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Technical Research

# SHEAR TRANSFER BEHAVIOR OF FIBROUS CONCRETE

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**Abstract:** Fibrous concrete's shear strength behavior is important in structural design. Brackets, corbels, and ledger beams are examples of concrete members that might collapse in shear. Such a failure might be brittle and sudden. Fibers improve concrete's behavior by increasing residual shear transfer and reducing crack development and extension. In an experimental study, nine push-off specimens were divided into three groups and examined as part of the experiment. Conventional concrete, conventional concrete with 1% glass fiber, and conventional concrete with 1% steel fiber were the groups. There were three push-off specimens with various shear reinforcement ratios in each of the groups that were examined (0.0, 0.45, and 0.68%). The specimens utilized had dimensions of 500mm x 250mm x 125mm. The vertical slip and horizontal separation at the shear plane were measured using two-stroke linear variable displacement transducers (LVDT). The effect of fiber type and the ratio of transverse reinforcement across the shear plane were the parameters evaluated. According to test results, the presence of fibers enhances final shear strength, which is more obvious in specimens without stirrups in the shear plane. Where the addition of 1% of glass fiber to normal strength concrete increased ultimate shear strength by 32.26%, 12.38%, and 12.5%, while adding 1% of steel fiber to normal strength concrete increased ultimate shear strength by up to 53.22%, 19%, and 25%, respectively, for the specimens without stirrups, two stirrups, and three stirrups. The fibrous specimens were stiffer and ductile failure was seen. Steel fibers improved overall concrete shear behavior better than glass fibers.

**Keywords**: *Shear transfer; fibrous concrete; steel fiber; glass fiber*; *push-off test; direct shear*

## 1. Introduction

Shear transfer over an interface in reinforced concrete is one of the most important aspects of concrete mechanics to explore. Shear forces are transported over an interface in a variety of conditions. Shear transfer planes include existing or possible cracks in ledger beams and corbels; the interface between a cast-in-place slab and a precast girder in bridges; and a cold joint in a shear wall. These planes should be carefully constructed so that their shear strength exceeds the diagonal tension capacity of the adjacent components [1–3]. The brittleness of reinforced concrete parts' shear failure is widely recognized. Steel fibers increase tensile behavior, ductility, and crack control in concrete [4]. Steel fibers also increase the shear load capacity and ductility of structural parts [5]. The character of these fibers is to halt or prevent the formation of cracks or to lessen the breadth of concrete cracks when they are randomly dispersed amongst the concrete mix [6]. The shear transfer mechanisms have been investigated using the push-off test [7-9].

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## 2. Previous Studies

Al-Sulayvani and Al-Feel in 2009 [10] investigated the shear transfer of uncracked fibrous concrete. The push-off and modified push-off types of test specimens were employed in the investigation. The volume proportion of fibers, the number of stirrups crossing the shear plane, and the direct to shear stress ratio were also examined. The presence of fibers increased the first cracking load and shear transfer strength in both push-off and modified push-off specimens, with the increase being more apparent in specimens without stirrups in the shear plane. Fibrous specimens were stiffer, failed in a ductile way, and had higher strain capacities than plain specimens lacking fibers.

Al-Chalabi in 2011[11] used push-off samples with a shear plan height of 200mm and a thickness of 100mm to examine the impact of adding steel wire meshes on the shear strength of reinforced concrete. Based on the number of layers of wire mesh spanning the shear plane, three groups of eleven push-off specimens were constructed. The shear parameter of traditional stirrups (ρfy) and the angle between the shear plan of the push-off samples and the steel wire mesh layer plan were the other factors that were evaluated. The test findings revealed that the use of rather widely spread (approximately 40mm) steel wire meshes had only a negligible impact on the shear transfer strength. In the best circumstances, the increase in shear transfer strength was only around 8%. The findings were better when steel wire meshes were used in conjunction with traditional shear reinforcement (stirrups), but the improvement was only around 13% more than for specimens reinforced with the same number of stirrups but without steel wire meshes.

Ghailan in 2013 [12] studied how reactive powder concrete and modified reactive powder concrete members behaved and how strong they were in direct shear. The study tested components made of reactive powder concrete and modified reactive powder concrete to see how concrete variety, steel reinforcement variable, and steel fiber volume proportion affected the direct shear failure characteristics. The maximum slip decreased as the steel fiber volume percentage increased, while the ultimate strength increased, according to test data.

Al-Quraishi et al. in 2018[13] investigated the direct shear strength of fiber normal strength concrete (NSC) and reactive powder concrete. The research looked at the impact of concrete compressive strength, steel fiber volume fraction, and shear reinforcement ratio on shear transfer capacity. Failure mechanisms, shear stress-slip behavior, and shear stress-crack width behavior were also discussed in the study. The results of the tests revealed that the volume fraction of steel fiber and the compressive strength of concrete in NSC and RPC have a significant influence on enhancing concrete shear strength. As predicted, shear reinforcing is the most important component in resisting shear stress caused by dowel action. NSC and RPC shear failure featured a sudden mechanism of failure (brittle failure) with an almost linear shear stress-slip relationship till failure.

