Strength Of Fiber Reinforced High-Strength Concrete With Stirrups Under Direct Shear

S.A.Saeed
Technical Institute
Dohuk

S.R.Sarhat
College of Eng.
University of Dohuk

ABSTRACT

The paper presents an experimental investigation of the direct shear transfer behavior of fiber reinforced high-strength concrete.

The experimental study was performed on steel fiber reinforced pushoff specimens with or without conventional stirrups.

For the specimens with plain steel fibers, significant increases in the shear strength of high-strength concrete were observed. In the tests involving the combination of steel fibers and conventional stirrups, major improvement in crack control and enhancement in shear strength were observed.

INTRODUCTION

Contrete having compressive cylinder strength, $f'c$, exceeding 6000 psi (41.4 MPa) is designated as high-strength concrete [1] .

High-strength concrete is known to manifest a more brittle behavior than normal-strength concrete. When shear stresses are involved, low shear strength behavior may be observed for concrete with high compressive strength [2].

Fibers have been used to reinforce brittle materials since ancient times. The first major attempt of evaluating the potential of steel fibers as a reinforcement for concrete was the investigation by Romualdi and Batson [3] in the United States in the early 1960s. Since then, a substantial amount of research, development, experimentation and applications of steel-fiber reinforced concrete have been occurred and are still taking place all over the world [4].

The use of steel fibers to improve the shear behavior of concrete is promising . Several tests have been reported on the direct shear behavior of fiber reinforced concrete using pushoff specimens [5,6]. Tan and Mansur [7] studied the interaction of steel fibers and stirrups in the shear transfer of (FRC) pushoff specimens with initially uncracked shear plane.

From the review of these reported tests it can be stated that the addition of fibers generally improves the shear strength and ductility of concrete. It has been reported that stirrups as shear reinforcement in concrete would be partially or totally replaced by the use of steel fibers[8-10]. Valle and Buyukozturk [2] studied the behavior of fiber reinforced high-strength concrete under direct shear and they concluded that steel fibers are more effective in high-strength concrete than in normal strength concrete and led to considerable increasing in both ultimate load and overall ductility. They also gave a shear transfer model for predicting the shear stress-shear strain behavior of the plain fiber reinforced concrete.

The reported tests on FRC involving high-strength concrete generally address the effects of limited parameters especially the interaction between fiber and stirrups. The main objective of this paper is to provide and experimental investigation of the direct shear transfer behavior of fiber reinforced high-strength concrete with conventional stirrups. The work has much in common with that of Ref.[2] and may be considered an extension to that work.

TEST PROGRAM

The experimental investigation was carried out through testing of initially uncracked pushoff specimens shown in Fig.(1). The specimens had dimensions of 21*10*3 in. (533*254*76 mm), with a shear plane area of 30 in^2 (19354 mm^2). These dimensions were determined on the basis established through previous researches [2,11].

The parameters of the investigation were :

1-Volume fraction of steel fibers (V_f) .

2-Shear reinforcement ratio ($_s$) .

By combining these variables, nine specimens were cast to examine the combined effect of steel fibers and conventional stirrups on the direct shear transfer behavior of high-strength concrete . Details of the tested specimens are listed in Table(1). In this table, each specimen is denoted by letter (F) for steel fibers or (S) for conventional stirrups or (SF) for both reinforcement.

The mix proportions chosen by weight were 1:1.7:2 , 0.35 (cement:sand:gravel , w/c ratio)with addition of 1% of high water-reducer superplasticizer millamin-10 to obtain high-strength concrete .The mix was designed to produce concrete of 50-60 MPa compressive strength. Plain steel fibers with a length of 20mm and diameter of 0.2 mm (aspect ratio-100) were used.

The steel reinforcement configuration is shown in Fig.(1). The vertical (longitudinal)reinforcement consisted of mild steel deformed bars (Ø12mm) with a yield strength of 414 MPa. These bars were included in all pushoff specimens to eliminate any possible failure modes other than that along the shear plane. For the specimens with stirrups, Ø10mm deformed bars with yield strength of 413 MPa were placed in hoops crossing the shear plane. Three 150*300 mm control cylinders were casted with each specimen to determine the compressive strength.

