Shear Behavior of Self Compacting Reactive Powder Reinforced Concrete T- beams

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Abstract

The present research can be divided into three categories following the respective three main objectives. The first objective is to develop a self-compacting reactive powder concrete (SCRPC).

The second objective is to study the effect of steel fiber content on mechanical properties of (SCRPC). The third objective is to study the effect of steel fiber content on shear behavior of (SCRPC) RC T-beams. Therefore, five beam specimens were tested, one of which were made with (NSC) (reference beam), while, the others were constructed with (SCRPC) with different steel fiber volume fraction. Besides the beam specimens, a series of casting and testing were carried out to study the properties of (SCRPC) in fresh and hardened states. Experimental results show that the use of (SCRPC) improves the shear resistance and allowing higher forces to be carried through both, web and flange. When the steel volume fraction (V_f) changed from (0%) to (1.5%), the ultimate shear strength increased about (75%) to (91%), while, the cracking load increased about (50%) to (108%). This means the cracking and an ultimate load depends essentially on concrete strength and steel volume fraction.

Key Words: T-Beam, Flange, Shear, Self compacting, Reactive Powder Concrete

1-Introduction

Reactive Powder Concrete (RPC) is a special high-strength, fiber reinforced, superplasticized, silica-fume system with improved homogeneity. This type of concrete is of considerable importance in many applications such as long spans of bridges, high-pressure pipes, blast resistant structures and also suitable for impermeable containers for hazardous fluids or nuclear wastes. [1].

Reinforced concrete system normally consists of slab and beams that is placed monolithically and as a result T-Beams (T-Shaped Beam) created and the two parts act together to resist the applied loads. When the double Tee or single Tee beams (T-section beams) subjected to shear stresses, the thin vertical part of beam (i.e. webs) will resist these stresses.

New researches on T-section beams show that the concrete flanges provide a certain level of shear resistance above a certain width [2, 3].

In the present research, shear behavior of reinforced concrete T-Beams which made with new type of concrete, self compacting reactive powder concrete (SCRPC), were studied as well as the properties of concrete in fresh and hardened states.

2-Objective of the Present Study

The present research can be divided into three categories following the respective three main objectives. The first objective is to develop a self compacting reactive powder concrete (SCRPC) through a mix composed from (1000 kg/m^3) of cement, (1000 kg/m^3) of fine sand (with particle size between (150µm) and (600µm)), silica fume of (100 kg/m^3), water of (230 kg/m^3) and four values of steel fibers volume fractions (V_f) of (0, 0.75, 1.0, 1.25 and 1.5%). The second objective is to study the effect of steel fiber content on mechanical properties of SCRPC (compressive strength and modulus of rupture). The third objective is to study the effect of steel fiber content and the employed of SCRPS on shear behavior of self compacting reactive powder RC T- beams.

3- Experimental Study

3-1 Experimental Program

3-1-1-Control Specimens

Properties of the SCRPC in both, fresh state and hardened state were studied through a series of casting and testing of concrete specimens. Properties of SCRPC in fresh state which includes consistency of the concrete, slump flow and mortar V-funnel test were examined. While, in the hardened state, the compressive strength and tensile strength in flexural (modulus of rupture) was carried out.

3-1-2 Beam Specimens

Tests were carried out on five T-beams (T-Shaped beams), simply supported under the effect of single point loading at mid span. The variables were the concrete type. The span, web dimensions, beam depth, beam length, longitudinal (tension) reinforcement and transverse reinforcement (stirrups) were kept constant for all tested specimens.

4- Properties of Fresh SCRPC

Five mix designs were carried out to examine and evaluate the properties of SCRPC in fresh and hardened states. Each mix was designated in a way to refer to type of concrete and the volume fraction of steel fibers (except the first mix which referred to normal strength concrete, NSC). Therefore, the mix designated as (SCRPC-1.5) is a mix concrete which made with a self compacting reactive powder concrete and volume fraction of steel fibers (V_f) of (1.5%).