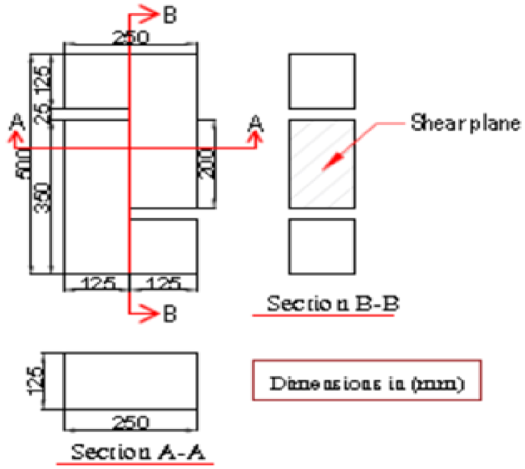
Madhlom et al. in 2021[14] introduced the study using push-off specimens to investigate the effect of fiber type and transverse reinforcement on shear transfer strength for fibrous concrete over an originally uncracked plane. The study investigated the effects of compressive strength, steel fiber percentages, aggregate presence, and shear reinforcement on shear strength. The findings revealed that increasing steel fiber content resulted in an improvement in shear strength and a decrease in brittleness. In comparison to the specimen without a shear rebar, the presence of a transverse steel rebar in the direction of the shear line improved the shear strength.

The influence of the steel fiber ratio and its connection with the shear reinforcement ratio on the behavior of direct shear strength is obvious from a review of the previous literature. There were no research papers that looked at the influence of glass fibers, specifically on direct shear. The present study investigated the impact of glass fibers on the shear transfer behavior of concrete. Also, the behavior of concrete with a 1% volume fraction of glass fibers, a 1% volume fraction of steel fibers, and a 0% volume fraction of fibers was compared under direct shear action.

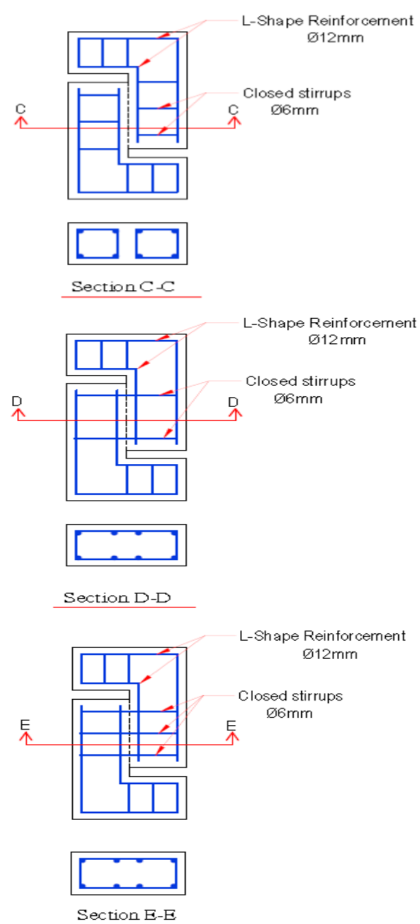
## 3. Experimental Investigation

### 3.1. General

Nine RC push-off specimens have been cast in the Structural Engineering Laboratory of the College of Engineering at Mustansiriyah University. Fig. 1 illustrates the specimen dimensions and their reinforcement. The specimens were made of concrete with a target compressive strength of 30MPa. The kinds of fiber (steel fiber and glass fiber) added to the concrete mixture, as well as the percentage of transverse reinforcement across the shear plane, were the parameters investigated. Push-off specimens were divided into three groups in the research. Table 1 shows the detailed groups.




a-Specimen Dimensions Details




b-Specimen Reinforcement Details

**Figure 1**. Specimens Dimensions and Reinforcement Details

**Table 1**. Characteristic of the tested specimens

| Group no. | Specimen ID | Fiber type | No. of Φ6mm stirrup |
|---|---|---|---|
| 1 | $NSC_0$ | None | 0 |
| | $NSC_2$ | None | 2 |
| | $NSC_3$ | None | 3 |
| 2 | $GFC_0$ | Glass fiber | 0 |
| | $GFC_2$ | Glass fiber | 2 |
| | $GFC_3$ | Glass fiber | 3 |
| 3 | $SFC_0$ | Steel fiber | 0 |
| | $SFC_2$ | Steel fiber | 2 |
| | $SFC_3$ | Steel fiber | 3 |

### 3.2. Materials Used

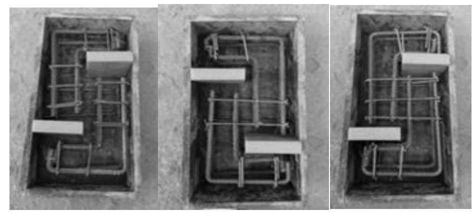
Throughout the test, ordinary Portland cement, complying with Iraqi Specification No.5/2019[15]. Washed natural sand and 12mm coarse aggregates were employed. The fine and coarse aggregates' physical qualities were found to comply with Iraqi standard No. 45/1984[16]. With a water-cement ratio of 0.45, the mixture ratio utilized was 1:1.5:3. Mild carbon steel fibers with hooked ends and alkali-resistant glass fibers with a volume fraction of ($V_f$=1.0%) were employed in this study. The 12mm and 6mm reinforcing bars used in the specimen construction had yield strengths of 495MPa and 615MPa, respectively.

