Direct Shear Behavior of Fiber Reinforced Concrete Elements

Hussein Al-Quraishi
Instructor
Building and Construction Dept.-
University of Technology
hussain.abbas@yahoo.com

Mouhammed Jessam Lafta
Assistant Instructor
Engineering and Technology Journal-
University of Technology
10959@uotechnology.edu.iq

Aseel Abdulazeez Abdulridha
Assistant Instructor
Building and Construction Dept.-
University of Technology
asas_87assafi@yahoo.com

ABSTRACT

Improving the accuracy of load-deformation behavior, failure mode, and ultimate load capacity for reinforced concrete members subjected to in-plane loadings such as corbels, wall to foundation connections and panels need shear strength behavior to be included. Shear design in reinforced concrete structures depends on crack width, crack slippage and roughness of the surface of cracks.

This paper illustrates results of an experimental investigation conducted to investigate the direct shear strength of fiber normal strength concrete (NSC) and reactive powder concrete (RPC). The tests were performed along a pre-selected shear plane in concrete members named push-off specimens. The effectiveness of concrete compressive strength, volume fraction of steel fiber, and shear reinforcement ratio on shear transfer capacity were considered in this study. Furthermore, failure modes, shear stress-slip behavior, and shear stress-crack width behavior were also presented in this study.

Tests' results showed that volume fraction of steel fiber and compressive strength of concrete in NSC and RPC play a major role in improving the shear strength of concrete. As expectedly, due to dowel action, the shear reinforcement is the predominant factor in resisting the shear stress. The shear failure of NSC and RPC has the sudden mode of failure (brittle failure) with the approximately linear behavior of shear stress-slip relationship till failure. Using RPC instead of NSC with the same amount of steel fibers in constructing the push-off specimen result in high shear strength. In NSC, shear strength influenced by the three major factors; crack surface friction, aggregate interlock and steel fiber content if present. Whereas, RPC has only steel fiber and cracks surface friction influencing the shear strength. Due to cementitious nature of RPC in comparisons with NSC, the RPC specimen shows greater cracks width.

It is observed that the Mattock model gives very satisfactory predictions when applied to the present test results with a range of parametric variations; ranging from 0 % to 0.5 % in steel fibers content; from 0 % to 0.53 % in transverse reinforcement ratio; from 15 to 105 MPa in compressive strength of concrete. While it gives a poor prediction for a specimen with 1% steel fiber.

Keywords: direct shear, fiber reinforced concrete, failure modes.

سلوك القص المباشر للاعضاء الخرسانية المسلحة بالالياف

حسين القريشي
مدرس
قسم هندسة البناء والانساءات-الجامعة التكنولوجية

محمد جسام لفتة
مدرس مساعد
مجلة الهندسة والتكنولوجيا-الجامعة التكنولوجية

اسيل عبد العزيز عبدالرضا
مدرس مساعد
قسم هندسة البناء والانساءات-الجامعة التكنولوجية

الخلاصة

لتحسين دقة العلاقة بين القوة والتشوه واشكال الفشل والقوة القصوى للاعضاء الخرسانية المسلحة المعرضة الى تحميل مستوي مثل عضو الساند و حائط متصل باساس، واللوائح يجب تضمين مقاومة القص. طرق تصميم القص للمنشات الخرسانية يعتمد بشكل كبير على انتقال القص خلال التشقق والذي يعتمد على عرض التشقق و تزحلق الازاحة وخشونة سطح التشقق.

هذه الدراسة تتضمن فحوصات عملية لدراسة القص المباشر خلال التشقق للخرسانة المسلحة بالالياف وخرسانة المساحيق الفعالة. الفحوصات اجريت على مستوي قص محدد مسبقا لنموذج الدفع الخارجي. تاثير مقاومة الانضغاط ومحتوى الالياف ونسبة حديد القص على مقاومة القص تم اخذها في هذه الدراسة. اضافة الى اشكال الفشل و علاقة اجهاد القص مع التزحلق وعلاقة اجهاد القص مع عرض التشقق تم ايضا اخذها بنظر الاعتبار.

النتائج اظهرت ان كمية الياف الحديد و مقاومة الانضغاط للخرسانة تلعب دور كبير في تحسين مقاومة القص للخرسانة. كما هو متوقع، تسليح القص له ايضا تاثير كبير في مقاومة اجهادات القص. فشل القص للخرسانة العادية وخرسانة المساحيق الفعالة هو فشل فجائي وقصيف مع علاقة تقريبا خطية بيت اجهاد القص والتزحلق. استعمال خرسانة المساحيق بدلا من الخرسانة العادية ينتج عنه مقاومة قص عالية جدا. في الخرسانة العادية مقاومة القص تتاثر بثلاث عوامل هي: احتكاك سطح التشقق، تداخل الحصى، ومحتوى الياف الحديد. بينما في خرسانة الباودر التفاعلي فقط الياف الحديد واحتكاك سطح التشقق يؤثران على مقاومة القص. نتيجة طبيعة الاسمنتية لخرسانة المساحيق الفعالة عرض الشقق كان كبير مقارنة بالخرسانة العادية.

