Comparison between the Behaviors of Different Concrete Types in Various Shear Tests

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Abstract. A comparison between three direct shear test specimens of (push-off shear specimens, FIP shear test, and inverted “L” shape shear failure plane) was investigated experimentally and numerically and cast using normal, high and ultra-high-strength concrete with the effect of steel fiber. This paper presents which shear strength analysis settings in which testing operation and arrangement of mold can be performed by the simplest and at the same rate guarantees stable and steady results. Many variables were chosen to investigate its impact on shear test and behavior. These variables are grade of concrete, steel fiber volume fraction, method of testing, type of loading and size of shear failure plane area. A comparison between experimental work and the finite element method offers a powerful and generic tool for studying the behavior of many structures by ANSYS program which can represent many structures. It was found that the inclusion of steel fiber enhances the ultimate shear capacity of the concrete compared to plain concrete and leads to ductile failure method, higher ultimate strength in addition to much enhanced integrity of structure.

1. Introduction

The joint resistance between two surfaces of two concrete layers represents the shear strength that appears during slipping [1-4]. In concrete structures, shear failure is considered a brittle failure. The method that converts concrete from brittle concrete to ductile concrete is by placing steel fiber with the concrete mixture and making concrete a homogeneous and isotropic material. The way to increase the durability of concrete is to add fiber fibers when mixing concrete [5-8]. Where these fibers are randomly distributed between the concrete mix and its function to stop or prevent the development of cracks or reduce the width of concrete cracks. It will be noted that the increase in the amount of fiber will lead to increased shear strength and the bearing of the concrete structure was fiber transferring the load from the concrete to the fiber. Increasing the amount of fiber in the concrete matrix works to stop the cracks and controls the propagation in the various concrete members [9-18]. To assess shear strength, there are several test methods: which are the push-off specimen Figure 1a, standard method (JSCE) Figure 1b, and FIP standard method Figure 1c.

Figure 1. Different shear tests.
Bairagi N K and Modhera C D (2004) [3] introduced an experimental design model for obtaining shear strength in the inadequacy of any standard scheme to estimate shear. They investigated the probability and safety of the test scheme recommended by them with the analysis method presented by JSCE method and concluded that the advanced method is more simplistic to manage related to the JSCE system. Maroliya M K (2012) [4] proposed a simple and reliable shear strength test setup with consistent results by testing a series of direct shear specimens with fiber randomly oriented in shear failure plane.

Experimental study with different variables on a comparison between three direct shear strength test adopting of normal, high and ultra-high-strength concrete material. A numerical simulation of three shear test using the finite element nonlinear 3D analysis is presented by using Ansys program, was also carried out and the results are compared with the experimental values.

2. Test Set-Up Specimen

Test included push-off specimen with dimensions of (340mm*200mm*100mm height, wide, and length) with shear failure plane of (100mm*100mm) and loading as shown in Figure 2, FIP standard test with dimensions (100mm*100mm*400mm, wide, height and length) with shear failure plane of (100mm*100mm) and loading as shown in Figure 3, and inverted “L” shape shear test with dimensions of (150mm*150mm) and shear failure plane of (150mm*70mm) as shown in Figure 4.

Figure 2. Details of Push-off test specimens and loading type.

Figure 3. Details of FIP shear test dimensions and loading set-up.

Figure 4. Details of L-shape test specimens and loading type, (all dimensions are in mm).

3. Mix Proportions and Mechanical Properties of concrete

Wooden and steel molds were prefabricated to cast the specimens. The experimental program includes testing 27 specimens with different concrete types tested under shear. Tests results of mechanical properties (compressive strength) of (normal, high and ultra-high-strength concrete) are shown in Tables 1 which presented mix proportions for all concrete mixes and Figures 5, 6 and 7. Result revealed that the effect of steel fiber has improved and increased compressive strength. Figure 8 presents the preparation of the samples, mixing of concrete and curing.
When steel fiber increases from (0, 1 and 2%) an increase in average compressive strength of about (0, 5.7 and 10%), (0, 10.2 and 18.6%) and (0, 18.1 and 41.7%) for normal concrete (NC), high strength concrete (HSC) and ultra-high strength concrete (UHSC).

