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Experimental Investigation of Static Behavior of Fibrous Concrete Simply Supported Deep Beams under Patch Loading

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Abstract

This paper investigates the effect of steel and polypropylene fibers on static behavior of simply supported deep beams of normal concrete strength under patch loading. Also the paper studied the effect of web opening and its positions on shear capacity and mode of failures for steel fiber concrete deep beams under the same conditions of loading and strength.

Sixteen beams of (1000*300*100mm), eighteen cubes (150*150*150mm) and thirty cylinders (150*300mm) in dimensions were cast with different fiber volume content (0, 0.4, 0.64 and 0.89%) as additives. Shear capacity, mode of failure and three of mechanical strengths were tested.

After testing, the results indicate that shear capacity increases with increasing volume of steel fiber content with change on mode of failure while midspan displacement decreases.
Key words: Deep beams; Steel fiber; Shear capacity; Displacement

دراسة الخواص الاستاتيكية للعتبات العميقة والمعززة بالألياف عند تعرضها الى حمل مركز لمساحة معينة

الخلاصـــة

يهدف هذا البحث إلى دراسة تأثير نسبة الألياف الفولاذية والبولي بروبولين لخرسانة ذات مقاومة اعتيادية وللعتبات العميقة عند تعرضها إلى حمل مركز ولمساحة معينة.

تم صب وفحص ستة عشر نموذجا من الجسور العميقة (1000*300* 100 ملم) وبدون اطواق تقوية. اثنا عشرة منها باستخدام الياف حديدية بمحتوى حجمي (0,0.4,0.64 &0.89%) ضمنها اربعة تم عمل فتحات فيها في منطقة الوسط (اثنان) وفي منطقة القص (اثنان) لمحتوى حجمي واحد من الالياف 0.64% للتعرف على سلوك القص واربعة باستخدام الياف من البولي بروبولين وبمحتوى حجمي(0.4 & 0.89%) لغرض المقارنة في سلوك القص بالإضافة إلى ثمانية عشر نموذجا من المكعبات القياسية (150*150*150 ملم) و ثلاثون نموذج اسطواني الشكل (150*300ملم) لفحص مقاومة الانضغاط والشد ومعامل المرونة للخرسانة . أظهرت النتائج أن زيادة المحتوى للألياف الفولاذية أدى إلى تغيير نمط الفشل من قص في المحتوى (0,0.4,0.64%) إلى قص مع انحناء في المحتوى 0.89% في حين ان وجود الفتحات ادى الى قلة في تحمل القص خاصة عندما تكون الفتحة داخل منطقة القص كذلك بينت النتائج ان استخدام الياف البولي بروبولين بمحتوى حجمي كبير يؤدي الى تقليل المقاومة بصورة عامة لذلك يفضل استخدامها في النسب الحجمية القليلة ولتحسين مقاومة الصدم والانكماش اللدن للخرسانة .

الكلمات الدالـــة :- الجسور العميقة ; الالياف الفولاذية ; تحمل القص ; الانحراف

Introduction

Beams with clear spans less or equal to 4 times the total member depth or with concentrated loads placed within twice the member depth of a support are classified as deep beams, according to ACI code 11.7 and 11.8 [1] . Deep beams are usually loaded along the top edge, as in Fig. (1-a) with reactions provide at the bottom. However, in some cases, as the side walls of storage bins, the loads may be applied along the bottom edges, as in Fig.(1-b). Loads may be applied more or less uniformity throughout the depth, as in Fig.(1-c), by other deep beam members framing in at right angles and reactions may also be distributed throughout the depth [2] . The behavior of reinforced concrete deep beams is influenced by many factors, such as clear span/ depth ratio, shear span / depth ratio, type of loading, position of the load, amount and type of web reinforcement, concrete strength, inclusion of other materials, such as type and percentage of fiber reinforcement, etc.

Steel – fiber reinforced concrete (SFRC) provides additional strength in flexure, fatigue, impact and spalling. The use of steel fibers leads to smaller concrete sections, improvement in surface quality and reduction in maintenance. The main applications of SFRC are in highways and air field pavements, hydraulic structures, etc. [3].

