Effect of Monotonic and Repeated Loading on Shear Transfer Behaviour of Geopolymer Concrete

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ABSTRACT

Geopolymer is an environmentally benign substance that may be utilized as a concrete repair material, a structural element in a building, or as a whole in construction. This paper presents an experimental study on the shear transfer of geopolymer concrete under monotonic and repeated loads. Ten push-off specimens with and without reinforcement across the shear plane were cast and evaluated. The geopolymer concrete was used in the first five push-off specimens, whereas the conventional concrete was used as a reference in the last five. The proposed push-off specimen was 500mmx250mmx125mm in size. Shear stress, vertical slip, and horizontal separation at the shear plane were measured for each load increment up to failure. To determine the vertical slip and horizontal separation at the shear plane, two-stroke linear variable displacement transducers (LVDT) were utilized. The shear strength of geopolymer concrete was found higher than that of conventional concrete in the tests. In addition, vertical slip and horizontal separation were smaller in geopolymer concrete than in conventional concrete

Keywords: Shear transfer, Repeated loads, Geopolymer concrete, Direct shear

1.Introduction

Concrete is the most often utilized construction material because of its adaptability. Flexure and shear were the major causes of a concrete member failure. Due to its fast advancement, a shear failure is a problematic manner of failure. Shear forces have a critical part in modern architectural design, resulting in various morphologies of structures. Sliding failure occurs when a shear force acts on concrete in a plane vertical to the force's direction. Geopolymer in special concretes was launched as a way to reduce the usage of cement while also ensuring that concrete building is environmentally sustainable. The cement industry improved the method of cement manufacture to minimize carbon emissions, but it was unable to limit CO_2 emissions since it is a necessary part of the basic process of limestone calcination in clinker fiery. As a result, the use of waste by-products from other sectors in the development of alternative construction materials is growing. Geopolymer concrete is a material derived from little treated natural materials or industrial by-products that has a low carbon footprint and is extremely durable. Geopolymers are by-products or compounds of physical origin. These inorganic aluminum–silicate polymers are amorphous in microstructure, comparable to zeolite[1-3]. According to the current literature, research on Geopolymer concrete contains its characteristics and mechanical strength evaluation[4-7]. The geopolymer concrete has been safely used by the precast manufacturers where stress is fixed at interfacial or connected zones associated with corbels, near beam-column connections, and beam slab contact. Friction from compressive loads, cohesiveness from aggregate interlocked roughness, and Dowel action, which crosses the surfaces, all contribute to shear transmission across the interface. In the literature, there were several models[8-12] for determining concrete shear transfer strength. The shear strength of concrete is determined using a variety of test specimens such as splitting, corbel with the moment, and pull-off. Anderson[13] was the first to use a push-off specimen to test interface shear transfer.

Due to complete shear transmission across surfaces as compared to other types of specimens that create both shear and moment, push-off specimens are the most suited and widely used.

2. Objective Of The Current Research

- Observe how shear stress values change as concrete type change (geopolymer concrete and normal concrete).
- To investigate the relationship between shear stress levels and stirrup reinforcement percentage.
- To see how shear stress values changed as the loading types changed (monotonic load and repeated load).

3. Materials Used

Cement- The cement used was ordinary Portland cement (type I) from Iraq. It was evaluated for chemical and physical properties in accordance with Iraqi specifications No.5/1984[14].

Metakaolin- Is a kaolinite clay mineral produced from chemical components Al2Si2O5(OH)4.

Fine Aggregate- Natural sand was used, with a maximum particle size of 4.75mm. The fine aggregate meets the criteria of Iraqi Specification No. 45/1984[15] according to the findings of the sieve analysis and physical attributes.

Coarse aggregates- This study employed natural coarse aggregate with a maximum size of 12mm. The coarse aggregate gradation and physical qualities comply with Iraqi standard No. 45/1984[15].