**Table 1. Compressive strength of (normal, high and ultra-high strength concrete).**

| Mix  | Cement (kg/m³) | Sand (kg/m³) | Aggregate (kg/m³) | w/c | Superplasticizer (%) by weight of cement | Silica fume by weight of cement | Steel fiber % by volume | Concrete Type | Compressive strength (MPa) | (%) compressive strength |
|------|----------------|--------------|-------------------|-----|------------------------------------------|-------------------------------|------------------------|---------------|---------------------------|------------------------|
| N1   | 450            | 640          | 1000              | 0.5 | 0                                        | 0                             | 0                      | Normal Concrete       | 35                      | 0.0                    |
| N2   | 450            | 640          | 1000              | 0.5 | 0                                        | 0                             | 1                      | Normal Concrete       | 37                      | 5.7                    |
| N3   | 450            | 640          | 1000              | 0.5 | 0                                        | 0                             | 2                      | Normal Concrete       | 38.5                    | 10.0                   |
| H1   | 560            | 650          | 1000              | 0.2 | 1.5                                      | 10%                           | 0                      | High strength concrete| 59                      | 0.0                    |
| H2   | 560            | 650          | 1000              | 0.2 | 1.5                                      | 10%                           | 1                      | High strength concrete| 65                      | 10.2                   |
| H3   | 560            | 650          | 1000              | 0.2 | 1.5                                      | 10%                           | 2                      | High strength concrete| 70                      | 18.6                   |
| UH1  | 1000           | 1000         | 0                 | 0.2 | 6                                        | 25%                           | 0                      | Ultra-high strength concrete| 72                      | 0.0                    |
| UH2  | 1000           | 1000         | 0                 | 0.2 | 6                                        | 25%                           | 1                      | Ultra-high strength concrete| 85                      | 18.1                   |
| UH3  | 1000           | 1000         | 0                 | 0.2 | 6                                        | 25%                           | 2                      | Ultra-high strength concrete| 102                     | 41.7                   |

**Figure 5.** Effect of fiber content on compressive strength of NC.

**Figure 6.** Effect of fiber content on compressive strength of HSC.

**Figure 7.** Effect of fiber content on compressive strength of UHSC.
4. Testing of Control Specimens (Compressive Strength Test)

Mix design is the process of adopting the most suitable materials of concrete and determining their relative quantities to achieve the desired strength. The compressive strength test was performed according to [ASTM C 39/C39M-01] on (100mm×200mm cylinders) cured for 28 days for all concrete types using a compression machine as shown in Figure 9. Three specimens average were used to determine the compressive strength for all mixes.

5. Shear strength Results and Discussions

The improvement in the shear strength is achieved from the steel fiber. Laboratory results displayed in Table 2 reveals that the concrete ultimate shear strength with the incorporation of fibers improves extremely and it can be noticed that the specimens do not fail suddenly, moreover higher shear load was concluded. Conventional shear strength difference concerning volume fraction of fiber has been plotted in Figures from 10-17. It can be remarked that the ultimate improvement in shear strength is observed for 2% fiber volume fraction. From table in can be concluded that the L-shape give convergent result to FIP test of about (90%), while for push of test the relation is about (70%), this is an indication that the push-off test gives much higher stresses compared to other test and the L-shape is a simple shear test design which possesses simplicity in design, casting, testing and presented results almost similar to the coded shear test.

| Mix | Concrete type | Shear strength (MPa) inverted L shape test (%) | Shear strength (MPa) Push off test (%) | Shear strength (MPa) FIP test (%) | FIP test/ L shape test | FIP test/ Push off test |
|-----|---------------|---------------------------------------------|---------------------------------------|----------------------------------|------------------------|------------------------|
| N1  | Normal        | 4.44                                        | 0.0                                   | 5.81                             | 0.0                    | 4.03                   | 0.0                    | 90.8                  | 69.4                  |
| N2  | Normal        | 6.74                                        | 51.8                                  | 8.12                             | 39.8                   | 6.14                   | 52.4                   | 91.1                  | 75.6                  |
| N3  | Normal        | 9.64                                        | 117.2                                 | 11.62                            | 100.0                  | 8.79                   | 118.1                  | 91.2                  | 75.6                  |
| H1  | High          | 5.76                                        | 0.0                                   | 6.94                             | 0.0                    | 5.26                   | 0.0                    | 91.3                  | 75.8                  |
| N2  | High          | 9.24                                        | 60.4                                  | 11.14                            | 60.5                   | 8.43                   | 60.3                   | 91.2                  | 75.7                  |
| N3  | High          | 12.90                                       | 124.0                                 | 15.56                            | 124.2                  | 11.76                  | 123.6                  | 91.2                  | 75.6                  |
| UH1 | Ultra-High   | 6.36                                        | 0.0                                   | 7.67                             | 0.0                    | 5.8                    | 0.0                    | 91.2                  | 75.6                  |
| UH2 | Ultra-High   | 10.91                                       | 71.5                                  | 13.16                            | 71.6                   | 9.96                   | 71.7                   | 91.3                  | 75.7                  |
| UH3 | Ultra-High   | 15.04                                       | 136.3                                 | 18.14                            | 136.5                  | 13.72                  | 136.6                  | 91.2                  | 75.6                  |
Figure 10. Normal concrete shear strength relationship with compressive strength for all shear tests.