Yoon- kium kwek etal , [4] studied the shear strength of steel fiber- reinforced concrete beams without stirrups. The experimental program consisted of testing twelve reinforced concrete beams of identical cross sectional dimensions (125*250mm) and flexural reinforcement (two D16 bars) with three steel fiber volume fractions (0, 0.5% and 0.75%) and three shear span –depth ratio (2,3 and 4)and two concrete compressive strengths(31 and 65 MPa). The results demonstrated that nominal stress at shear cracking and ultimate shear strength increased with increasing fiber volume, decreasing shear span- depth ratio, and increasing concrete compressive strength. As the fiber content increased, the failure mode changed from shear to flexure.

J.A.Saeed [5] studied the strength and behavior of fibrous reinforced concrete continuous deep beams with particular reference to shear strength. The experimental program consisted of testing 24 two-spans deep beams with three different fiber volume fractions of 0.25, 0.5 and 0.75% with variable shear span to depth ratios varied between (1.25 - 1.67). Results indicate that ,(i)- the increasing of fiber volume fraction content from 0.00 to 0.75% affected the concrete compressive strength, tensile strength and modulus of rupture (ii)-Due to the inclusion of steel fibers , the deflection of all the tested beam were decreased for about 15% to 16% in the linear elastic range and about 17% to 19% near failure and (iii)- The first observed flexure and shear cracking load increased with increasing the fiber volume fraction from 0.00 to 0.75% in different percentage.

R. H. Shab and S.V. Mishro[6] investigated the effect of inclusion of steel fibers in concrete on crack and deformation characteristics of deep beams for various spans to depth ratio. Twelve beams, simply supported under single point loading were cast and tested under gradually increasing load at their centers. The results indicate that, the primary cause of failure was in the form of splitting of the beam along the diagonal cracks extending for depth/3 towards the loading points and the inclusion of steel fibers significantly reduces the cracking and deformation behavior of plain concrete deep beams by resisting tensile stresses.

Lim and OH [7] studied the experimental and theoretical investigation on the shear of steel fiber reinforced concrete . They tested nine beams to investigate the influence of fiber reinforcement on the mechanical behavior of reinforced concrete beams in shear. The major test variables were the volume fraction of steel fibers and the ratio of stirrups to the required shear reinforcement .Their test results showed that the first crack shear strength increased as the fiber content increased and the improvement in ultimate shear strength was also achieved. Their study was also indicating that fiber reinforcement can reduce the amount shear stirrups required and that the combination of fibers and stirrups may meet strength and ductility requirements.

A. R. Yoysif [8] investigated the structural behavior of reinforced concrete continuous deep beams with web openings. The experimental program consisted of twenty four fibrous and nonfibrous continuous deep beams, which the slenderness, the amount of steel fibers and location of the web openings were varied. The tested beams were two-span deep beams which were loaded at midspan. The results indicated that the presence of web opening within exterior or interior shear spans had great effects on the beam capacity and its behavior, which the diagonal cracking between loads and supports being dominant, also the results indicated that crack patterns were less effected by the addition of steel fibers, however an increase in the ultimate load capacity was obtained. The amount of increase in the ultimate load was about 10% in solid beams and beams having openings within midspan region.

M. V. Krishna, etal., [9] studied the flexure and shear behavior of polypropylene fiber reinforced fly ash concret. Deep beams of size (100*300*750) mm in dimensions and (100*300*800)mm in dimensions for flexure and shear modes of failure, respectively, were cast in a standard rectangular mould and water cured for 28 days with three percentage of polypropylene fibers (0, 0.5 and 1.0%) by weight of cement were considered. The results indicated that with the increase of fiber content to 0.5% and 1.0%, the ultimate shear force increased by 16.67 % and 22.22 % for beams of 20 MPa characteristic strength concrete in comparison to the values of normal concrete , also the results showed that the load – deflection curved almost linear up to the first crack and becoming non-linear beyond that . An increase in ultimate deflection was noticed in reinforced concrete beams containing polypropylene fiber when compared against plain concrete beams which is an indicative of the post – cracking ductility imported also.

This research study the static behavior of normal strength (shear strength capacity especially) on models of deep beams supported at two ends and subjected to patch loading (20 cm) as a constant distance beyond the vertical center line of beams with variable volume fractions of steel and polypropylene fibers, also the research study the effect of the position of web opening on the shear capacity and on the mode of failure of deep beams.

Experimental Work

A total of 16 beams specimens (1000* 300*100mm) (length* depth* width),30 cylindrical specimens (150* 300mm) and 18 control cubes (150*150*150mm) in dimensions were caste and tested after 28 days of water curing, as shown in Table (1).