### 3.3. Concrete mix

In a pan mixer, the needed amounts of components per cubic meter of concrete are batched and mixed as shown in Table 2. The concrete is then placed into push-off molds. Fibers were precisely weighed at 1.0% by the volume of concrete and properly mixed in until there was a consistent distribution of all materials and consistency without any lumps. Wet jute bags were used to cover the push-off specimens, and all of the de-molded specimens were submerged in water for days according to ASTM C31/C31M-12[17] as shown in Fig. 2.

**Table 2.** Properties of concrete mix

| Cement kg/m³ | Gravel kg/m³ | w/c | Sand kg/m³ | Target strength MPa ($f'_c$) |
|---|---|---|---|---|
| 400 | 1200 | 0.45 | 600 | 30 |



a-Push-off specimen molds

b-Casting push-off specimens

c-Push-off specimens curing

**Figure 2.** Stages of casting, molding and curing of specimens

### 3.4. Measurements

A load cell that was correctly calibrated was used to measure the induced compression load. The specimens were instrumented with two-stroke linear variable displacement transducers, one placed vertically to record the vertical slip of the shear plane and the other horizontally to determine crack width.

### 3.5. Test Arrangements

The research was conducted at Mustansiriyah University's College of Engineering's structural engineering and material construction laboratories. As indicated in Fig. 3, push-off tests were performed utilizing a standard testing hydraulic machine with a full capacity of (3000kN). The load was imposed in 5kN increments, with measurements collected from two-stroke linear variable displacement transducers (LVDT) after each increment. The load was maintained until complete failure occurred. After the mechanism of failure was accomplished, the (LVDTS) were removed to allow for additional photos of ultimate shear cracks.

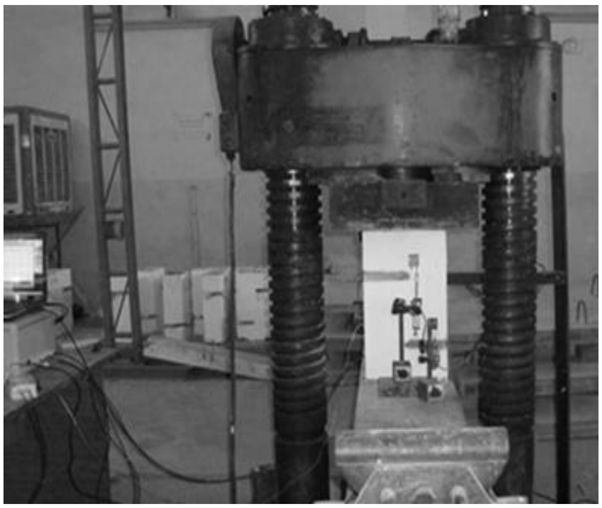


**Figure 3.** Specimen set-up and equipment

## 4. Test Results and Discussion

### 4.1. Effect of Fibers on Compressive Strength

As seen in Table 3, adding fibers increased the compressive strength of the cube of fibrous concrete when compared to the first group of concrete without fibers [18]. When 1% glass fibers were added to the second group of concrete, the compressive strength increased by 8.1% over the first group. When 1% steel fibers were added to the third group, the compressive strength increased by 11.36%.

### 4.2. Shear Strength

#### *4.2.1. Fibers' Influence*

Table 3 shows the shear stress values for the NSC, GFC, and SFC. The presence of fibers improves final shear strength [19], according to the findings. As 1% glass fibers were included in specimens ($GFC_0$, $GFC_2$, and $GFC_3$), the ultimate shear strength values increased by 32.26%, 12.38%, and 12.5%, respectively, when compared to the reference group ($NSC_0$, $NCS_2$, and $NSC_3$). However, the addition of 1% steel fiber to specimens ($SFC_0$, $SFC_2$, and $SFC_3$) increased ultimate shear strength by 53.22%, 19%, and 25%, respectively, as compared to the reference group ($NSC_0$, $NCS_2$, and $NSC_3$). The steel fiber group has greater ultimate shear strength than the glass fiber group because steel fibers have a higher modulus of elasticity and tensile strength. When comparing specimens with no stirrups across the shear plane to those with stirrups in the shear plane, the presence of glass fiber or steel fiber resulted in a larger increase in the values of ultimate shear strength peculiarity. This might be due to the high shear capacity of specimens provided with stirrups. Fig. 4 shows the effects of different types of fibers and reinforcing ratios on shear stress values.