Figure 11. Normal concrete shear strength relationship with fiber content for all shear tests.

Figure 12. High strength concrete shear strength relationship with compressive strength for all shear tests.

Figure 13. High strength concrete shear strength relationship with fiber content (%) for all shear tests.

Figure 14. Ultra-high strength shear strength relationship with compressive strength for all shear tests.

Figure 15. Ultra-high strength shear strength relationship with fiber content (%) for all shear tests.
6. Mode of Failure and Crack Patterns

In this study, 27 specimens were tested with different shapes and sizes. According to these variables, ultimate loads, crack patterns, as well as modes of failure, are different. For the non-fibrous specimens, the specimens failed by brittle compression failure with cracks along and parallel to the shear plan formed at lower loads. For fibrous specimens when the load was applied to the specimens, minor cracking at the shear region took place, as load increased, the crack did not open widely since the extension of the crack was arrested by the fibers. The fibers increase the friction force between the fiber and the matrix.

Figure 18 shows the failure and the cracks pattern for all shear test.

Figure 16. Shear strength relationship with compressive strength for all types of concrete and all shear test.

Figure 17. Shear strength relationship with fiber content (%) for all types of concrete and all shear test.
7. Nonlinear Finite Element Modeling (ANSYS)

The finite element method with a computer program (ANSYS) has been used for modeling all the specimens in the present study [19-21]. Modeling of structures involves creation elements of various components to represent the structural behavior including boundary conditions, material properties and loading. In this study, a comparison between three direct shear specimens of (push-off shear specimens, FIP shear test, and inverted “L” shape shear failure plane) was presented for various concrete types with many variables, and the results are compared with the experimental results by keeping same loading and material properties. After preparing all the available data of material and geometrical properties, all specimens were divided into no. of elements and the boundary conditions are needed to be applied where the supports and loadings exist to ensure that the model acts the same way as the experimental specimens. Table 3 shows a comparison of the finite element results with the experimental results for all specimens in which Ansys have a powerful simulation capability. Figure 19 shows the modeling of specimens, boundary conditions, loadings, meshing and stress diagram. Loads are applying on the top of the specimen, as nodal loads.

8. Results and Discussion

The maximum shear stress is defined as the ultimate shear strength during the test as the specimens can carry. The ultimate force carried by the specimens represented the shear transfer through the shear plane divided by the area of the shear plane. In this research, three shear plane area equals to (150x70mm for L-shape specimen, 100x100mm for FIP specimen and 100x100mm for push-off test specimen). Many geometry specimens for different shapes of the direct shear test were studied using finite element analysis. For all specimens the shear failure are concentrated in the shear failure plane area, as a result, and the figures below shows that shear crack propagation can be observed at the middle of prism for (FIP test), shear stresses are concentrated near the shear zone boundaries and decreased toward the center of the shear plane for (push-off test) and for the (L shape specimen) the stresses are concentrated at the connection area of L shape. The effect of steel fiber reduces the cracking propagation regarding the shear forces. The increasing in steel fiber and grading of concrete lead to an increase in ultimate shear strength. Plain concrete specimens showed, as expected, a sudden and brittle failure at a very low shear strain. The specimens with a higher percentage of fibers carried a higher load due to the steel fibers in the concrete mix. This may be due to the bridging and confining effect of the steel fibers to the composite.

| Mix | Concrete type | Shear strength (MPa) Push off test EXP. | Finite element | FEM/EXP. | Shear strength (MPa) FIP test EXP. | Finite element | FEM/EXP. | Shear strength (MPa) inverted L shape test EXP. | Finite element | FEM/EXP. |
|-----|----------------|-----------------------------------------|----------------|----------|------------------------------------|----------------|----------|-----------------------------------------------|----------------|----------|
| N1  | Normal         | 5.81                                    | 5.35           | 0.92     | 4.03                               | 3.7            | 0.92     | 4.44                                         | 4.19           | 0.94     |
| N2  | Normal         | 8.12                                    | 7.71           | 0.95     | 6.14                               | 5.67           | 0.92     | 6.74                                         | 6.62           | 0.98     |
| N3  | High           | 11.62                                   | 10.81          | 0.93     | 8.79                               | 8.12           | 0.92     | 9.64                                         | 9.47           | 0.98     |
| H1  | High           | 6.94                                    | 6.80           | 0.98     | 5.26                               | 4.8            | 0.91     | 5.76                                         | 5.39           | 0.94     |
| H2  | High           | 11.14                                   | 10.81          | 0.97     | 8.43                               | 7.89           | 0.94     | 9.24                                         | 8.96           | 0.97     |
9. Parametric study