لقد تم ملاحظة ان موديل ماتوك يعطي نتائج مرضية عند تطبيقه على نتائج فحوصات هذه الدراسة لمدى متغيرات من 0 الى 0.5% محتوى الياف الحديد و من 0 الى 0.53% نسبة حديد القص و من 15 الى 105 مقاومة الانضغاط للخرسانة. بينما اعطت نتائج ضعيفة للنماذج التي تحتوي على 1% الياف حديد.

الكلمات الرئيسية: القص المباشر، الخرسانة المسلحة بالالياف، أشكال الفشل.

1. INTRODUCTION

Concrete is the most widely used for building construction. The concrete failure usually occurs due to the effect of shear and bending. The shear failure is unfavorable modes of failure due to its sudden progression. This rapid type of failure made it necessary to investigate more effective ways to design the reinforced concrete members, **Birkeland** and **Birkeland, 1966**.

In general, the shear failure of the normal strength concrete member is brittle. The inclusion of fibers into concrete matrix increases the tensile strength and adjusted the modes of failure to ductile failure. Consequently, the inclusion of fibers in concrete members enhances the shear strength and increases their shear load capacity, **Birkeland,** and **Birkeland, 1966.** The concrete and the shear reinforcement are the main parts contribute the shear strength of concrete. Shear friction or aggregate interlock represents the concrete shear strength. The shear stiffness decrease as the cracks widen due to contact being lost between the cracks faces.

Assessment the effect of aggregate interlock is complex due to difficulties in calculating the crack roughness and localized stresses around reinforcing bars, tension stiffening, dowel action and time-dependent effects such as creep, **Hofbeck, et al.**, **1969**. The popular way for measuring the direct shear strength of concrete is the push-off specimen. This, essentially prism member comprised of two L-shaped blocks, connected in an inverted position to formulate the shear plane.

In the last decade, models of shear strength were suggested using different approaches, such as distributed stress field model, modified compression field theory and shear strength based on the push-off specimen. This study focuses on shear strength mechanism of fiber reinforced concrete members through crack shear stresses and crack shear slip using push-off specimen.
Many types of research had attained to investigate the shear strength of reinforced concrete members.
Birkeland and **Birkeland, 1966,** investigated the shear friction theory in push-off specimens. **Hofbeck, et al.**, **1969**, **Mattock**, and **Hawkins, 1972**, made a further study on shear transfer mechanism. They studied the effect of concrete strength and distributed of shear reinforcement through the shear plane. The results show that the shear reinforcement extremely improves the shear strength. **Jongvivatsakul**, **et al., 2011**, studied the shear stress-slip behavior of fiber reinforced concrete members. The effectiveness of shear reinforcement ratio, fiber content and concrete compressive strength were studied. They found, the shear strength improved due to increase the steel fiber content and shear reinforcement. **Rahal, et al., 2013**, tested fifteen push-off specimens to study the shear strength of high and normal self-compacted concrete. The results indicated that the compressive strength of concrete had a significant role in improving the shear strength of concrete while, had a minor influence on the crack slip and crack width. **Xiao, et al., 2012,** tested 32 push off the specimen to study the shear strength of recycled aggregate concrete. The recycled coarse aggregate replacement ratio, the compressive strength of recycled aggregate, water to cement ratio and shear reinforcement was studied as variables. The test results showed that the mechanism of shear transfer in recycled aggregate is the same as in natural aggregate. The compressive strength and lateral reinforcement had the major role affect the shear strength of recycled aggregate. **Waseem, et al., 2016**, tested push off the specimen to study the shear strength of recycled aggregate concrete with several compressive strength and replacement ratio of recycled aggregate were the variables. The results indicate that the compressive strength of recycled concrete had the most significant variable in shear strength.
It is very important to be addressed that, the concept of shear failure is tensile failure accompanied by aggregate interlock or fiber bridging.
The use of; a micro cementitious material such as silica fume, quartz sand, superplasticizers to reduce water to cement ratio led to a new generation of concrete named reactive powder concrete (RPC).
Review of the above studies addressed the subject of shear strength of normal strength concrete (NSC) and the effectiveness variables that effects on it. However, few studies have focused on the comparisons on the shear strength between NSC and the RPC.
Hence, these paper reports test results of experimental work which aimed to better understanding the shear strength of a non-precracked push-off for NSC and RPC specimens.

2. RESEARCH SIGNIFICANT

The goal of this investigation is to study the shear strength and failure modes for NSC and RPC using the push-off specimens. The tests were performed along the certain shear plane of the push-off specimens prior to 6 mm crack shear slip. The influences of compressive strength of concrete, steel fiber content and shear reinforcement ratio on shear transfer capacity were studied. Finally, it compared between the present test results and the previous Mattock model of the shear strength was carried out.

3. PUSH-OFF TEST SPECIMENS

The push-off specimen consists of two L-blocks connected together in inverted position to produce a plane of pure shear (shear plane). The axial compression force must be applied at the top and bottom of the specimen to produce a pure shear in the adjacent area between two blocks. It is very important to note that the axial compression force must coincide with the shear plane direction. A sketch representation of push-off specimen is shown in **Fig. 1**.