#### *4.2.2. Transverse Reinforcement' Influence*

As shown in Table 3, the ultimate shear strength of the specimens ($NSC_2$ and $NSC_3$) with reinforcement ratios of 0.45% and 0.68% improved by (69.35% and 93.5%, respectively) as compared to the specimen ($NSC_0$) without shear reinforcement. Additionally, the specimen with a reinforcement ratio of 0.68%, $NSC_3$, had a 14.3% greater ultimate shear strength than the specimen with a reinforcement ratio of 0.45%, $NSC_2$. From the above, it is clear that due to dowel action, shear reinforcement significantly affects the value of ultimate shear strength. Similar results were obtained by **Al-Quraishi et al.** [13]. For the second group of specimens with glass fiber with Vf = 1%, when compared to the specimen ($GFC_0$) without shear reinforcement, the value of the ultimate shear strength of the specimens ($GFC_2$ and $GFC_3$) with reinforcement ratios of 0.45% and 0.68% increased by (43.9% and 64.63%, respectively). Also, the ultimate shear strength of the specimen with the reinforcing ratio (0.68%) was observed to be greater by 14.4% when compared to the specimen ($GFC_3$) with the reinforcement ratio (0.45%). For the third group of steel fiber specimens with (Vf=1%). The value of the ultimate shear strength of the specimens ($SFC_2$ and $SFC_3$) with reinforcement ratios (0.45% and 0.68%) rose by 31.58% and 57.9%, respectively, as compared to the specimen ($SFC_0$) without shear reinforcement. The specimen ($SFC_3$) with the reinforcement ratio (0.68%) was found to have a 20% higher ultimate shear strength than the specimen ($SFC_2$) with the reinforcement ratio (0.45%).

**Table 3.** Shear strength of push-off specimens

| Group no. | Labeling | Type of concrete | $f_{cu}$ (MPa) | Shear reinforcement ratio (%) | Failure load (kN) | Ultimate shear strength (MPa) |
|---|---|---|---|---|---|---|
| 1 | $NSC_0$ | Normal strength | 31.7 | 0 | 62 | 2.48 |
| | $NSC_2$ | Normal strength | 31.7 | 0.45 | 105 | 4.2 |
| | $NSC_3$ | Normal strength | 31.7 | 0.68 | 120 | 4.8 |
| 2 | $GFC_0$ | Glass Fibre reinforced Concrete | 34.27 | 0 | 82 | 3.28 |
| | $GFC_2$ | Glass Fibre reinforced Concrete | 34.27 | 0.45 | 118 | 4.72 |
| | $GFC_3$ | Glass Fibre reinforced Concrete | 34.27 | 0.68 | 135 | 5.4 |
| 3 | $SFC_0$ | Steel Fibre reinforced Concrete | 35.3 | 0 | 95 | 3.8 |
| | $SFC_2$ | Steel Fibre reinforced Concrete | 35.3 | 0.45 | 125 | 5 |
| | $SFC_3$ | Steel Fibre reinforced Concrete | 35.3 | 0.68 | 150 | 6 |

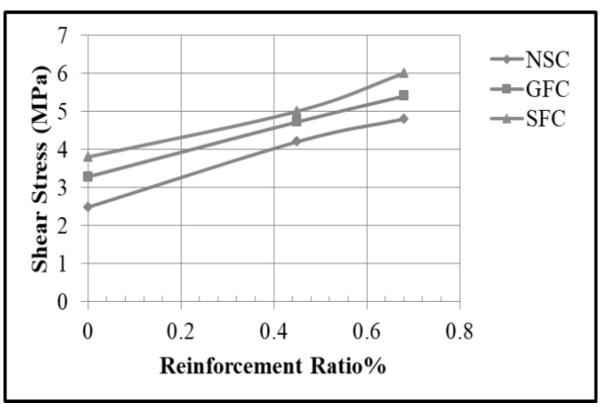



**Figure 4.** Variation of shear stress with different types of fibers and reinforcement ratio

### 4.3.The Shear Stress-Slip Behavior

#### *4.3.1 Fibers' Influence*

The influence of different types of fibers (glass and steel) on shear transfer strength across the shear plane was studied. The shear stress-slip relation for specimens without reinforcement, specimens with reinforcement (0.45%), and specimens with reinforcement (0.68%) are shown in Figs. 5, 6, and 7. The figures indicate that the presence of fibers reduces slip at the early stages of loading by increasing stiffness and that the specimens exhibit ductile behaviour at the end stages for all three reinforcement settings [20]. For instance, at a shear stress of 2MPa, for specimens without stirrups, the decrease in slip for the specimens with glass fiber and steel fiber was 70 and 74.2%, respectively, when compared to the specimen without fiber. While the reduction in slip for specimens with two stirrups was 53.85% and 61.50%, respectively, for the specimens with glass fiber and steel fiber in comparison to the specimen without fiber. For specimens with three stirrups the reduction in slip was 68.9 and 87%, respectively, when compared to the specimen without fiber, for specimens with glass and steel fiber.