9.1 Effect of size of shear failure plane area

The inverted “L” shape is taken here to study the area size of the shear plane as shown in table 4. Three shear failure planes were taken in this paper to study its effect on shear strength and behavior as shown in Figure 20. These planes are (150mm*70mm), (150mm*60mm) and (150mm*80mm). The theoretical study shows that shear failure planes with size (150mm*70mm) give the closet solution to the experimental test specimens. These behaviors are agreed with the experimental work of Bairagi N K and Modhera C D (2004) [3]. Figure 21 shows the effect of the size of the shear failure plane area for different concrete.

Table 4. Effect of size of shear failure plane area.

| Mix | Concrete type | EXP. (MPa) | Finite element (Ansys) (150mm*70mm) (MPa) | FEM/EXP. | Finite element (Ansys) (150mm*60mm) (MPa) | FEM/EXP. | Finite element (Ansys) (150mm*80mm) (MPa) | FEM/EXP. |
|-----|---------------|------------|----------------------------------------|----------|----------------------------------------|----------|----------------------------------------|----------|
| H3  |               | 15.56      | 14.78                                  | 0.95     | 11.76                                  | 10.86    | 0.92                                   | 12.90    | 12.72                                  | 0.99     |
| UH1 | Ultra-High    | 7.67       | 8.44                                   | 1.1      | 5.8                                    | 5.35     | 0.92                                   | 6.36     | 6.02                                   | 0.95     |
| UH2 |               | 13.16      | 12.11                                  | 0.92     | 9.96                                   | 9.3      | 0.93                                   | 10.91    | 10.52                                  | 0.96     |
| UH3 |               | 18.14      | 17.23                                  | 0.95     | 13.72                                  | 12.66    | 0.92                                   | 15.04    | 14.68                                  | 0.98     |

Figure 19. Modeling of specimens, boundary conditions, loadings, meshing and stress diagram.
9.2 Effect of loading type
The inverted “L” shape is taken here to study the loading type of shear plane as shown in Table 5. Two loading types were taken to study its effect on shear strength and behavior as shown in Figure 22. These types are (circular loading) and (rectangular loading). The experimental and theoretical study shows that rectangular loading gives higher load and shear stress compared to circular loading with increasing in a load of about (5.86, 6.77 and 7.23%) for normal, high and ultra-high-strength concrete. These behaviors are agreed with the experimental work of Bairagi N K and Modhera C D (2004) [3]. Figure 23 shows the effect of loading type on the shear failure plane area for different concrete types.

Table 5. Effect of loading type.

| Mix  | Concrete type | EXP. (MPa) | Finite element (Ansys) (circular) (MPa) | FEM/EXP. | EXP. (MPa) | Finite element (Ansys) (rectangular) (MPa) | FEM/EXP. | % Increasing with rectangular load |
|------|---------------|------------|----------------------------------------|----------|------------|------------------------------------------|----------|-----------------------------------|
| N1   | Normal        | 4.44       | 4.19                                   | 0.94     | 4.03       | 0.91                                     | 4.08     | 0.918                             |
| H1   | High          | 5.76       | 5.39                                   | 0.94     | 5.3        | 0.92                                     | 5.64     | 0.98                             |
| UH1  | Ultra-High    | 6.36       | 6.02                                   | 0.95     | 5.97       | 0.94                                     | 6.17     | 0.97                             |
Comparison between Exp., FEM, others Equations for Shear Strength Prediction

Many researchers try to propose the shear strength in terms of equation depend on their data and other researchers’ data. But when comparing the shear strength obtained from the experimental test with other equations, differences have appeared. Some researcher’s equations are presented here:

Khanlou et al. (2013) [9] proposed empirical formula depends on their data and other data to predict the shear strength, through a regression analysis for these data. Their equations are separated into two equations, one with fiber and the other without fiber. Their equations depend mainly on compressive strength and fiber volume frication, where:

$$\tau_u = 0.75 \times \sqrt{f'_c} + 4 \times V_f^{0.9}$$

... (1)

Where $f'_c$ is a cylinder compressive strength for fiber concrete, and $v$ is the volume fraction of fiber.