From **Fig. 1** the shear stress and normal stress σ are uniformly distributed in the pre-selected shear plane according to:

$$\sigma = (P / b.L) \quad .....(1)$$

$$\tau = (P / b.h) \quad .....(2)$$

Where; P: axial compressive force, b: width of shear plane, L: total length of the specimen, and h: height of the shear plane.

To make sure that the failure of the specimen in pure shear across the pre-selected plane and to avoid other unwanted modes of failure, reinforcing longitudinal and lateral steel bars were designed and placed away from the shear plane to prevent the flexural failure. The dimensions detail with reinforcement of push-off specimen is presented in **Fig. 2**. It may be noted that the main reinforcement was 6-ϕ10 and transverse reinforcement was 4-ϕ6 were provided in all specimens for each L block to prevent flexural failure. The plywood molds with reinforcing bars are shown in **Fig. 3**.

The push-off specimens of one batch were cast in the laboratory using a concrete mixer. The cast of the concrete in formwork plywood was horizontally along the thickness of the specimen. Two plywood of 150 mm long and 25 mm thickness was used to make the slots.

After casting the concrete, the specimens were covered with plastic sheet to avoid the excessive evaporation. The specimens were de-molded after 24 h for NSC and 48 for RPC specimen respectively. The push-off specimen was ready for testing after 28 days of curing at a room temperature. **Fig. 4** shows the specimen after casting of concrete was completed.

4. MATERIALS PROPERTIES AND MIX PROPORTIONS

Two types of concrete were used in this investigation; NSC and RPC. The material used in constructing the NSC was: Ordinary Portland cement –type I; Coarse aggregate, 5-20 mm in size; fine aggregate and potable water. The mix proportion of NSC is presented in Table 1 and the target compressive strength for cubes was 15 and 30 MPa. The slump test for the two of normal concrete was presented in Table 2.

To improve the concrete compressive strength beyond the value of NSC, the present study used RPC as a matrix which consists of silica fume, Portland cement and quartz sand with a maximum size of 0.5 mm. Glenuim 54 is used as superplasticizer to reduce the water to cement ratio and to increase the workability due to the inclusion of steel fiber in a matrix. The steel fiber of 15 mm long, 0.2 mm in diameter and the aspect ratio of 75 was used. A mix proportions of RPC proposed by **Hirschi** and **Wombacher, 2012,** was adopted in this study and the target compressive strength of cubes was 105 MPa, as in **Table 3**.

The chemical and physical properties of Portland cement were tested according to the provisions of Iraqi specification No.5/1984 as shown in **Table 4** and **5** respectively.
The properties of fine and coarse aggregate were tested according to the provisions of Iraqi specification No.45/1980 as shown in **Table 6** and **7** respectively.
The yield strength of 10 mm and 6 mm reinforcing bars used in constructing the specimen was 420 MPa and 580 MPa respectively.
At least three cubes of 15 x 15 x 15 cm were used to measure the compressive strength of concrete and three cylinders of 150 x 300 mm was used to measure the tensile strength of concrete at 28 days for NSC and for RPC.
The compressive strength of concrete was tested according to BS1881-116 and the tensile strength of concrete was tested according to ASTM C496. The test results are presented in Table 8. **Fig. 5 and 6** show the concrete cubes and cylinders after failure.

5. EXPERIMENTAL PROGRAM

The experimental work was conducted in the Materials and Structural Laboratories – Building and Construction Engineering Department - University of Technology. The experimental program can be described as follows:
A total of six push-off specimens were tested. The influence of steel fiber content on the shear strength was studied on three specimens (L1-Ref, L2-fib0% and L3-fiber1%). The concrete compressive strength was studied on three specimens (L1-Ref, L6-fc15, and L5-RPC). The effect of shear reinforcement ratio on the shear strength was studied by comparisons of two specimens (L1-Ref and L4-Rei0.53%). The characteristics of the tested push-off specimens with reinforcement details are summarized in **Table 9**.

In **Table 9**, each specimen is given a unique name with a letter and digits. The letter and the digits before the hyphen sign identify the push-off specimen. Ref means the reference push-off specimen with properties indicated in **Table 9**. fib0% and fib1% means the specimen has 0% and 1% steel fiber content respectively. Rei0.53% means the specimen has 0.53% shear reinforcement ratio. Finally, RPC means the specimen constructed from reactive powder concrete.

6. MEASUREMENTS

The applied axial compression force was measured using an accurately calibrated load cell. The shear crack slip (s) which represents the relative movement between two L blocks of the push-off specimen was measured using the dial gauge 1 installed at bottom of the specimen. The shear crack opening (w) was measured using dial gauges 2 and 3 installed at the beginning and at end of a middle-third length of the shear plane. The locations of dial gauges are described in **Fig. 7**.

7. TESTING PROCEDURE

In Structural Laboratory of Building and Construction Engineering Department, a shear test of the push-off specimen was carried out. The hydraulic machine of 2500 kN was used to test the specimen and 10 mm thick steel plate stranded at the top and bottom of the specimen to freely permit the horizontal movement.