Materials

Ordinary Portland cement and crushed river aggregates were used. Sand of fineness modulus of 3.4 and crushed gravel of maximum size of 19mm as coarse aggregate were used. The concrete mix proportion was 1:1:2 by weight with water cement ratio of 0.5 kept constant for all specimens which designed according to ACI method for specified minimum strength (fcu =32MPa). Two types of fibers used, steel fiber (SF) and polypropylene fiber (PPF). Steel fibers (SF) of plain rectangular with aspect ratio equal to 36 with yield strength of 420 MPa were used in cast deep beams and also for beams with opening. One size of square opening 100*100mm was investigated and one parameter considered which the position of the web opening was. Polypropylene fibers (PPF) with 12mm length and 18 µmm diameter were used. Longitudinal reinforcement consist of two bars of φ 12mm of 378 MPa yield strength were used at the bottom of beams .The specimens were cast taking special care to ensure uniform distribution of fibers and to prevent them from balling up by mixing the fine material (cement & sand) first, then the fiber, after that the coarse aggregate and then the mixing water was added in two stages, the first 50% will add to ensure a good arrangement of fibers then the second 50% of water will be added. Placing and vibrating of concrete was implemented externally which contain steel fiber of 0, 0.4, 0.64 and 0.89% of volume of concrete were carried.

Testing Procedure

a- Beam Specimens:- The beams were tested under uniform increase of loading at the top (20 cm) beyond the vertical center line of testing beams. Fig.(2) showed the specimen details.

A compression machine (2000 kN capacity) used for the tests. A dial gauge of (0.002mm) in accuracy was fixed at the lower part of base plate form to measure the mid-span displacements at every stage of loading. An open box of (20*10*2 cm) interior dimension was used by filling it with medium sand (one size) to ensure symmetric uniform loading through the patch area.

b- Control Specimens:-

(b-1)- Compressive Strength (fcu):- Eighteen cubes (150*150*150mm) in dimensions were tested using hydraulic compression machine with maximum capacity 2000 kN .

(b-2)- Splitting Tensile Strength (fsp):- Eighteen cylindrical specimens (150* 300mm) in dimensions were tested.

(b-3)- Modulus of Elasticity (Ec):- Twelve cylindrical specimens (150* 300mm) in dimensions were tested to determine the modulus of elasticity using electrical cells and the strain was measured by using strain indicator P-3500 (half bridge).

Results and Discussion

Table (2) shows an increase in compressive strength with an increase of steel fiber content. The increasing ratio of compressive strength for the steel fiberous to that of non fiberous concrete varied from 4.4% to 11.1% with increasing steel fiber content from nil to 0.89%, while for splitting tensile strength, the table shows an increase in strength with increase in steel fiber content. The increasing of splitting tensile strength for the steel fiberous to that of non- fiberous concrete varied from 15.4% to 26% with increasing steel fiber content from nil to 0.89% and for modulus of elasticity, the table shows also an increase of modulus of elasticity with an increase in steel fiber content .The increasing ratio of modulus of elasticity for steel fiberous to that of non-fiberous varied from 10.9% to 18.7%.

For polypropylene fibers concrete with volume fraction 0.4 and 0.89%, the table (2) shows a decrease in both compressive and splitting tensile strength (this volumes fractions were used to compare it with the same amount of steel fibers). This reduction in strength is due to high volume fraction used and low density of polypropylene (0.91 gm/cm³).
In deep beams under patch loading and like other loading, the first cracks (flexure cracks) were observed at the midspan of beam where the moment will be near the maximum value , these cracks stopped after loading below 50% of failure load, later shear crack develop near the end supports and extended towards the load applied at both sides and all the concrete beams specimens failed in shear, which corresponding in each case to sudden failure along single shear cracks, see Fig.(3), except for fiber volume 0.89%, where a combination of shear and flexure cracks have been seen at failure. Table (3) and Figs.(4,5,6 and 9) shows the effect of steel fibers content of 0,0.4,0.64 and 0.89% on the shear capacity and displacement of deep beams. As the steel fibers content increased, both the maximum applied load and ultimate displacement increased also.
The increase of failure load for the fiberous to that of non- fiberous concrete ranges from 11.1% to 35% while the displacement was increased also at failure load for the fiberous to that of non- fiberous concrete and ranges 18.4% to 67.6%.
As the steel fiber volume increased from nil to 0.89%, the angle of load – displacement curves from horizontal axis (displacement) is increased towards the vertical axes (load) as shown in Figs(4,5,6 and 7).
Table (3) and Figs.(8,9) shows that web opening within midspan and shear span caused a decrease in the shear capacity of concrete beams. Beams with opening within the midspan(B9, B10) had a higher shear capacity than beams opening within the shear span (B11,B12) which also showed a large deflection .
Table(3) and Figs.(10,11) showed that there is a significant decrease in shear capacity of beams with polypropylene fibers but the mode of failure showed a coincidence with the beams of steel fibers.