Alkaline solution-Alkaline activators such as sodium hydroxide flakes or pellets and sodium silicate are employed to provide an excellent binding solution for the geo polymeric mix (GPC). The sodium hydroxide solution used had a 14 molar concentration. 24 hours before to casting, sodium hydroxide and sodium silicate solution were produced.

Super-plasticizer- The mixtures will be prepared with a super-plasticizer defined as (High Water Reducing Agent HWRA), which is built on poly-carboxylic ether and is marketed under the name Glenium 51, is chloride-free, and complies with ASTM C494[16] , sorts F and A.

Mixing Water- Tap water is utilized in the concrete mixes as well as the treatment of the concrete samples (cubes, cylinders, and prisms).

4. Concrete Mix Design

Jawad[17] developed the NSC mix. Al-Attar's previous study[18] informed the GPC blend. Table (1) and (2) show the final blend proportions.

Table 1: Properties of concrete mix (NSC)

Cement kg/m^3	**Gravel kg/m^3**	**w/c**	**Sand kg/m^3**	**Target Strength MPa (fć)**
400	1200	0.45	600	30

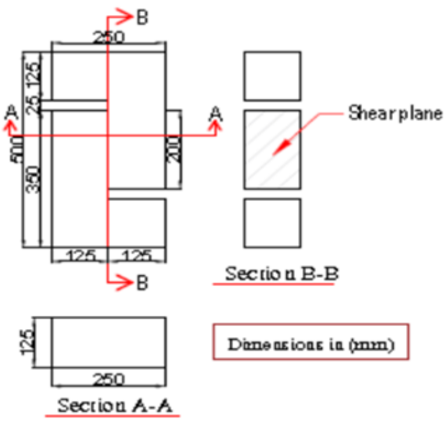
Table 2 : Properties of concrete mix (GPC)

Metakaolin kg/m³	Sand kg/m³	Gravel kg/m³	Alkaline solution (L/m³)	Water (L/m³)	Superplasticizer (L/m³)
400	1100	720	180	40	12

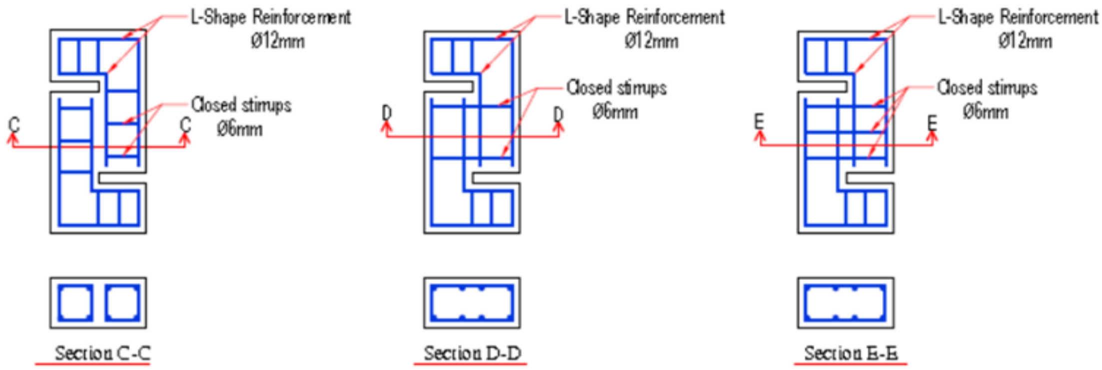
5. Experimental Investigatoin

5.1 Test Program

The main goal of this research is to study at the shear transfer problem with and without reinforcement across an uncracked shear plane (NC and GPC). The ten push-off specimens were cast and examined without cracking along the shear plane. Three of the most relevant factors evaluated were concrete type, reinforcing parameter, and loading type. Figure (1) shows a schematic representation of the push-off test specimen. Characteristics of the tested specimens are shown in Table (3).