The specimens were tested under load-control applied in a vertical direction at a rate of 5 kN. In all tests, loading was continued till clearly the whole shear failure was seen. After the mode of failure was completed, the gauges and steel plates were removed to allow more photographs of final shear cracks to be taken. The time spent in testing one push-off specimen was about 20 minutes. **Fig. 8** shows the push-off specimen under test.

8. TEST RESULTS AND DISCUSSION

This section presents test results of:

- The ultimate shear strength of tested specimen.
- The effect of steel fiber content, the compressive strength of concrete and transverse reinforcement ratio on the shear strength of concrete.
- The shear stress-slip behavior and shear stress-crack width behavior.
- Modes of Failure.

8.1 Ultimate Shear Strength

The load at failure is recorded directly from the calibrated load cell. The loads at failure and shear strength are listed in **Table 10**. In which, the ultimate shear strength is calculated by dividing the axial compression force at the failure by the shear plane area (length of the shear plane which is 200 mm by the width of the shear plane which is 150 mm).

The maximum shear strength occurred at the specimen constructed from RPC with 0.5% steel fiber (L5-RPC), this is due to the high compressive strength of RPC, and minimum shear strength occurred in NSC specimen without steel fiber (L2fib0%), this is due to the low compressive strength of concrete. Further, the shear reinforcement, compressive strength of concrete, steel fiber content have important factors that influence the shear strength of concrete as will discuss in the following sections.

8.2 The Effect of Steel Fiber Content

As pointed before, the tested specimens have three percentages of fibers content; the specimen L2-fib0% has 0% steel fiber content, the specimen L1-Ref has 0.5% steel fiber content and the specimen L3-fib1% has 1% steel fiber content.

According to **Table 11**, the shear strength of concrete enhancement is increased by 34.6% and 76.9% when the steel fiber content is increased from 0% to 0.5% and from 0% to 1% respectively.

As mentioned before, the failure mechanism of shear in concrete is the tensile strength in a direction perpendicular to the applied load. Therefore, the steel fiber content plays major role in improving the tensile strength and consequently the shear strength.

8.3 The Effect of Compressive Strength of Concrete

To study the effect of compressive strength of concrete on direct shear strength, a three push-off specimen were tested. L6-fc15 specimen from NSC has a compressive strength of 15.6 MPa, L1-Ref specimen from NSC has a compressive strength of 31.5 MPa and L5-RPC specimen from RPC has a compressive strength of 105.1 MPa. The loads at failure and shear strength are listed in **Table 12**. Increasng the compressive strength of concrete from 15.6 to 31.5 MPa increased the shear strength of concrete by 118.7%, and increasing the compressive strength from 15.6 to 105.1 MPa increased the shear strength of concrete by 568.7%. These findings indicate that the shear strength of concrete significantly affected by the compressive strength of concrete.

8.4 The Effect of Transverse Reinforcement Ratio

To investigate the effect shear reinforcement on the concrete shear strength, deformed horizontal bars passing through the plane of shear were used to represent the lateral constraint. The comparison is made between the specimen L4-Rei0.53% which has transverse reinforcement of two horizontal deform bars of 10 mm in diameter (shear reinforcement = 0.53%) with L2-Ref specimen without transverse reinforcement.

According to test results listed in **Table 13**, the shear strength was increased by 57.1% when the shear reinforcement was increased from 0% to 0.53%. This expectedly due to the major role of shear reinforcement to resist the applied axial force due to dowel action.

8.5 The shear stress-slip behavior

In this section, the behavior of shear stress-slip is studied. The shear stresses were calculated as mentioned before by dividing the vertical axial compression force on the shear plane area. The shear slip means the relative displacement between the two parts of L blocks in the push-off specimen which was measured using dial gauge installed at the end of the specimen. **Fig. 9** shows the shear stresses and slip relationship.

The test results indicate that the specimen with shear reinforcement (L4-Rei0.53%) has the significantly lesser shear slip than the specimen without shear reinforcement (L1-Ref). Further, the specimen with low compressive strength (L6-fc15) or specimen without steel fiber (L2-fib0%) shows a higher shear slip in comparisons with the reference specimen (L1-Ref).

Using RPC (L5-RPC) instead of NSC (L1-Ref) in constructing the push-off specimen results in an increase in the shear slip, this is due cementitious nature of RPC.

It was remarkable, that the specimen L4-Rei0.53% with lateral constraint has rapid progression failure after yielding of transverse reinforcement.

The stiffness of L4-Rei0.53% specimen constructed with shear reinforcement was greater than the other specimens; this is due to lateral constrained. Further, the stiffness of RPC (L5-RPC) was greater than specimens constructed from NSC (L1-Ref).

The brittle nature of shear failure in concrete member results in the approximately linear behavior of shear stress-slip relationship of NSC as well as in RPC.