The mixture that expected to need the higher suerplasticizer content to satisfy the self-compactibility requirements, for the research mixtures, is the RPC mixture which contains both, the silica fume and the steel fibers of (117.9 kg/m^3). The method followed to find the self-compactibility amount needed for each mix is by checking first the slump flow with different superplasticizer amount until reaching the aimed value of (240-260mm), then checking the other requirement of self- compactibility. This is because slump flow test is the simplest and faster one. A dosage of (8%) of the total weight of the cement was used for the first trial mixtures. Table (1) shows an example of trial mix for (SCRPC-1.5) and Table (2) shows the details of concrete mixes.

Table 1: Trial Mix for SCRPC-1.5

HRWRA % by Wt. of Cement	Slump Flow (240-260mm)	V-Funnel Time (7-11sec.)
8	Less than 240 mm	-
9	Less than 240 mm	-
9.5	Less than 240 mm	-
10	Less than 240 mm	-
11	Less than 240 mm	-
11.5	240	10

Table 2: Details of Design Mixes.

Mix Designation	Cement (kg/m^3)	Sand (kg/m^3)	Silica Fume (kg/m^3)	Steel Fibers (kg/m^3)	Water (kg/m^3)	SPD % by the wt. of the cement
NSC*	1000	1000	-	-	450	-
SCRPC-0	1000	1000	-	-	230	10.50
SCRPC-0.75	1000	1000	100	58.95	230	10.80
SCRPC-1.0	1000	1000	100	78.6	230	11.07
SCRPC-1.25	1000	1000	100	98.25	230	11.00
SCRPC-1.5	1000	1000	100	117.9	230	11.50

* Reference Mix (Normal Strength Concrete)

4-1-Consistency of the Concrete Mixtures

For reference concrete, the consistency was tested by the flow table test in accordance with ASTM C1437-01(4). The flow is the resulting increase in average base diameter of the mortar mass, expressed as a percentage of the original base diameter (100mm), i.e.:-

$$Flow = \frac{D-100}{100} x100 \quad \text{….. (1)}$$

Where:-D= average diameter of the spread concrete (mm) measured in four directions.

For self-compacting concrete, flow and V-funnel tests have been proposed by **Okamura and Ouchi**(5) and **EFNARC**(6) to estimate the flowability and to determine the flow time of the mortar.

4-2-Mortar Slump Flow Test

The slump flow test is used to determine filling ability. A value between (240-260mm) is required for self compacting mortar. see Figure (1)

Figure 1: Consistency test by Flow Table

4-3-Mortar Funnel Test

Viscosity and fillingability can be assessed by the V-funnel flow time. This test measures the ease of flow of the mortar; shorter flow times indicate greater flowability. For self compacting mortar a flow time of between (7-11) seconds is considered appropriate [6]. see Figure (2)

Figure 2: Viscosity and fillingability by V-funnel flow time test

Table 3: Properties of the SCRPC in the Fresh State

Mix Designation	Flow-C1437 %	Slump Flow (mm)	V-Funnel (sec.)
NSC*	150	-	-
SCRPC-0	-	245	10.5
SCRPC-0.75	-	240	11.0
SCRPC-1.0	-	245	10.0
SCRPC-1.25	-	240	11.0
SCRPC-1.5	-	240	10.5

* Reference Mix (Normal Strength Concrete)

5- Properties of Hardened SCRPC

5-1-Compressive Strength

Compressive strength of concrete was carried out by using (50x50x50mm) cubes according to

ASTM C109/C109 M-05[7]. The average of three cubes was adopted at each testing age (7, 28 and 60 days). Table (4) illustrates the mechanical Properties of design mixes.

5-2-Modulus of Rupture

Tensile strength in flexural (modulus of rupture) were carried out by using (50x50x300 mm) prismatic specimens (prism) under central point loading according to ASTM C 293-79[8]. The average of two prisms was adopted at each testing age (7, 14 and 28 days).

Table 4: Mechanical Properties of Design Mixes of SCRPC

Mix Designation	f_{cu} (MPa)*				f_r (MPa)**		
	7day	14 day	28 day	60 day	7 day	14 day	28 day
NSC	37.6	38.8	39.8	43.2	4	4.2	4.3
SCRPC-0	58.7	62.8	68	77.2	9	9.6	10.3
SCRPC-0.75	59.6	65.2	74.4	87	15.6	17.1	19.5
SCRPC-1.0	66	68.8	79	89.4	16.8	17.5	20.1
SCRPC-1.25	72.3	81.6	99	111.6	18	20.3	22.6
SCRPC-1.5	88.7	99.6	107	113.4	20	22.4	24.1

* Average of three cubes per each testing age.