For non-fiber concrete the equation is expressed as:

$$\tau_u = 0.75 \times \sqrt{f'_c}$$

... (2)

Khaloo and Kim (1997) [22] proposed an equation for shear strength to plain concrete depends on their experimental results:

$$\tau_u = 0.65 \times \sqrt{f'_c}$$

... (3)

Mansur et al. (2008) [10] proposed an equation for shear strength to plain concrete depends on their experimental results:

$$\tau_u = 0.56 \times (f'_c)^{0.615}$$

... (4)

Boulekbache et al. (2012) [23] change the correlations of others proposed equation for shear strength of plain concrete to be:

$$\tau_u = 0.72 \times (f'_c)^{0.8}$$

... (5)

The experimental shear strength from the test and shear strength taken from others equations are plotted as shown in the Figures from 24-28 and presented in Table 6, where figures shows a comparison between the experimental test results and the results from others proposed equations for ultimate shear strength.

It can be seen that the equation proposed by Mansour et al. (2008) [10] gives the closet results to the present experimental work but only for the mixes without fiber and for the mixes contains fiber the results is much lower than the present experimental work results.

### Table 6. Comparison between experimental shear strength and researchers equations.

| Mix | Concrete type | $f'_c$ (MPa) | SF % | Shear strength (MPa) Push off test | Shear strength (MPa) FIP test | Shear strength (MPa) inverted L shape test | Khanlou et al. (2013) [9] | Khaloo and Kim (1997) [22] | Mansur et al. (2008) [10] | Boulekbache et al. (2012) [23] |
|-----|---------------|--------------|------|----------------------------------|-------------------------------|------------------------------------------|-----------------------------|--------------------------|-----------------------------|-------------------------------|
|     |               |              |      |                                  |                               |                                          |                             |                          |                             |                               |
### Table

| Sample Type | Value   | Experimental Result | Khanlou et al. (2013) [9] Equation |
|-------------|---------|----------------------|------------------------------------|
| N1 Normal   | 35      | 5.81                 |                                    |
| N2 Normal   | 37 1    | 8.12                 |                                    |
| N3          | 38.5    | 11.62                |                                    |
| H1 High     | 59 0    | 6.94                 |                                    |
| H2 High     | 65 1    | 11.14                |                                    |
| H3          | 70 2    | 15.56                |                                    |
| UH1 Ultra-High | 72 0 | 7.67                 |                                    |
| UH2 Ultra-High | 85 1 | 13.16                |                                    |
| UH3         | 102 2   | 18.14                |                                    |

### Figures

**Figure 24.** Comparison between experimental result and Khanlou et al. (2013) [9] equation.

**Figure 25.** Comparison between experimental result and Khanlou et al. (2013) [9] equation.

**Figure 26.** Comparison between experimental result and Khaloo and Kim (1997) [22] equation.

**Figure 27.** Comparison between experimental result and Mansur et al. (2008) [10] equation.
11. CONCLUSIONS

1. This research represented an experimental study of shear forces tested by different tests. Three types of concrete were studied here these are (normal, high and ultra-high-strength concrete with or without steel fiber.

2. The experimental test work on all shear test shows that the samples specimens without fibers failed and fractured into a brittle behavior with no warning before the failure. While the presence and occupation of fiber in the specimen failed in a ductile manner, were the fiber increase the performance of concrete and increase the tensile and shear strength by fiber bridging the crack and prevent the concrete from fracture.

3. When steel fiber increases from (0, 1 and 2%) an increase in average compressive strength of about (0, 5.7 and 10%), (0, 10.2 and 18.6%) and (0, 18.1 and 41.7%) for normal concrete NC, high strength concrete (HSC) and ultra-high strength concrete (UHSC) were achieved.

4. It can be noted that the maximum increase in shear strength is found for 2.0% fiber volume fraction for all tests.

5. It can be concluded that the L-shape give convergent result to FIP test of about (90%), while for push of test the relation is about (70%), this is an indication that the push-off test gives much higher stresses compared to other test and the L-shape is a simple shear test design which possesses simplicity in design, casting, testing and presented results almost similar to the coded shear test.

6. The nonlinear finite element analysis (Ansys program) can be used to trace the behavior of shear transfer specimens with different shapes and different parametric study which shows good agreement with experimental results.

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