8.6 Shear Stress-Crack Width Behavior

An average crack width in the transverse direction to the applied axial compression force during load increments were recorded using two dial gauges installed at begging and end of the middle-third length of the shear plane. The shear stress, in contrast, to crack width for tested specimens is illustrated in **Fig. 10**. One can see from **Fig. 10**, the crack width of the RPC specimen was greater than NSC specimens. This is due to the cementitious nature of RPC. Also, the specimen with shear reinforcement (L4-Rei0.53%) has the less crack width till the peak load and sudden large crack width after ultimate load.

Comparison between the crack width in L1-Ref and L3-fib1% specimen shows that the increase in steel fiber content decreases the crack width as the steel fiber restraint the widening of crack through bridging effect,
It was also remarkable, that the absence of steel fiber or decrease the compressive strength of concrete from 28.5 MPa to 15.6 MPa as in L2-fib0% and L6-fc15 specimen respectively in comparisons with the reference specimen L1-Ref, increased the value of crack width. This, due to constrained of crack width occurred from the presence of steel fiber or higher value of compressive strength used.
In particular, in NSC the crack width in direct shear test influenced by the three major factors; crack surface friction, aggregate interlock and steel fiber content if present. Whereas, in RPC has only steel fiber and crack surface friction influence the crack width. This, due to cementitious nature of RPC in comparisons with NSC, therefore, the RPC specimen (L5-RPC) shows the highest value of crack width in compares with NSC specimens.

8.7 Modes of Failure

In the direct shear test, there are no flexural cracks in the horizontal arms of the push-off specimen were observed, this, due to sufficient main reinforcing bars had been provided to resist the flexural failure.
The shear cracks generally developed along the interface between coarse aggregate and mortar. In this surface, due to shear deformation, the frictional force will develop namely aggregate interlock which represents the shear strength of concrete. The amount of coarse aggregate in unit volume of concrete had the predominant factor in shear strength of concrete. The concrete compressive strength and lateral constraint also had a significant influence on the shear strength of concrete members.
In the RPC, no coarse aggregates in the unit volume are used and presence of steel fiber has the dominant role of shear transfer capabilities.
The failure of push-off specimens occurred suddenly with a loud noise due to the brittle manner of failure.
According to **Fig. 11**, the mode of failure for NSC and RPC are identical; started with a crack at or near the junction line between two L blocks (at shear plane). By load increments, the crack widening and moves along the shear plane. This type of failure is the typical failure in direct shear tests.

9. PREDICTION OF SHEAR STRENGTH CAPACITY

From the observation of test results, the push-off specimen fails in two stages: (1) the shear stress controlled by the concrete alone (cohesive of concrete plus aggregate interlock) till the concrete shear friction capacity is reached; and (2) additional shear stress is resisted by the shear reinforcement (dowel action).
A general model of ultimate shear strength can be written as:

$$v_u = v_c + v_{bar} \qquad .....(3)$$

Where; v_c is the shear friction of concrete; v_{bar} is the shear stress resisted by the shear reinforcement.

According to experimental work presented by **Mattock, 2001,** Equation 8 is presented in the form of:

$v_u = 0.117 f_c^{'} + 0.8\, \rho_b\, f_y$ …..(4)

Where; 0.117 is the shear friction factor of concrete; $f_c^{'}$ is the compressive strength of concrete cylinders; ρ_b is the shear reinforcement ratio; and f_y is the yield stress of reinforcing bar.

This equation is similar to the models proposed by **Birkeland** and **Birkeland**, **Hofbeck, et al.**, **1966**, **Mattock** and **Hawkins, 1972**, and **Kahn** and **Mitchell**, **2002**.
The present test results were compared with the Mattock model to check the applicability of this model in NSC and RPC, with and without shear reinforcement, with and without steel fiber. The comparisons are presented in **Table 14**.
It is observed that the Mattock model gives very satisfactory predictions when applied to the present test results with a range of parametric variations; ranging from 0 % to 0.5 % in steel fiber content; from 0 % to 0.53 % in shear reinforcement ratio; from 15 to 105 MPa in compressive strength of concrete. While it gives a poor prediction for a specimen with 1% steel fiber.

10. CONCLUSIONS

- The shear strength of concrete was significantly affected by the compressive strength of concrete and steel fiber content.
- The shear reinforcement is the predominant factor in resisting the shear stress due to dowel action.
- The shear failure of NSC and RPC has the sudden mode of failure (brittle failure) with the approximately linear behavior of shear stress-slip relationship till failure.
- Using RPC instead of NSC with the same amount of steel fibers in constructing concrete specimens result in significantly higher shear strength of concrete.
- In NSC the shear strength influenced by the three major factors; crack surface friction, aggregate interlock and steel fiber content if present. Whereas, in RPC has only steel fiber and crack surface friction.
- Due to cementitious nature of RPC in comparisons with NSC, the RPC specimen shows the higher value of crack width in compares with NSC specimens.
- In NSC, increase the compressive strength of concrete or increase the steel fiber content results in a smaller shear slip and smaller crack width.
- The shear stiffness of RPC specimen was 205.7% greater than that of NSC specimen.