** Average of two prisms per each testing age.

6-Beam Specimens Details

As mentioned before, five beam specimens are tested. Each beam specimens were designated in a way to refer to the employed type of concrete and the volume fraction of steel fibers (except the first beam specimen which referred to normal strength concrete). Therefore, the beam specimen designated (SCRPC-1.5) is referred to beam which made with a self compacting reactive powder concrete and volume fraction of steel fibers (V_f) of (1.5%), see Table (5).

All beam specimens were reinforced with (2ϕ10mm) deformed bars as a main reinforcement (flexural reinforcement) at bottom of the web. While, slightly reinforcement of (4ϕ6mm) mild steel, smooth bars at the top flange were used. To eliminate the shear resisting contribution of stirrups and to ensure the specimens to fail in shear mode of failure, the tested beams were made with minimum shear reinforcement (stirrups) and maximum spacing. Therefore, (ϕ4mm@150mm) mild steel, smooth bars were used as shear reinforcement. It may be noted that, the main function of stirrups is to hold in place the top and bottom longitudinal reinforcement, see Figure (3).

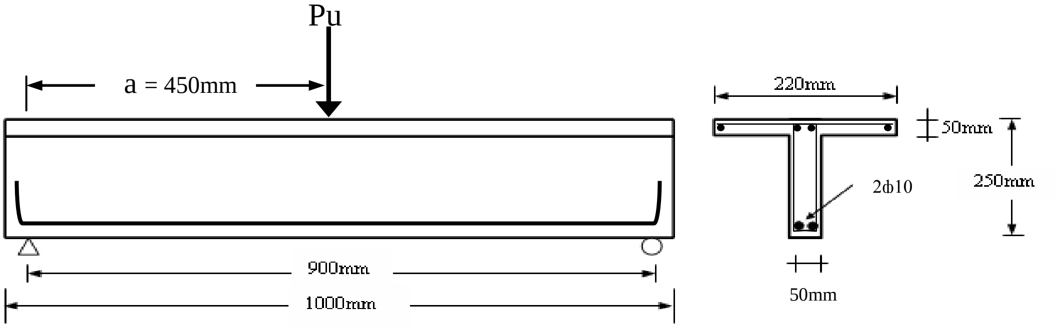

Figure 3: Dimensions and Details of Tested T-Beams

Table 5: Details of Beam Specimens

Beam Designation	Beam Dimensions (mm)				Reinforcement		f_{cu} (MPa)
	h	t_f	b_f	b_w	*Longitudinal*	*Stirrups*	*28 day*
NSC*	250	50	220	50	2ϕ10mm	ϕ4mm@150mm	39.8
SC-0.75							74.4
SC-1.0							79
SC-1.25							99
SC-1.5							107

* Reference Beam.

7- Test Measurements and Instrumentation

Hydraulic universal testing machine (MFL system) was used to test the beam specimens as well as control specimens. Central deflection has been measured by means of (0.01mm) accuracy dial gauges (ELE type) and (30mm) capacity. The dial gauges were placed underneath the bottom face of each span at mid, Figure (4). The beam specimens were placed on the testing machine and adjusted so that the centerline, supports, point load and dial gauge were in their correct or best locations.

