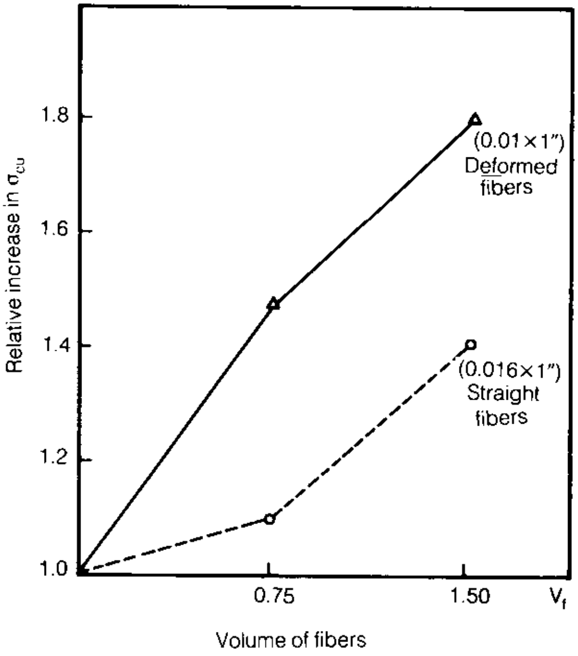

Fig. 13. **The average increase in ultimate flexural strength due to the addition of fibers**

water-cement ratio, percentage fine aggregate, and fiber type and concentration on ultimate flexural strength were determined. From the results obtained in this study the following conclusions can be made:

1. First crack and ultimate flexural strength of SFRC can be predicted by using the equation obtained based on Law of Mixtures approach.
2. The result of this study showed that the fiber spacing concept does not satisfactorily explain the strengthening mechanism of randomly oriented short steel fiber reinforced concrete.
3. SFRC can be made with an aggregate maximum size equal to or less than the fiber length with practically no impact on the ultimate flexural strength (1/4″ to 1″ range used).
4. The contribution of fibers to the ultimate flexural strength was the greatest when low or medium water-cement ratio was used.

5. The first crack flexural load defined as the load level at which load deflection diagram deviated from linearity, can be misleading in two cases:

    a) When a high content of steel fibers was used, a large number of fibers were present in the area where the first crack initially started. The presence of those fibers caused the crack to extend very slowly and thus forced the load-deflection diagram to maintain linearity beyond the actual first cracking load.

    b) When a high water-cement ratio was used, coupled with vibration compaction, the steel fibers and coarse aggregates settled into the bottom half of the mould, causing a large number of fibers to be present in the area where the first crack started. The presence of those fibers influenced the linearity of the load-deflection diagram, as explained in 5(a) above.

6. The fine aggregate content needed in the mix depended primarily on the type and amount of fibers added. A high volume of fibers having a high aspect ratio (l/d = 100) needed the use of a high percentage of fine aggregate. A low volume of straight fibers (l/d = 63) needed low fine aggregate content.

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تأثير مكوِّنات الخرسانة العادية على خواص الخرسانة المسلَّحة بالألياف المعدنية

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ملخص البحث. الأهداف الرئيسة لهذه الدراسة هي معرفة تأثير مكوّنات الخرسانة العادية على خواص الخرسانة المسلَّحة بالألياف المعدنية. لقد أوضحت الدراسة أن إجهاد العزم الأقصى الناتج لا يتأثر بمقاس الركام المستخدم كما أن كمية الرمل المستخدم تعتمد على النسبة الحجمية المستخدمة من الألياف المعدنية ونوع الألياف. كما أثبتت النتائج أن استخدام نسب متوسطة وعالية من الرمل تؤدي إلى تحسين تشغيل الخرسانة وقوتها. لقد تم تسجيل أعلى قيمة لإجهاد العزم عند تقليل نسبة مياه الخلط واستخدامها بنسب قليلة إلى متوسطة (٠,٤٢ إلى ٠,٥١). وأوضحت الدراسة أن إجهاد العزم الأقصى يتناسب طرديًا تقريبًا مع نسبة تركيز الألياف المعدنية في الخرسانة.