Conclusions

1- As the steel fiber content increased from nil to 0.89% increasing the compressive strength by abort 11.1% comparing with no fiberous concrete.
2- As the steel fiber content increased from nil to 0.89% increasing the splitting tensile strength by abort 26% comparing with no fiberous concrete
3 - As the steel fiber content increased from nil to 0.89%, increasing the modulus of elasticity by abort 8.7% comparing with no fiberous concrete.
4- The mode of failure of deep beams subjected to patch of loading without shear stirrups is almost shear failure except for high fiber content (0.89%) were the failure is a combination of shear and flexure modes .
5- As the fiber content increased from nil to 0.89%, the beginning of shear crack will be delayed and the widening of cracks is increased.
6- As the fiber content increased from nil to 0.89%, the displacement of beams was decreased at the constant loading.
7- As the fiber content increased from nil to 0.89%, all beams exhibited large deflection at failure loads than non fiberous concrete, indicating high ductility and energy absorption property, therefore, the deflection is a major design limitation.
8- According to the significant decrease in strengths for concrete with the specified polypropylene fibers, the

percentage of fiber content should be used by a small amount varied between 0.1 to 0.2% taking into consideration that polypropylene fibers used to achieve an improvement in impact strength of hardened concrete and to lower the probability of the occurrence of plastic shrinkage of fresh concrete.

9- The presence of web opening showed a significant decrease in shear capacity of beams. The shear capacity had more reduction with beams of web opening within the shear span more than beams with opening within the midspan of beams.

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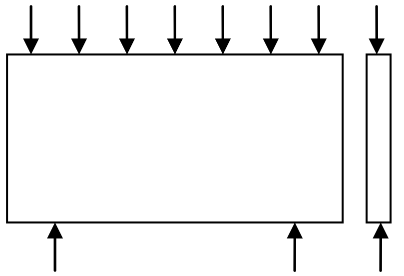
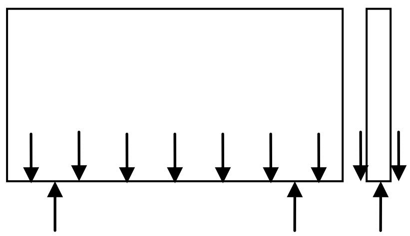
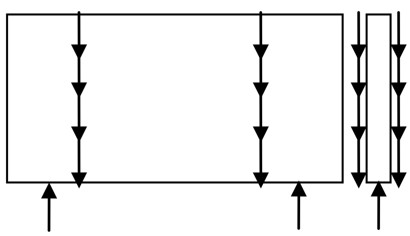
a- Steel Fiber (SF)



(1-a)



(1-b)



(1- c)

Fig.(1):Placement of loads on deep beams

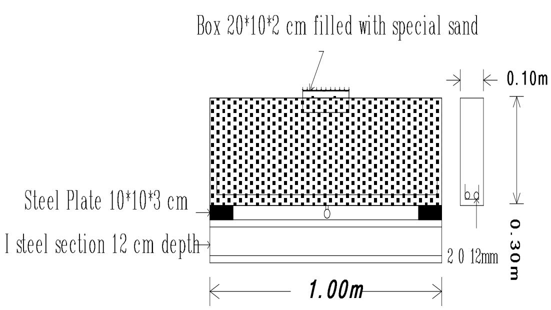


Fig. (2) Details of specimens beams

(a)

(b)