a-Specimen Dimensions Details



b-Specimen Reinforcement Details

Figure 1: push-off test specimen details

Table 3 : Characteristic of the tested specimens

Group no.	Labelling	Type of concrete	No. of Φ6mm stirrup	Type of loading
1	NSC_0	Normal strength	0	Monotonic load
	NSC_2	Normal strength	2	Monotonic load
	NSC_3	Normal	3	Monotonic

		strength		load
	NSC_{2R}	Normal strength	2	Repeated load
	NSC_{3R}	Normal strength	3	Repeated load
2	GPC_0	Geopolymer	0	Monotonic load
	GPC_2	Geopolymer	2	Monotonic load
	GPC_3	Geopolymer	3	Monotonic load
	GPC_{2R}	Geopolymer	2	Repeated load
	GPC_{3R}	Geopolymer	3	Repeated load

5.2 Push-off Specimens Casting

The needed materials per cubic meter of concrete are grouped in Table (1) and mixed in a pan mixer. Concrete is then poured into push-off molds Figure (2). Following that, wet jute sheets were used to cover the NSC push-off specimens, and all of the de-molded NSC specimens were submerged in water for 28 days.

The solid materials of GPC push-off specimens were dry mixed before casting Table (2). The alkaline solution is made 24 hours ahead of time by adding the needed water to the solids. Wet mixing often went on for another four minutes. After 24 hours, GPC push-off specimens were de-molded Figure (3) . GPC specimens are stored at room temperature till the day of test.

Figure 2: NSC push-off specimens casting

Figure 3: GPC push-off specimens casting

6. Instructions

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 positioned vertically to detect vertical shear plane displacement and the other horizontally to determine crack width.

7. Test Setup

The push-off specimen is made up of two L-blocks that are inverted together to create a shear plane. Under direct shear (monotonic, repeated) loading, ten reinforced concrete double inverted L forms were examined. Figure (4) shows the details of test setup for the push-off specimen. Two stroke linear variable displacement transducers (LVDT) were mounted to the specimen to record the vertical slip and horizontal displacements with each load increment. Hydraulic compressive testing equipment with a capacity of 3000kN was used for the test.

Figure 4: Specimen set-up and instrumentation.

8. Results And Discussion

The results of the tests are presented in this section:

- Effect of concrete type on ultimate shear strength.
- The influence of the transversal reinforcement ratio on concrete shear strength.
- The influence of loading types on concrete shear strength.
- The relation of shear stress-slip and shear stress-crack width.
- The Failure Modes.

8.1 Effect of concrete type

The following equation is used to calculate the specimen's ultimate shear strength:

$$\tau_{max} = P_{max} / (b.L) \quad (1)$$

Where: τ is the shear strength of concrete; P_{max} is the maximum applied load; b is the specimen width and L is the length of shear plane.

Table (4) shows the ultimate shear strength values for the specimens tested. The increase in the ultimate shear strength of the geopolymer concrete specimen without transversal reinforcement was about (12.9%) compared to the specimen with normal concrete and without transversal reinforcement. When comparing specimens of geopolymer concrete containing transversal reinforcement with percentages (0.45% and 0.68%) with normal strength concrete specimens and with the same reinforcement percentages, the increase in shear strength was (6.67% and 5.83%) respectively.

Table 4 : Shear strength of push-off specimens

Labeling	Type of concrete	f_{cu} (MPa)	Shear reinforcement ratio (%)	Failure load (kN)	Ultimate shear strength (MPa)
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
NSC_{2R}	Normal strength	31.7	0.45	70	2.8

NSC_{3R}	Normal strength	31.7	0.68	82.1	3.28
GPC_0	Geopolymer	28	0	70	2.8
GPC_2	Geopolymer	28	0.45	112	4.48
GPC_3	Geopolymer	28	0.68	127	5.08
GPC_{2R}	Geopolymer	28	0.45	73.8	2.95
GPC_{3R}	Geopolymer	28	0.68	84.3	3.37