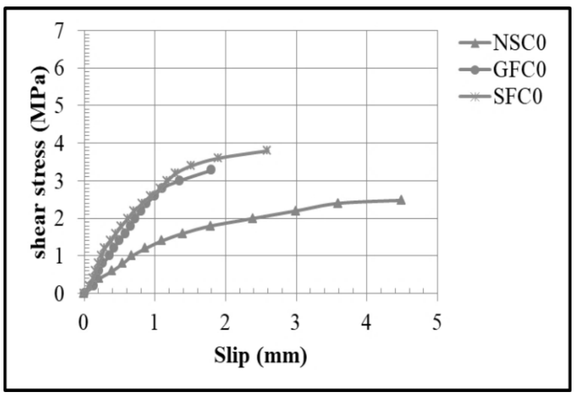



**Figure 5.** Shear stress-slip for specimens without reinforcement

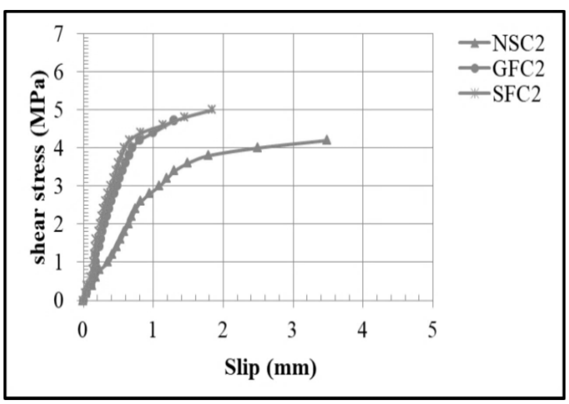



**Figure 6**. Shear stress-slip relationship for specimens with reinforcement (0.45%)

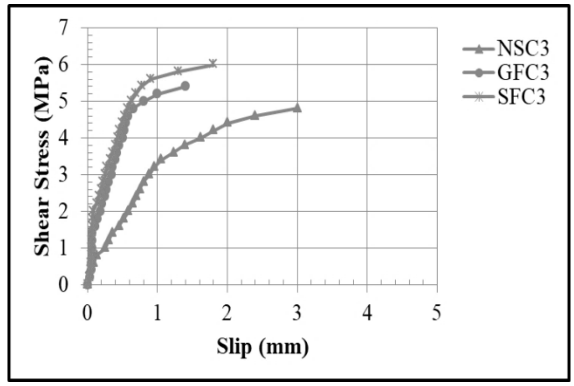



**Figure 7**. Shear stress-slip relationship for specimens with reinforcement (0.68%)

### *4.3.2 Transverse Reinforcement' Influence*

The number of stirrups may be varied to modify the transverse reinforcement ratio. The reinforcement ratios of two and three stirrups across the shear plane were utilized in this investigation, with the reinforcement ratios of 0.45% and 0.68%, respectively. The test results demonstrated that when the reinforcement ratio increased, the behavior became stiffer[20]. The shear load was handled by concrete alone until cracking appeared in the first group of specimens without fiber reinforcement with ($V_f$=0%). Shear stress was handled after cracking by shear plane interlock and stirrup reinforcement. The influence of changing the reinforcement ratio from 0 for the $NSC_0$ specimen to 0.45% and 0.68% for the $NSC_2$ and $NSC_3$ specimens, respectively, is shown in Fig. 8. For the second group of specimens with glass fiber with ($V_f$=1%), Fig. 9 shows the relationship between shear stress and vertical slip for $GFC_0$, $GFC_2$, and $GFC_3$ specimens, for which the transverse reinforcement ratio was 0, 0.45%, and 0.68%, respectively. Fig. 10 represents the relation between shear stress and vertical slip for $SFC_0$, $SFC_2$, and $SFC_3$ specimens with transverse reinforcement ratios of 0, 0.45%, and 0.68%, respectively, for the third group of steel fiber specimens with ($V_f$=1%). In general, increasing the transverse reinforcement ratio resulted in more stiff behavior for all concrete groups tested.