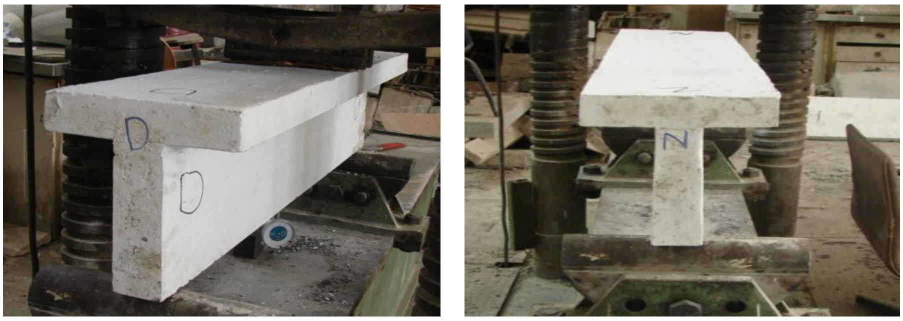

Figure 4: Setup of Tested Beams

8- Test Procedure of Beam Specimens

All beam specimens were tested using universal testing machine (MFL system) with monotonic loading to ultimate states. The tested beams were simply supported over an effective span of (900mm) and loaded with a single-point load; Figures (3) and (4) shows the setup of beam specimens.

The beams have been tested at ages of (28) days. The beam specimens were placed on the testing machine and adjusted so that the centerline, supports, point load and dial gauge were in their correct or best locations.

Loading was applied slowly in successive increments. At the end of each load increment, observations and measurements were recorded for the mid-span deflection and crack development and propagation on the beam surface.

When the beams reached advanced stage of loading, smaller increments were applied until failure. They fail abruptly without warning (sudden failure) and the diagonal cracks that develop becomes wider and as a result, the load indicator stopped recording anymore and the deflections increased very fast without any increase in applied load.

The developments of cracks (crack pattern) were marked with a pencil at each load increment.

9-Results and Discussion

As mentioned before, one of the main objectives of this study are to examine or assess the shear behavior of SCRPC T-shaped beams containing different volume fraction of steel fibers. During the experimental work, ultimate loads, load versus deflection at mid-span for each beam were recorded. Photographs for the tested beams are taken to show the crack pattern and some other details.

The recorded data, general behavior and test observations are reported as well as recognizing the effects of various parameters on the shear behavior.

9-1 General Behavior

Photographs of the tested beams are shown in Figure (5) and test results are given in Table (6). All beams of this study were designed to fail in shear, which was characterized by sudden failure and diagonal wide cracks which extended from supports towards the load locations. The general behavior of the tested beams can be described as follows:

At early stages of loading, several cracks initiated in the mid span of tested beams (flexural cracks), with further loading, these cracks extended upwards and became wider in shear span. One or more cracks propagated faster than the others and reached the compression flange (near applied load), where crushing of the concrete near the positions of applied loads had occurred due to high concentrated stresses under load.

As expected, the main cracks (diagonal cracks) for all tested beams commenced at the shear span and all beams exhibited sudden failure. It is may be noted that, at advanced stage of loading, no splitting or defragmentation of tested T-Beams occurred, this is due contraptions of steel fibers to carry high stresses (at a certain degree) and absents of steel reinforcement to hold these parts in the transverse direction.

9-2 Mode of Failure

The experimental evidences show that the diagonal cracks extended horizontally along the tension reinforcement and eventually, the failure take place due to crushing failure in the concrete near the compression face (near applied load) and this mode of failure called “Shear-Compression” failure.

Figure 5: Crack Patterns for T-Beams

9-3 Ultimate Strength (P_u)

The recorded ultimate loads of the tested beams are presented in Table (5). As expected, test results show that the reference beams (NSC) has the minimum ultimate strength in comparison with the rest beams. This may be due to combination of ability of flanges to sustain larger compressive force at advanced stages of loading and absent of any leak (openings or joints) in the flange. The compression flanges can carry any load increment prior to failure, and this depends mainly on the ultimate compressive strength of the concrete in the flange.

For tested beams (SCRPC-0.75, SCRPC-1.0, SCRPC-1.25 and SCRPC-1.5), which had different steel volume fraction, the increased in shear strength was (75%-91%) in comparison with reference beam. The presence of steel fibers lead to increase the stiffness of tested beams, and this leads to an increase in carrying capacity.

Generally, it can be seen that the tested beams containing a certain steel volume fraction exhibit greater ultimate strength than the reference beam (which made fully with normal strength concrete).