8.2 The Influence of Transversal Reinforcement Ratio

To investigate the influence of shear reinforcement on concrete shear strength, deformed horizontal bars passing over the plane of shear were used to imitate the lateral constraint. Table (4) shows the test results, for normal strength concrete, when comparing specimens (NSC_2 and NSC_3) containing transverse reinforcement ratio (0.45% and 0.68%) with the specimen (NSC_0) without transverse reinforcement, an increase in ultimate shear strength was observed by rates (69.35% and 93.5%), respectively. And when comparing the specimen has the reinforcing ratio (0.68%) with the specimen containing the reinforcement ratio (0.45%), an increase in the ultimate shear strength was found by (14.3%). As for the geopolymer concrete, when comparing specimens (GPC_2 and GPC_3) with transverse reinforcement ratios (0.45% and 0.68%) with the specimen (GPC_0) without transverse reinforcement, an increase in the maximum shear strength was observed in proportions (60% and 81.43%) respectively. And when comparing the specimen (GPC_3) having the transverse reinforcement ratio (0.68%) with the specimen (GPC_2) containing the transverse reinforcement ratio (0.45%), an increase in the ultimate shear strength was found by (13.4%).

8.3 The Influence of Loading Types

Four specimens were exposed to repeated load testing, as described in the experimental program. Each specimen was subjected to five loading cycles, with each cycle consisting of loading each specimen up to (50% failure load) and then reducing the stresses to (10% failure load). The first group's reference specimens (NSC_2 and NSC_3) of normal strength concrete with transverse reinforcement ratios of (0.45% and 0.68%) were subjected to monotonic loads in increasing increments until failure. The specimens (NSC_{2R} and NSC_{3R}) of normal strength concrete with transverse reinforcement ratios of (0.45% and 0.68%) in the same group were subjected to a five-cycle repeated load test. The second group's reference specimens (GPC_2 and GPC_3) of geopolymer concrete with transverse reinforcement ratios of (0.45% and 0.68%) were subjected to monotonic loads in increasing increments until failure. The specimens (GPC_{2R} and GPC_{3R}) geopolymer concrete with transverse reinforcement ratios of (0.45% and 0.68%) in the same group were subjected to a five-cycle repeated load test. If the tested specimen did not fail in the specified load of the five cycles, the load was increased until failure occurred. The ultimate shear strength is affected by the type of loading, as shown in Table (5).

Table5 : Effect of loading type on failure load

Groups no.	**Specimen**	**Type of loading**	**No. of cycles**	**Failure load (kN)**	**Decreasing (%)**
1	NSC_2	Monotonic	--	105	33.33
	NSC_{2R}	Repeated*	5	70	
	NSC_3	Monotonic	--	120	31.6
	NSC_{3R}	Repeated*	5	82.1	
2	GPC_2	Monotonic	--	112	33.1
	GPC_{2R}	Repeated*	5	73.8	

	GPC_3	Monotonic	--	127	33.62
	GPC_{3R}	Repeated*	5	84.3	

*50% of Monotonically Loaded Specimens

When the kind of loading changed from (monotonic) to (repeated) the failure load capacity dropped. The loss of strength occurs as a consequence of base material deterioration and the loss of ability to bear load approaching failure, when energy dissipation in the reinforcement and concrete reaches its lowest level, causing deformation and lowering load capacity.

8.4 Shear Stress-Slip Behavior

The nature of the shear stress-slip relation is investigated in this section. As previously stated, shear stresses were determined by dividing the straight compression load on the shear plane area. The shear slip refers to the vertical separation between the two portions of the L blocks in the push-off specimen, as measured by (LVDT) at the top of the specimen. The shear stress-slip behavior for the two groups (NSC and GPC) normal strength concrete and geopolymer concrete is shown in Figures (5) through (13). The behavior of the two groups follows a nearly linear pattern until failure, confirming the brittle nature of the shear failure. The test study found that the specimens with shear reinforcement had much less shear slip than the specimens without shear reinforcement in both groups (NSC and GPC). Furthermore, specimens with a reinforcement ratio of (0.68%) show less slip than specimens with a reinforcement ratio of (0.45%).