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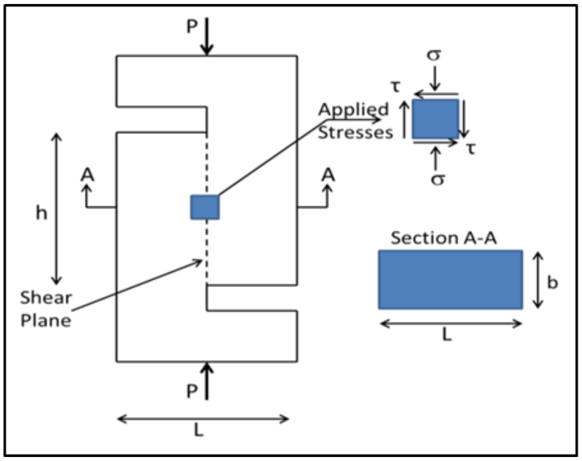

Figure 1. Push-off specimen.

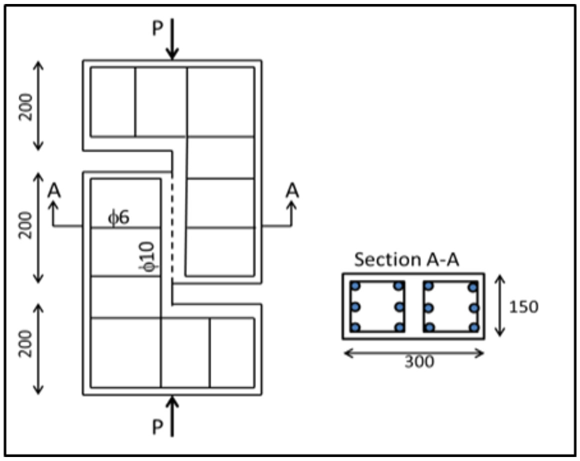

Figure 2. Steel reinforcement details.

Figure 3. Typical mold with reinforcement.

Figure 4. Casting the concrete into specimen.

Figure 5. Concrete cubes at failure.

Figure 6. Concrete cylinders after failure.

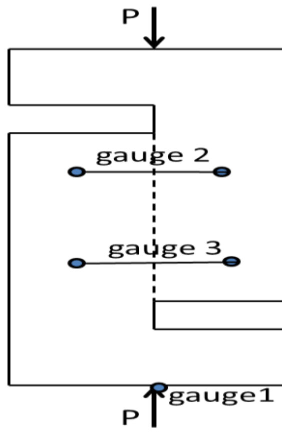

Figure 7. Locations of dial gauges.

Figure 8. The push-off specimen under test.

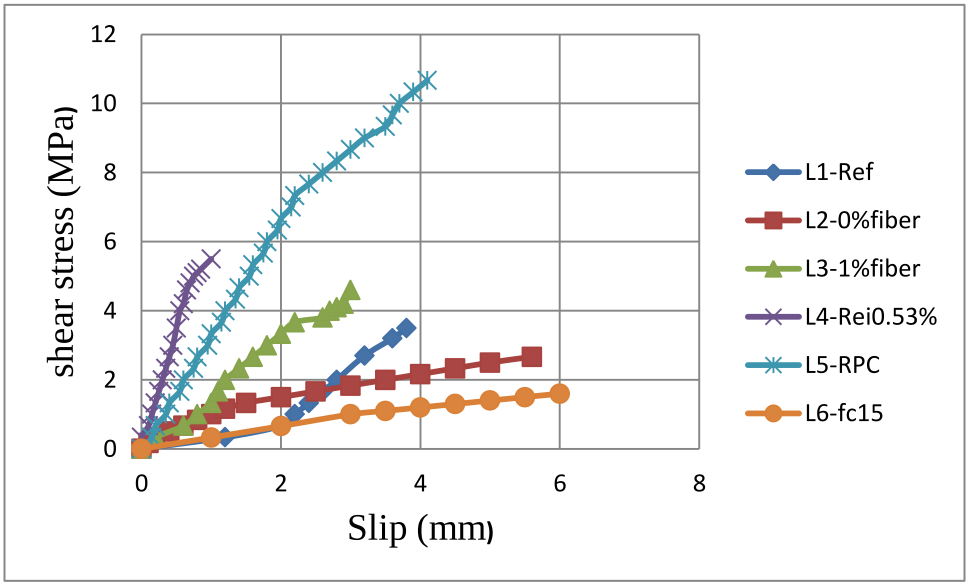

Figure 9. Shear stress-slip relationship.