Fig.(3) Crack pattern and position

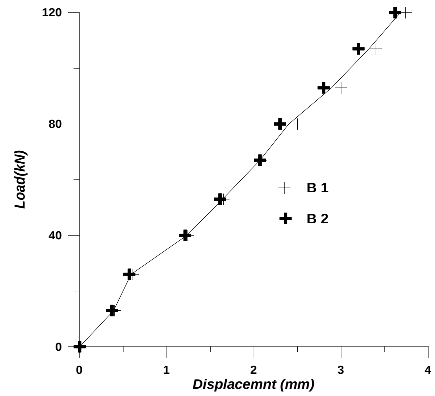


Fig.(4) Displacement-Load Relationship(0%Vf)

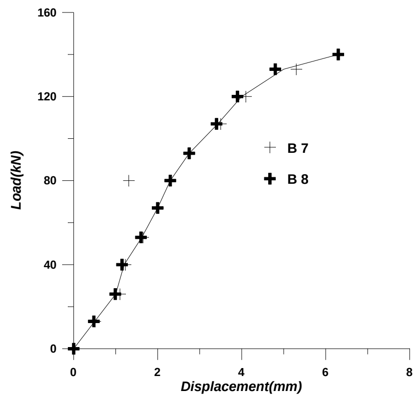


Fig.(7) Displacement-Load Relationship(0.89%Vsf)

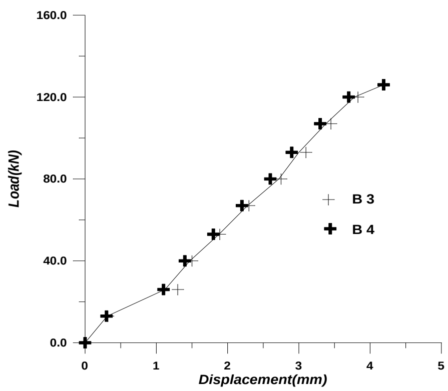


Fig.(5) Displacement-Load Relationship(0.4%Vsf)

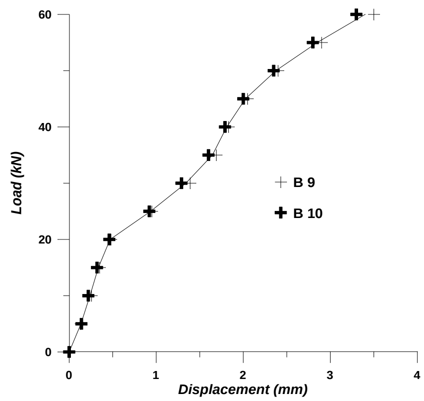


Fig.(8) Displacement-Load Relationship(0.64%Vsf-OMS)

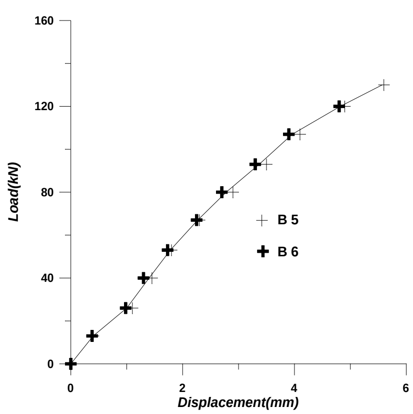


Fig.(8) Displacement- Load Relationship (0.64 % Vsf)

Fig.(6) Displacement-Load Relationship(0.64%Vsf)

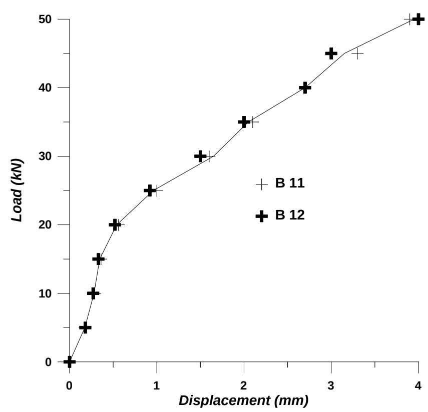


Fig.(9) Displacement-Load Relationship(0.64%Vsf-OSS)

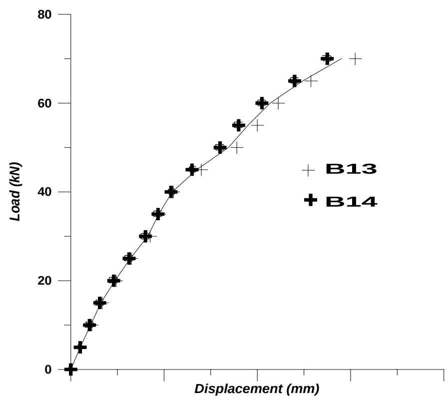


Fig.(10) Displacement-Load Relationship(0.4%Vppf)