The results of the study showed convergence in the slip values of geopolymer concrete specimens compared to normal concrete specimens. As the slip values of geopolymer concrete are slightly lower than regular concrete, as shown in Table (6).

Table 6 : Slip and crack width at ultimate shear stress

Specimen	**Shear reinforcement ratio (%)**	**Failure load (KN)**	**Ultimate shear strength (MPa)**	**Max. slip (mm)**	**Max. crack width (mm)**
NSC_0	0	62	2.48	4.5	0.35
NSC_2	0.45	105	4.2	3.5	0.65
NSC_3	0.68	120	4.8	3	0.8
NSC_{2R}	0.45	70	2.8	2.2	0.32
NSC_{3R}	0.68	82.1	3.28	1.8	0.38
GPC_0	0	70	2.8	2.7	0.28
GPC_2	0.45	112	4.48	1.8	0.58
GPC_3	0.68	127	5.08	1.5	0.75
GPC_{2R}	0.45	73.8	2.95	1.2	0.29
GPC_{3R}	0.68	84.3	3.37	1.03	0.35

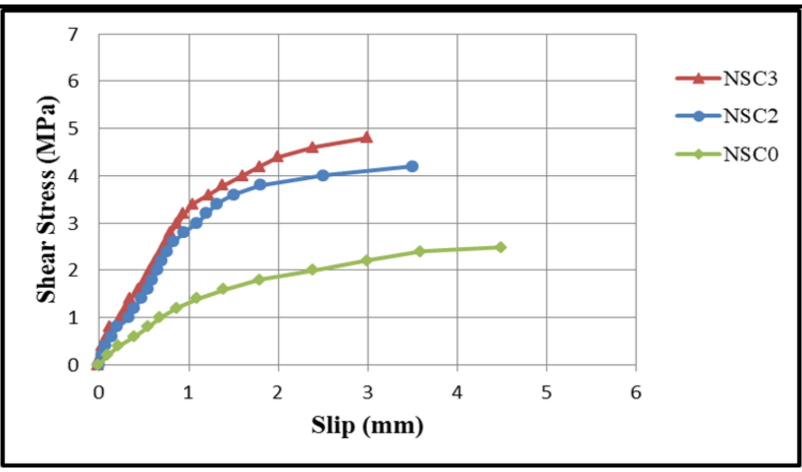


Figure 5 : Shear stress-Slip relationship group (1) normal strength concrete

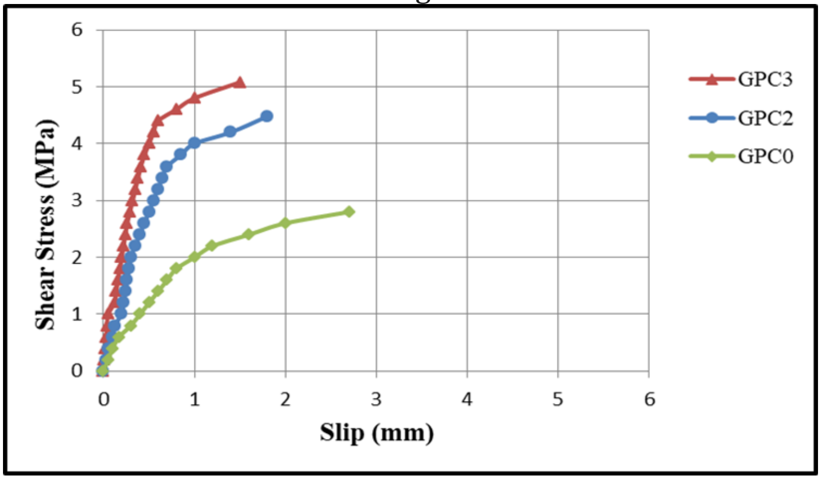


Figure 6 : Shear stress-Slip relationship group (2) geopolymer concrete

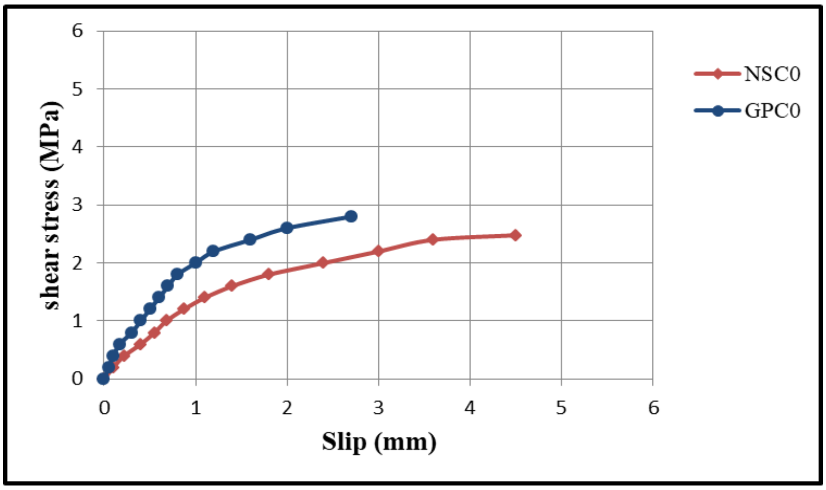


Figure 7 : Shear stress-Slip relationship for specimens without reinforcement

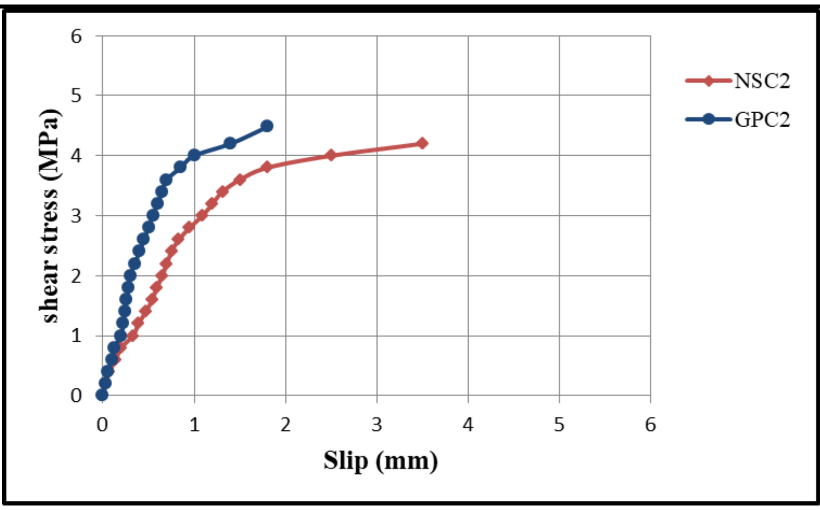


Figure 8 : Shear stress-Slip relationship for specimens with reinforcement (0.45%)