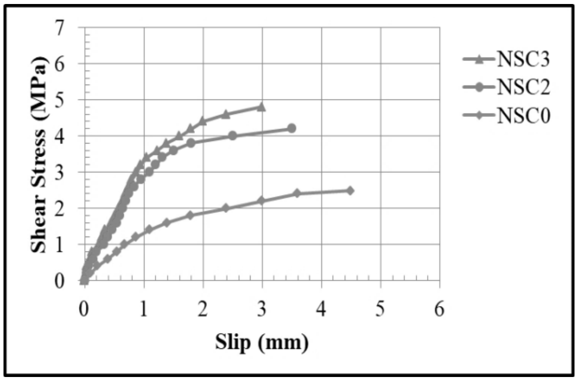



**Figure 8**. Shear stress-slip relationship for group no.1 specimens

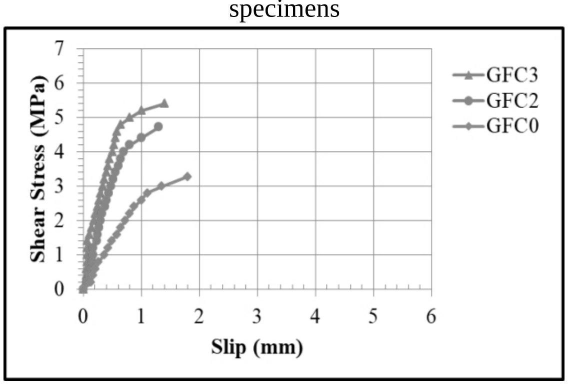



**Figure 9.** Shear stress-slip relationship for group no.2 specimens

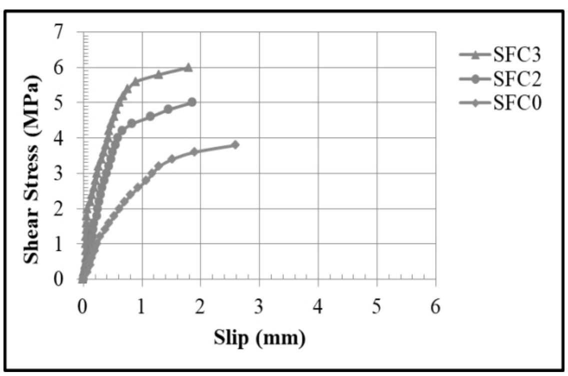



**Figure 10.** Shear stress-slip relationship for group no.3 specimens

## 4.4. The Shear Stress-Crack width Behavior

4.4.1. *Fibers' Influence*

Figs. 11, 12, and 13 illustrate the relationship between shear stress and crack width, illustrating that the behavior is linear up to the cracking stress for specimens in all groups. By adding fibers (glass or steel), the behavior becomes stiffer [21]. For specimens without transverse reinforcement, the maximum crack width dropped by 40% and 48.57% for $GFC_0$ and $SFC_0$, respectively, as compared with $NSC_0$. In the specimens with a transverse reinforcement ratio of 0.45%, the maximum crack width dropped by 61.54% and 66.15% for $GFC_2$ and $SFC_2$, respectively, as compared with $NSC_2$. Finally, in the specimens with a transverse reinforcement ratio (0.68%), the maximum crack width dropped by 62.5% and 66.25% for $GFC_3$ and $SFC_3$, respectively, as compared with $NSC_3$.