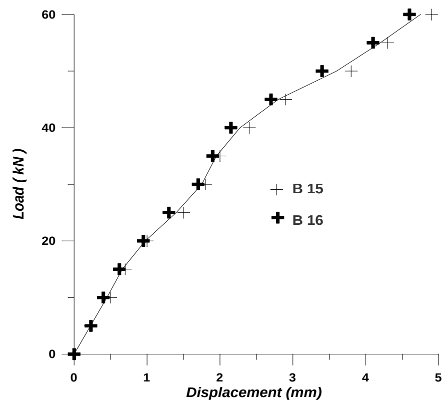


Fig.(11) Displacement-Load Relationship(0.89%Vppf)

Table (1): Specimens Details

Fiber content Vf %	Type and Number of Tested Specimens			
	Compression Strength	**Splitting Tensile Strength**	**Modulus of Elasticity**	**Shear Capacity**
0	3 cubes 150*150*150mm	3 cylinders 150*300mm	3 cylinders 150*300mm	2 beams(B1,B2) 1000*300*100mm
0.4	3 cubes 150*150*150mm	3 cylinders 150*300mm	3 cylinders 150*300mm	2 beams (B3,B4)1000*300*100mm
0.64	3 cubes 150*150*150mm	3 cylinders 150*300mm	3 cylinders 150*300mm	2 beams(B5,B6) 1000*300*100mm
0.89	3 cubes 150*150*150mm	3 cylinders 150*300mm	3 cylinders 150*300mm	2beams (B7,B8)1000*300*100mm

b- Steel Fibers (Position Opening)

Fiber content Vf %	Type and Number of Tested Specimens	
	Position of Center of Opening (100*100*100) mm	
	Midspan(MS)	Shear Span (SS)
0.64	2 beams (B9,B10)1000*300*100mm	2 beams (B11,B12)1000*300*100mm

c- Polypropylene Fiber(PPF)

Fiber content Vf %	Type and Number of Tested Specimens		
	Compression Strength	Splitting Tensile Strength	Shear Capacity
0.4	3 cubes 150*150*150mm	3 cylinders 150*300mm	2 beams (B13,B14)1000*300*100mm
0.89	3 cubes 150*150*150mm	3 cylinders 150*300mm	2 beams (B15,B16) 1000*300*100mm

Table (2): Measured Properties of Hardened Concrete

% Fiber content	fcu* (MPa)		fsp* (MPa)		Ec* (GPa)
	Type of fibers				
	Steel	Poly-propylene	Steel	Poly-propylene	Steel
0	36		3.45		23
0.4	37.6	26.6	3.98	3.4	25.5
0.64	38.8	-----------	4.2	-----------	26.6
0.89	40	24	4.35	2.82	27.3

* Average of three results

Table (3) :Summary of Test Beams Program

Beam Designation	Volume Of Fiber V f %	Type of Fiber	Shear span /depth ratio	Failure Load kN	Ultimate Disp. (mm)	1st Flexure Crack Load kN	1st Shear Crack Load kN	Failure Mode	Notes
B1	0	Steel	1.2	100	3.35	37.5	62.5	Shear	Vsf *
B2				112	3.75	37	60	Shear	Vsf
B3	0.4			118	3.81	40	65	Shear	Vsf
B4				120	4.71	40	65	Shear	Vsf
B5	0.64			125	5.46	42	70	Shear	Vsf
B6				130	5.6	43	71	Shear	Vsf
B7	0.89			137.5	5.1	50	75	Flexure-Shear	Vsf
B8				142	6.33	50	78	Flexure-Shear	Vsf
B9	0.64			60	3.3	30	40	Flexure-Shear	Vsf-OMS+
B10				64	3.5	32	40	Flexure-Shear	
B11				53	3.9	30	40	Shear	Vsf-OSS++
B12				51	4.0	28	40	Shear	
B13	0.4	Poly propylene		75	6.1	40	50	shear	Vppf**
B14				70	5.5	40	50	shear	Vppf
B15	0.89			60	4.9	30	40	shear	Vppf
B16				55	4.6	30	40	shear	Vppf

Vsf (volume of steel fiber) **Vppf (volume of polypropylene fiber)
+ OMS(opening at midspan of beam). ++ OSS(Opening at shear span of beam)