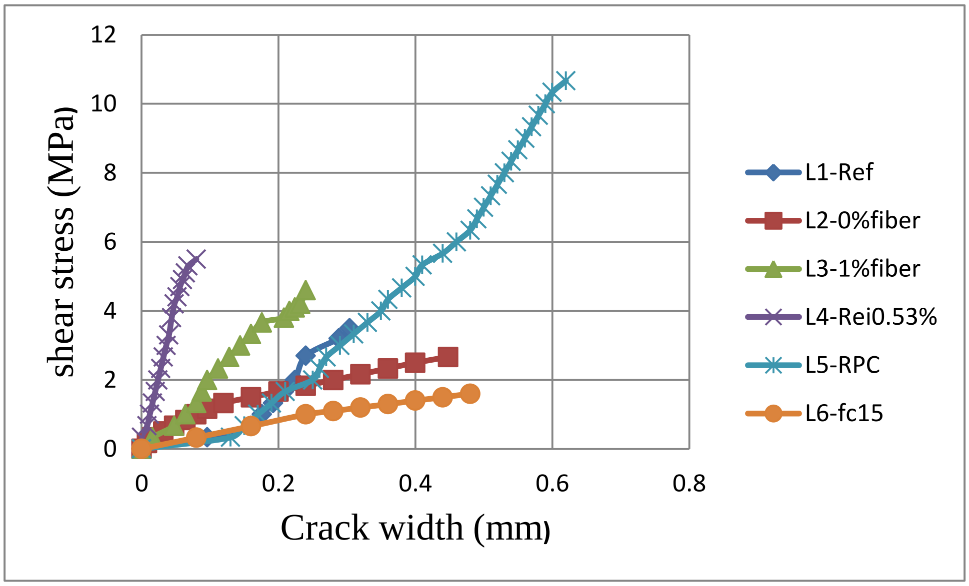

Figure 10. Shear stress-crack width behavior.

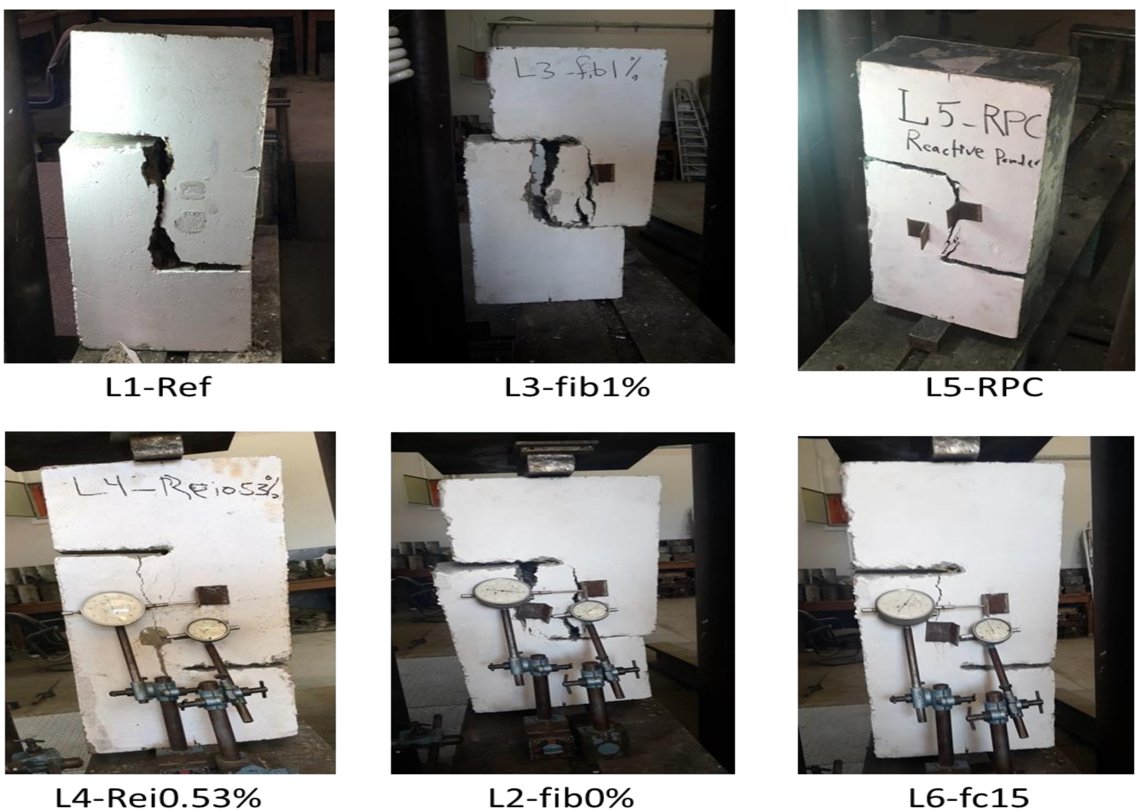

Figure 11. Modes of failure of tested specimen.

Table 1. Mix proportion of NSC.

Material	Weight (kg/m^3) for NSC1	Weight (kg/m^3) for NSC2
Cement (Kg/m3)	375	360
Gravel	1130	1080
Sand	660	775
Water	195	183.6
Water/Cement	0.52	0.51

Table 2. Slump test.

Type of Concrete	Slump (mm)
NSC1	50
NSC2	45

Table 3. Mix proportion of RPC.

Material	Weight (kg/m^3)
Cement	810
Silica Fume	186.3
Quartz Sand	631.8
Superplasticizer	36.4
Steel fiber (0.5%)	39.25
Water	170.1
Water/Cement	0.21
Water/Cementitious	0.170

Table 4. Physical properties of Portland cement**.**

Physical properties	Test results	Limits of Iraqi specification No.5/1984
Specific surface area m2/kg	372	≥230
Soundness (Autoclave) %	0.01	≤0.8
Setting time (Vicat′s apparatus) Initial setting time, hrs: min Final setting time, hrs: min	 3:58 4:50	 ≥45 min ≤10 hrs
Compressive strength 3 days (MPa) 7 days (MPa)	 29.80 34.84	 ≥15 ≥23

Table 5. The chemical composition of Portland cement.