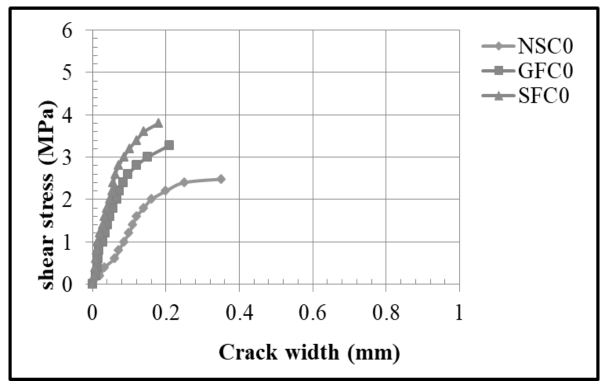



**Figure 11**. Shear stress-crack width relationship for specimens without reinforcement

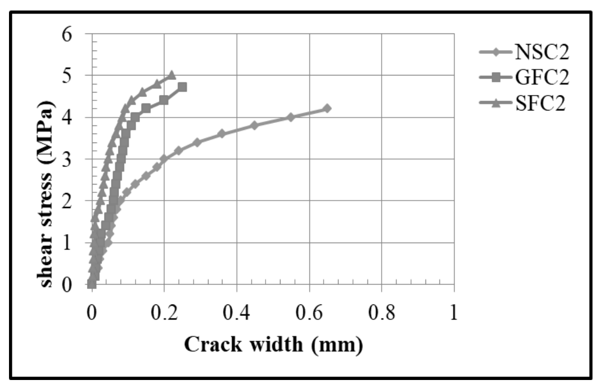



**Figure 12**. Shear stress-crack width relationship for specimens with reinforcement (0.45%)

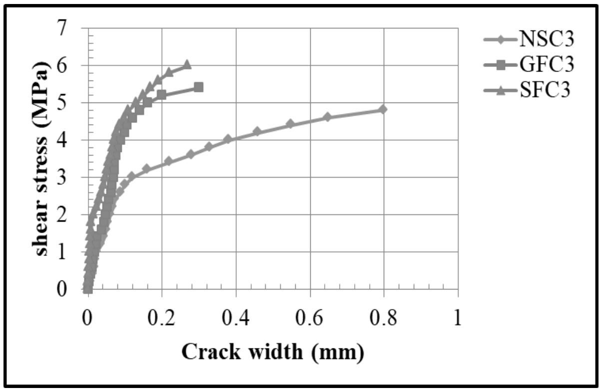



**Figure 13**. Shear stress- crack width relationship for specimens with reinforcement (0.68%)

### 4.4.2. *Transverse Reinforcement' Influence*

The influence of the transverse reinforcement ratio on the behavior of shear stress-crack width for the three concrete groups is shown in Figs. 14, 15, and 16. Increasing the shear reinforcement ratio leads to a decrease in the crack width in the early loading stages by increasing stiffness and the specimens exhibit ductile behavior at the end stages for all three reinforcement settings [20]. For instance, at a shear stress of 2MPa, for specimens of the first group without fibers, the decrease in crack width for the specimens with shear reinforcement ratios of 0.45% and 0.68% was 50% and 62.5%, respectively, when compared to the specimen without shear reinforcement. For specimens of the second group with glass fibers, the decrease in crack width for the specimens with shear reinforcement ratios of (0.45% and 0.68%) was 42.4% and 51.5%, respectively, when compared to the specimen without shear reinforcement. For specimens of the third group with steel fibers, the decrease in crack width for the specimens with shear reinforcement ratios of (0.45% and 0.68%) was 52.1% and 68.75%, respectively, when compared to the specimen without shear reinforcement.

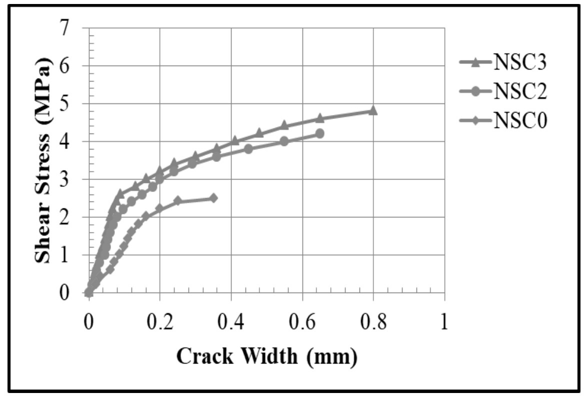



**Figure 14.** Shear stress-crack width relationship for group no.1 specimens

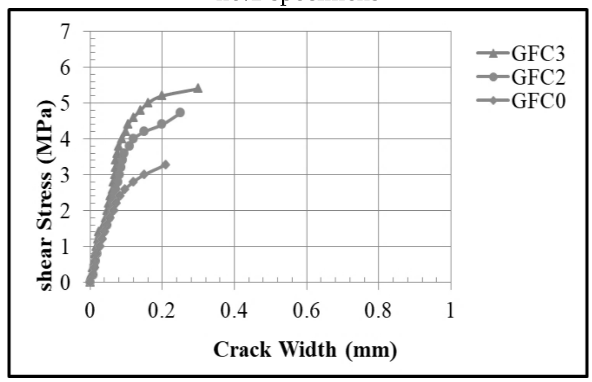



**Figure 15.** Shear stress-crack width relationship for group no.2 specimens

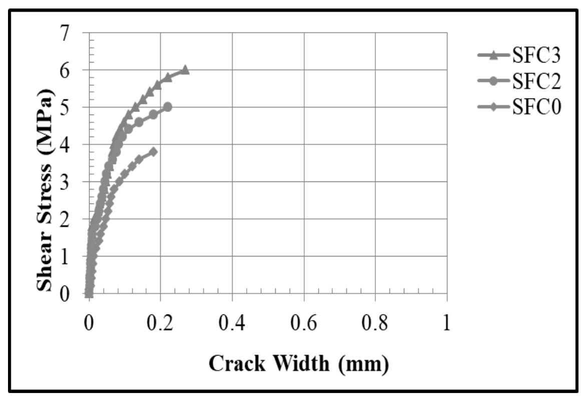
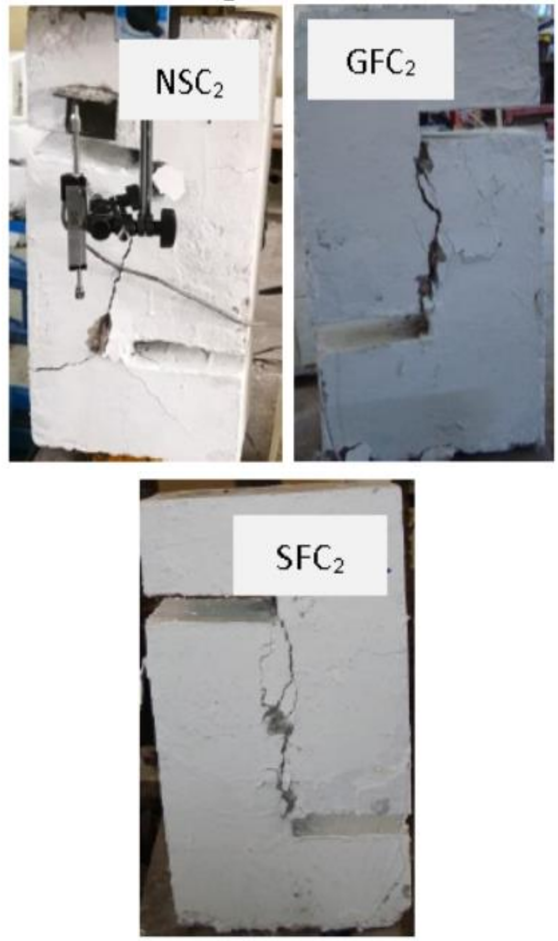