Table 5: Ultimate, Cracking Loads and Mode of Failure of Tested Beams

Beam Designation	Load (kN)		P_c/P_u (%)	Shear Force (kN)		Mode of Failure
	P_u	P_c		V_u	$(V_u)_i/V_u$	
NSC*	55	6	11	27.5	-	Shear-Compression Failure
SC-0.75	101	10.5	10	50.5	1.84	
SC-1.0	96	9	9	48	1.75	
SC-1.25	109	12	11	54.5	1.98	
SC-1.5	105	12.5	12	52.5	1.91	

* Reference Beam, P_u=55kN and V_u =20.5 kN

Table 6: Comparison between Calculated and Measured Shear Force

Beam Designation	Compressive Strength (MPa)		Shear Force (kN)		$(V_c)_{Cal.}/(V_u)_{Exp.}$ (%)
	f_{cu}	f_c'*	$(V_u)_{Exp.}$	$(V_c)_{Cal.}$**	
NSC*	39.8	32	27.5	22	0.80
SC-0.75	74.4	60	50.5	30	0.59
SC-1.0	79	63	48	31	0.64
SC-1.25	99	79	54.5	34	0.62
SC-1.5	107	86	52.5	36	0.69

* $f_c' = 0.8\ f_{cu}$

**ACI-318 ($V_c = \frac{1}{3}\sqrt{f_c'}\,.d.b_w$)

9-4 Effect of Concrete Strength on Ultimate Capacity

As shown in Table (6), when the compressive strength of concrete increased, the ultimate capacity increased. This may be increasing in the stiffness of tested beams. Due to abrupt changes in the sectional configuration, opening corners are subject to high stress concentration that may lead to reduction in stiffness of the T-Beam and produced cracking and excessive deflection, see Figures (6) and (7).

9-5 Effect of Steel Fiber Volume Fraction on Ultimate Capacity

As shown in Table (5), when the steel volume fraction (V_f) changed from (0%) to (1.5%), the ultimate shear strength increased about (75%) to (91%), while, the cracking load increased about (50%) to (108%). This means that the presence of steel fibers improves the load carried capacity at both, initial stage (first cracking load) and ultimate stage (at failure) for all tested beams.

9-6 Deflections

Load-deflection curves of the tested beams at mid-span at all stages of loading up to failure are constructed and shown in Figure (6).

As shown in Figure, at the beginning, all curves were identical and the tested beams exhibited linear behavior and the initial change of slope of the load-deflection curves occurred between (6.0kN to 15kN), which may be indicated the first crack loads. Beyond the first crack loading, each beam behaved in a certain manner. Behavior of reference T-Beam (NSC) exhibited less load and deflection in comparison with the other beams. This beam had a less stiffness due to absent of steel fibers and less compressive strength, which caused decreasing in the load carrying capacity beyond the first cracking and this was reflected on the corresponding deflections

Load-deflection curves for the tested beams (SCRPC-0.75, SCRPC-1.0, SCRPC-1.25, and SCRPC-1.5) exhibits smooth increase in both applied loads and deflections. Presence of steel fibers caused increasing in the load carrying capacity beyond the first cracking and this was reflected on the corresponding deflections. For T-Beams (SCRPC-1.25 and SCRPC-1.5), slight increase in ultimate deflection of beam (SCRPC-1.5) was observed by comparing with (SCRPC-1.25). This is may be due to presence of steel volume fraction grater in the beam (SCRPC-1.5) than in the beam (SCRPC-1.250), which led to decreasing of beam stiffness and as a result, slight increases in deflection take place.

Generally, all SCRPC beams exhibits ductile behavior in comparison with NSC beam (reference beam).