TEST RESULTS AND DISCUSSION

Shear Strength :

The results obtained from the tests are summarized in Table(1). Both the compressive strength and the maximum shear stress $_{max}$ are given for each specimen tested. The shear stress was obtained by dividing the applied load by the area of shear plain. In the specimens reinforced with steel fibers only, the addition of 0.4% and 0.8% steel fibers caused an increase in the shear strength by about 35% and 50% respectively, as shown in Fig.2 .This is attributed to the improved bond characteristics between the fibers and the matrix with the high-strength mixes. In specimens with conventional stirrups only, the presence of 1.4% and 2.6% stirrups led to an increase in the shear strength by about 35.5% and 42.2% respectively as shown in Fig.3 .

The combination of steel fibers with stirrups caused increases in the shear strength up to about 92.8% over (P) specimens. It is clear from Table(1) that the combination of steel fibers with stirrups was effective in increasing the shear strength of specimens PSF11 (V_f =0.4% , $_s$=1.47%) . However increasing V_f in PSF12 specimen to 0.8% or $_s$ in PSF21 to 2.6% caused reduction in this effectiveness. This may be attributed to difficulty of obtaining a through mix.

It is also seen from Table(1), that the algebric sum of the contributions of steel fibers and stirrups (when considered separately in the enhancement of the shear strength) not equal to the contribution of both of them when considered altogether. This result agree closely with that reported by Sarhat[12] and Al-Jaf[13] for normal fibrous concrete.

Fig(4) shows that the relation between ultimate shear load and the volume fraction of steel fibers or shear reinforcement ratio is nonliner.

Crack Patterns and Modes of Failure:

The observed failure mode of concrete specimens without fiber or steel stirrup reinforcement(P specimens) was very brittle, with no warning before collapse. These specimens lost their integrity, breaking into several pieces. Specimens PF1 and PF2 which are reinforced with fibers alone developed several small diagonal cracks. With these specimens, ultimate failure occurred when these series of diagonal cracks joined together, forming a crack band along the shear plane.

For specimens involving steel stirrups crossing the shear plane(PS1 and PS2), discrete diagonal cracks were formed and extended at 50 to 75 deg. with respect to the horizontal direction, creating well-defined compressive struts in the concrete. In combination of these struts with the tensile force carried by stirrups, formed a truss-like action. Ultimate failure occurred when the concrete struts crushed in compression.

Specimens PSF11, PSF12, PSF21 and PSF22 which are reinforced with steel fibers and stirrups showed more ductile behavior. In these specimens small discrete cracks were formed and the extension and propagation of these cracks was very slow. This means that the combination of steel fibers with stirrups led to better controlling of cracks.

CONCLUSIONS

In view of the results obtained in this investigation, the following points have been concluded:

1-The addition of steel fibers alone led to considerable increase in the ultimate shear strength of high-strength concrete(35% and46.6% enhancements for 0.4% and 0.8% volume fraction of steel fibers respectively).

2-The usage of steel stirrups alone led to an increase in the ultimate shear strength of high-strength concrete(35.5% and 42.2% by using shear reinforcement ratio 1.47% and 2.6% respectively).

3-Greater shear strength increase were found with combination of steel fibers with stirrups. About 92.8% increase was obtained by using 0.4% steel fibers with 1.47%stirrups. This combination proved to increase significantly the overall ductility.

4-The algebric sum of the contributions of steel fibers and stirrups(when considered separately) in the shear strength enhancement differ from that of both effects altogether, and the relation between the ultimate shear strength and the amount of fibers or stirrups is non linear.

List of symbols

$f'c$	Compressive cylinder strength.
V_f	Volume fraction of steel fibers.
FRC	Fiber reinforced concrete.
FRHSC	Fiber reinforced high-strength concrete.
P	Specimens without steel fibers and stirrups.
PF	Specimens reinforced with steel fibers.
PS	Specimens reinforced with steel stirrups.
PSF	Specimens reinforced with steel fibers and stirrups.
ρ_s	Shear reinforcement ratio.
λ	Shear stress.