**Figure 16.** Shear stress-crack width relationship for group no.3 specimens

### 4.5. Mode of failure

Shear cracks appeared around the higher and lower openings when the force was gradually applied, and as the load was increased, the cracks spread toward the specimens' center. The failed specimens $NSC_0$, $GFC_0$, and $SFC_0$ are shown in Fig. 17-a without shear reinforcement. The illustration demonstrates how the specimens ($GFC_0$ and $SFC_0$) maintained their cohesion at failure, but $NSC_0$ without fibers split in two when the maximum stress was reached [10]. $NSC_2$, $GFC_2$, and $SFC_2$ with 0.45% shear reinforcement and $NSC_3$, $GFC_3$, and $SFC_3$ with 0.685% shear reinforcement, respectively, are the failed specimens shown in Fig. 17-b and c. In contrast to Fig. 17-a, where there was no shear reinforcement, the figure demonstrates that the cracks at failure were smaller. The two primary factors that influence the crack width in the direct shear test are the crack surface friction and aggregate interlock in NSC specimens. The fiber concentration affects crack width in addition to those elements in GFC and SFC specimens [13].


a-Specimens without reinforcement




b-Specimens with reinforcement ratio (0.45%)


c-Specimens with reinforcement ratio (0.68%)

**Figure 17.** Mode of failure

## 5. Conclusions

Fibers (glass or steel) increased the tensile strength of concrete, which enhanced the ultimate shear strength value. Adding 1% glass fiber to normal strength concrete enhanced ultimate shear strength by 32.26%, 12.38%, and 12.5%, respectively, for the specimen without stirrups, the specimen with 2 stirrups, and the specimen with 3 stirrups. Adding 1% steel fibers to normal strength concrete enhanced ultimate shear strength by up to 53.22%, 19%, and 25%, respectively, for the specimen without stirrups, the specimen with two stirrups, and the specimen with three stirrups.

The presence of fibers enhanced the stiffness of the tested specimens, which reduced the vertical displacement (slip) at the same shear stress. For instance, at a shear stress of 2MPa, for specimens without stirrups, the decrease in slip for the specimens with glass fiber and steel fiber was 70 and 74.2%, respectively, when compared to the specimen without fiber. The reduction in slip for specimens with two stirrups was 53.85% and 61.50%, respectively, for the specimens with glass fiber and steel fiber in comparison to the specimen without fiber. For specimens with three stirrups, the reduction in slip was 68.9 and 87%, respectively, when compared to the specimen without fiber, for specimens with glass and steel fiber.

Adding fibers causes concrete's behavior to become stiffer. The maximum crack width of the specimens under study decreased as a result. So, the maximum crack width of glass fiber and steel fiber specimens without stirrups decreased by 40 and 48.57%, respectively, when compared to specimens of normal strength concrete without stirrups.

For specimens with two stirrups, the maximum crack width dropped by 61.54 and 66.15%, for specimens with glass fiber and steel fibers, respectively, as compared to the specimen without fiber. For specimens with three stirrups, the maximum crack width dropped by 62.5 and 66.25%, for specimens with glass fiber and steel fibers, respectively, as compared to the specimen without fiber. This means that by adding fibers (glass or steel), the behavior becomes stiffer.

The presence of the transverse reinforcement of the specimens tested for the three groups led to an increase in the ultimate shear strength due to the dowel action. The ultimate shear strength of the normal concrete without fiber, the specimens with reinforcement ratios of 0.45% and 0.68% improved by 69.35% and 93.5%, respectively, as compared to the specimen without shear reinforcement. The second group of specimens with glass fiber with (Vf=1%) when compared to the specimen without shear reinforcement, the value of the ultimate shear strength of the specimens with reinforcement ratios of (0.45% and 0.68%) increased by (43.9% and 64.63%, respectively). For the third group of steel fiber specimens with (Vf=1%). The value of the ultimate shear strength of the specimens with reinforcement ratios (0.45% and 0.68%) rose by 31.58% and 57.9%, respectively, as compared to the specimen without shear reinforcement in the same group.

## Conflict of interest

There is no conflict of interest in publishing this article.

## 6. Abbreviations

| | |
|---|---|
| NSC | Normal Strength Concrete |
| GFC | Glass Fiber reinforced Concrete |
| SFC | Steel Fiber reinforced Concrete |
| $V_f$ | Fiber volume fraction |

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