Oxide composition	Abbreviation	Content (%)	Limit of Iraqi specification No.5/1984
Lime	Cao	62.44	-
Silica Dioxide	SiO2	20.25	-
Alumina Trioxide	Al2O3	4.73	-
Iron Oxide	Fe2O3	4.32	-
Magnesia Oxide	MgO	1.5	≤5.0%
Sulphate	SO3	1.88	≤2.8% if C3A>5%
Loss on Ignition	L.O.I	3	≤4.0%
Insoluble residue	I.R.	0.8	≤1.5%
Lime saturation factor	L.S.F.	0.93	0.66-1.02
Main compounds (Bogue′s equation)			
Tricalcium Silicate	C3S	56.9	-
Dicalcium Silicate	C3S	15.21	-
Tricalcium Aluminate	C3A	5.23	-
Tetracalcium alumino-ferrite	C4AF	13.13	-

Table 6. Fine aggregate properties**.**

Sieve size (mm)	Cumulative passing %	Limits of Iraqi specification No.45/1980, zone 2
4.75	100	90-100
2.36	90.15	75-100
1.18	74.22	55-90
0.6	51.37	35-59
0.3	19.3	8-30
0.15	3.79	0-10
Fineness modulus=2.61		
Specific gravity=2.65		
Sulfate content=0.08% (Iraqi specification requirement ≤0.5%)		
Absorption=0.75%		

Table 7. Coarse aggregate properties**.**

Sieve size (mm)	Cumulative passing %	Limits of Iraqi specification No.45/1980, zone 2
14	100	100
10	100	85-100
5	15.3	0-25
2.36	0.53	0-5
Specific gravity=2.66		
Sulfate content=0.08% (Iraqi specification requirement ≤0.1%)		
Absorption=0.52%		

Table 8. The compressive and tensile strength of concrete.

Type of concrete	Average compressive strength of cubes (MPa)	Average tensile strength of cylinders (MPa)
NSC1	15	2.2
NSC2	30	4.1
RPC	105	9.8

Table 9. Characteristics of tested specimens.

Specimen	Type of concrete	Fiber Content (%)	f_{cu} (MPa)	Shear Reinforce ment ratio (%)
L1-Ref	NSC	0.5	30.2	0
L2-fib0%	NSC	0	28.5	0
L3-fib1%	NSC	1	35.6	0
L4-Rei0.53%	NSC	0.5	30.3	0.53
L5-RPC	RPC	0.5	105.1	0
L6-fc15	NSC	0.5	15.6	0

Table 10. Shear strength of push-off specimens.

Specimen	Type of concrete	Fiber Content (%)	f_{cu} (MPa)	Shear Reinforcement ratio (%)	Failure load (kN)	Ultimate shear strength (MPa)
L1-Ref	NSC	0.5	30.2	0	105	3.5
L2-fib0%	NSC	0	28.5	0	80	2.6
L3-fib1%	NSC	1	35.6	0	140	4.6
L4-Rei0.53%	NSC	0.5	30.3	0.53	165	5.5
L5-RPC	RPC	0.5	105.1	0	320	10.7
L6-fc15	NSC	0.5	15.6	0	50	1.6

Table 11. Effect of steel fiber content on shear strength.

Specimen	Fiber content (%)	Load at failure (kN)	Ultimate shear strength (MPa)
L2-fib0%	0	80	2.6
L1-Ref	0.5	105	3.5
L3-fib1%	1	140	4.6

Table 12. Effect of compressive strength of concrete on shear strength.

Specimen	Compressive strength (MPa)	Load at failure (kN)	Ultimate shear strength (MPa)
L6-fc15	15.6	50	1.6
L1-Ref	31.5	105	3.5
L5-RPC	105.1	320	10.7

Table 13. Effect of shear reinforcement on the shear strength of concrete.

Specimen	Transverse reinforcement ratio (%)	Load at failure (kN)	Shear strength (MPa)
L1-Ref	0	105	3.5
L4-Rei0.53%	0.53	165	5.5

Table 14. Comparison between the present and Mattock ultimate shear strength.

Specimen	Type of concrete	Fiber Content (%)	f_{cu} (MPa)	Shear Reinforce ment ratio (%)	Exprimental shear stress (MPa)	Mattock shear stress (MPa) [10]	Ratio of present and Mattock shear strength
L1-Ref	NSC	0.5	31.5	0	3.5	2.95	0.84
L2-fib0%	NSC	0	28.5	0	2.6	2.66	1.02
L3-fib1%	NSC	1	35.6	0	5.3	3.33	0.62
L4-Rei0.53%	NSC	0.5	30.3	0.53	5.5	4.6	0.84
L5-RPC	RPC	0.5	105.1	0	10.7	9.83	0.92
L6-fc15	NSC	0.5	15.6	0	1.6	1.46	0.92