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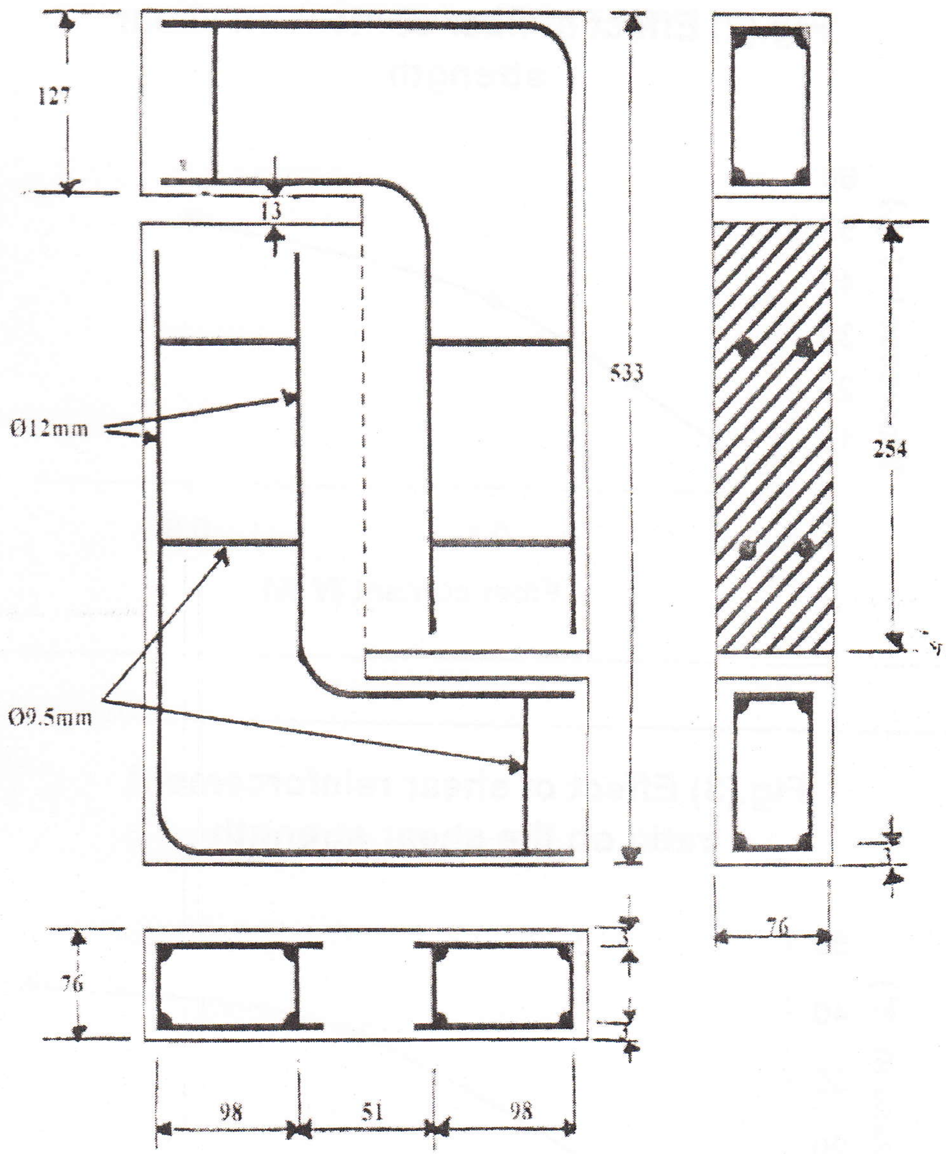


Fig. (1) Geometry and steel reinforced for pushoff specimen.