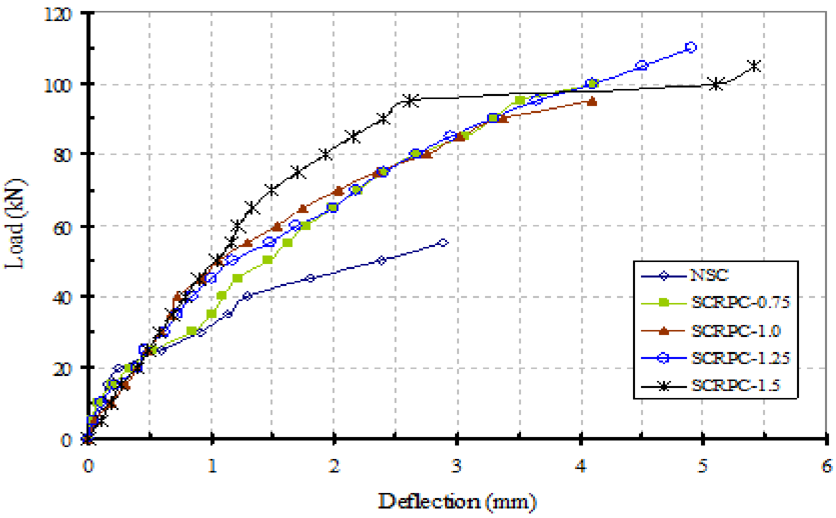

Figure 6: Load-Deflection Relationship for Tested beam Specimens

10- Conclusions

1- The workability requirement for successful placement of SCRPC necessity that the concrete should exhibits excellent deformability and proper stability to flow under own weight without segregation and blockage.

2- All (SCRPC) beams exhibits ductile behavior in comparison with (NSC) beam (reference beam).

3-The use of (SCRPC) improves the shear resistance and allowing higher forces to be carried through both, web and flange. When the steel volume fraction (V_f) changed from (0%) to (1.5%), the ultimate shear strength increased about (75%) to (91%), while, the cracking load increased about (50%) to (108%). This means the cracking and an ultimate load depends essentially on concrete strength and steel volume fraction.

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12-Notation

a =	Shear Span;
b_f =	Flange width;
d =	Effective depth of T-Beam;
$f_c^{'}$ =	Cylinder compressive strength of concrete;
f_{cu} =	Cube compressive strength of concrete;
f_r =	Flexural tensile strength of concrete (modulus of rupture);
f_y =	Yield strength of steel;
h =	Total depth of T-Beam;
L =	Effective Span
P_u =	Ultimate load;
t_f =	Flange thickness;
b_w=	Web thickness;
V_u=	Ultimate Shear Force;
$(V_u)_i$=	Ultimate Shear Force of a certain beam;
ϕ =	Reinforced bar diameter;

سلوك القص للعتبات الخرسانية المسلحة ذات المقطع-T والمصنوعة من خرسانة المساحيق الفعالة ذاتية الرص

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الخلاصة:
أعدت هذه الدراسة لثلاثة أهداف، (أولا) تطوير نوع من الخرسانة تتوفر فيها مواصفات الخرسانة ذاتية الرص و خرسانة المساحيق الفعالة للحصول على خرسانة المساحيق الفعالة ذاتية الرص. (ثانيا) دراسة تأثير نسبة ألياف الحديد على الخواص الميكانيكية لخرسانة المساحيق الفعالة ذاتية الرص. (ثالثا) دراسة سلوك القص للعتبات المسلحة ذات المقطع-T والمصنوعة من خرسانة المساحيق الفعالة ذاتية الرص. تم إجراء سلسلة من الفحوصات المختبرية على خمسة عتبات خرسانية مسلحة ذات مقطع(T)، العتبة الأولى (العتبة المرجعية) تم صناعتها من الخرسانة الاعتيادية وبدون ألياف أما بقية العتبات فتم صناعتها باستخدام خرسانة المساحيق الفعالة ذاتية الرص مع نسب مختلفة من ألياف الحديد. لكافة العتبات المفحوصة، تم الإبقاء على أبعاد الوترة (Web)، أبعاد الشفة (Flange)، العمق الكلي، فضاء العتبة، حديد التسليح الطولي و العرضي بدون أي تغيير. بالإضافة إلى ذلك، تم إجراء سلسلة من الفحوصات على نماذج السيطرة (مكعبات و مواشير) لدراسة خواص الخرسانة الطرية و المتصلبة. اظهرت النتائج المختبرية نقصان في مقاومة القص بحدود (22%-32%) في العتبات التي تحتوي على فتحة واحدة في الشفة، ونقصان بحدو(17%-39%) في العتبات التي تحتوي على فتحتين في الشفة. بالنسبة للعتبات التي تحتوي على مفاصل انشائية، اظهرت النتائج المختبرية نقصان في مقاومة القص بحدود (23%) عند مقارنتها مع العتبة المرجعية.