Fig.(2) Effect of fiber content on shear strength

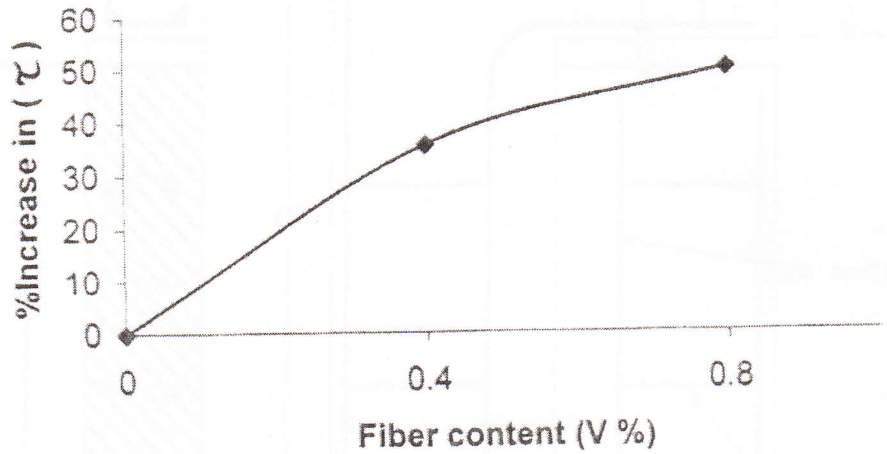


Fig.(3) Effect of shear reinforcement ratio on the shear strength

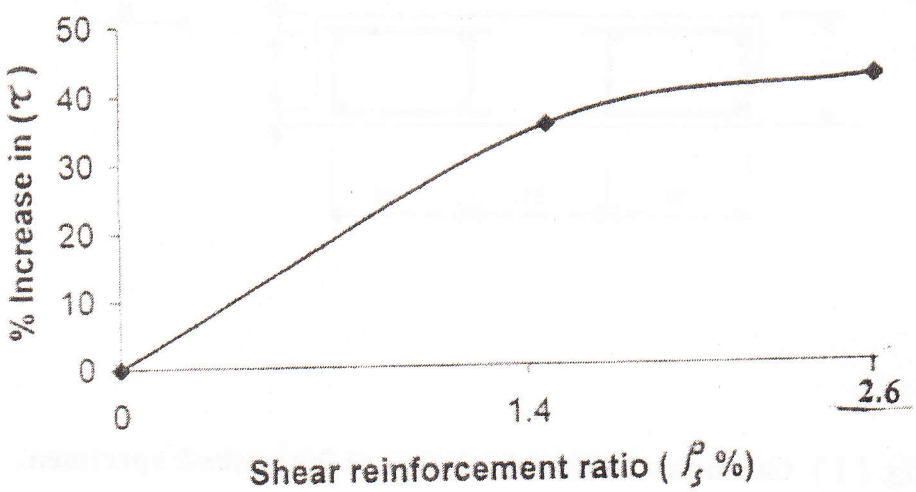


Fig.(4) Relationship between ultimate shear load and volume of fraction of steel fibers

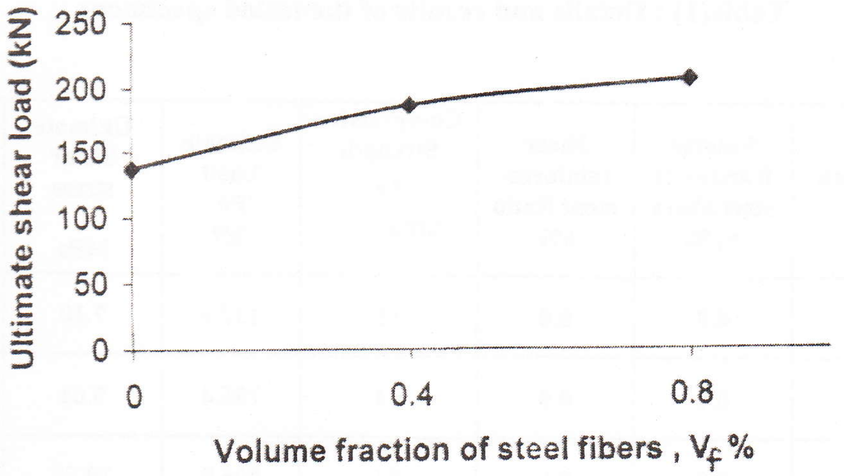
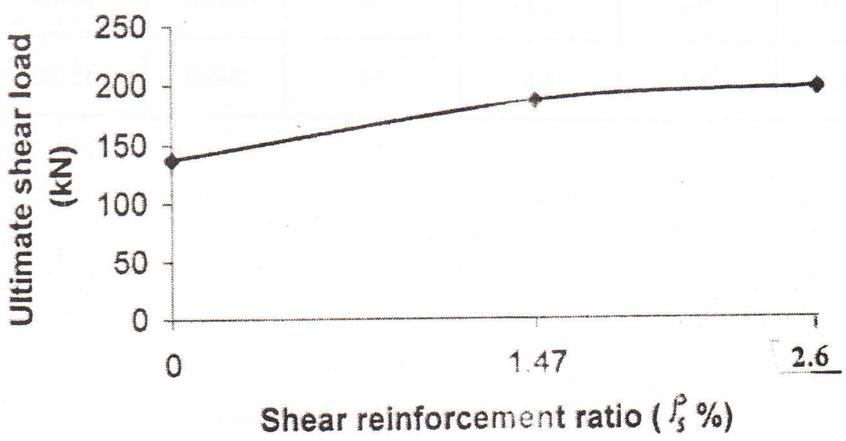


Fig.(5) relationship between ultimate shear load and shear reinforcement ratio



Table(1) : Details and results of the tested specimens

No.	Specimen type	Volume fraction of steel fibers V_f %	Shear reinforce-ment Ratio s%	Compressive Strength f c MPa	Ultimate Load Pu kN	Ultimate Shear stress MPa	Increase in over P Specimen %
1	p	0.0	0.0	51	137.4	7.10	……..
2	PF1	0.4	0.0	54	186.4	9.61	35.6
3	PF2	0.8	0.0	57	206.0	10.65	50
4	PS1	0.0	1.47	52	186.0	9.64	35.5
5	PS2	0.0	2.6	53	196.2	10.10	42.2
6	PSF11	0.4	1.47	55	264.8	13.68	92.8
7	PSF12	0.8	1.47	57	235.5	12.16	71.3
8	PSF21	0.4	2.6	55	255.0	13.18	85.6
9	PSF22	0.8	2.6	59	235.0	12.10	71.1

مقاومة الخرسانة عالية المقاومة المعززة بالألياف الفولاذية والأطواق تحت تأثير القص المباشر

صلاح رفعت سرحت
كلية الهندسة
جامعة دهوك

سركوت عبدالرحمن
المعهد الفني / دهوك

الخلاصة

يقدم هذا البحث دراسة عملية لمعرفة مقاومة خرسانة عالية المقاومة و المعززة بالألياف الفولاذية تحت اجهادات القص المباشر. تم فحص نماذج تحت اجهادات القص المباشر للتحري عن فاعلية الألياف الفولاذية لوحدها أو بالترافق مع الأطواق كتسليح قصي لخرسانة عالية المقاومة.

أظهرت الدراسة بان استخدام الألياف أدى إلى الزيادة في مقاومة القص لهذا النوع من الخرسانة. كما تبين من الفحوصات بان استخدام الألياف بالترافق مع الأطواق أدى إلى سيطرة اكبر على التشققات و إلى زيادة واضحة في مقاومة القص لخرسانة عالية المقاومة. و أخيرا تبين بان مساهمة كل من الألياف الفولاذية والأطواق في مقاومة القص لا يمكن جمعها جبريا.

بەرگری کۆنکریتی بەهێز بە ئاسنی پشتینەیی و وردە لەژێر باری برینی یەکسەریدا

صلاح رفعت سرحت
کۆلیجی ئەندازیاری
زانکۆی دهۆك

سەرکەوت عبدالرحمن
پەیمانگای تەکنیکی / دهۆك

کورتە

ئەم لیکولینەوەیە تایبەتمەندی پراکتیکی هەیە بو زانینی رەوشتی کونکریتی زور بەهیز کە بە ریشالی ئاسنین بەهیز کراوە لە ژیر پالەپەستوی برینی یەکسەر.

لەم لیکولینەوەیدا نموونە تاقی کراونەتەوە بو ئەوەی رولی ریشالی ئاسنین چ بەتەنها و چ لەگەل قەفیسی ئاسنین بزانین بو بەرگری برینی یەکسەر لە کونکریت دا . ئەم لیکولینەوەیە دەری خست کە بە کارهینانی ریشالی ئاسنین دەبیتە هوی زیادکردنی بەرگری برین لە کونکریتدا بە ریژەیەکی باش هەر وەها بە کار هینانی ریشالی ئاسنینی لە گەل قەفیسدا دەبیتە هوی کەم کردنەوەی درزو وزیادکردنی بەرگری برین . لە کوتاییدا تاقی کردنەوەکان بەروونی ئاشکرایان کرد کە ناتوانین رولی ریشالی ئاسنین و قەفیس بە جیاجیا وەك کردەیەکی ماتماتیکی کوبکەینەوە .