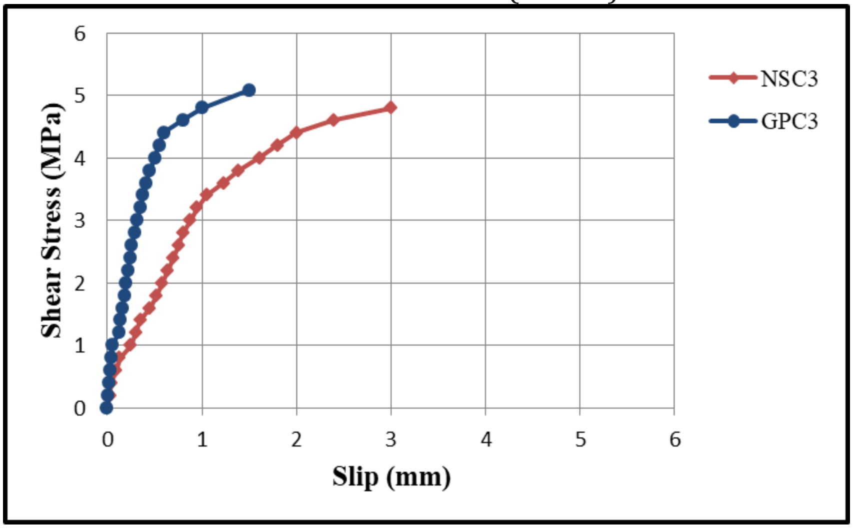


Figure 9 : Shear stress-Slip relationship for specimens with reinforcement (0.68%)

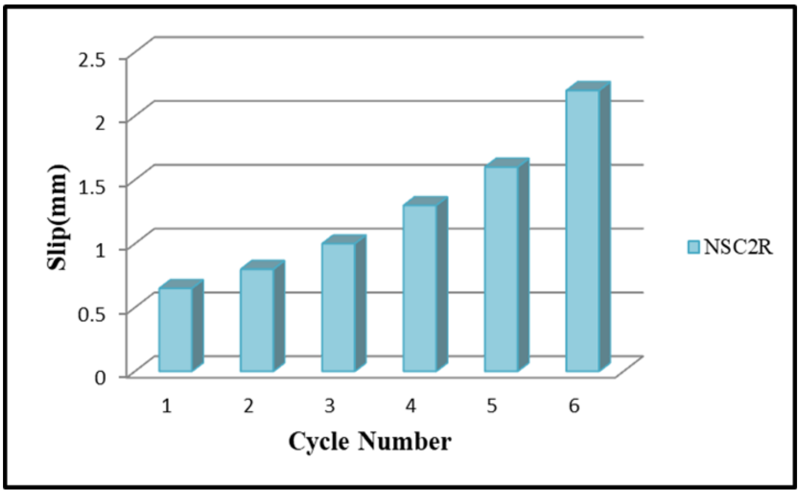


Figure 10 : Slip behaviore for specimen NSC2R with reinforcement ratio (0.45%) under repeated load group (1) normal strength concrete

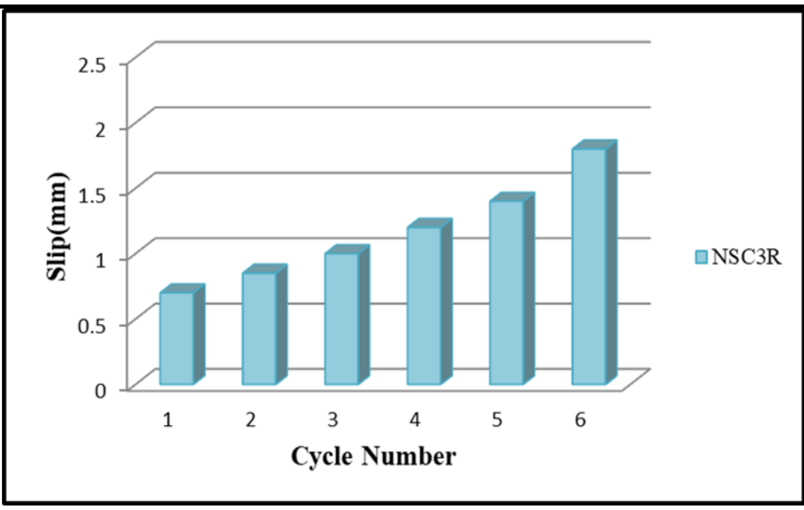


Figure 11 : Shear stress-Slip relationship for specimen NSC_{3R} with reinforcement ratio (0.68%) under repeated load group (1) normal strength concrete

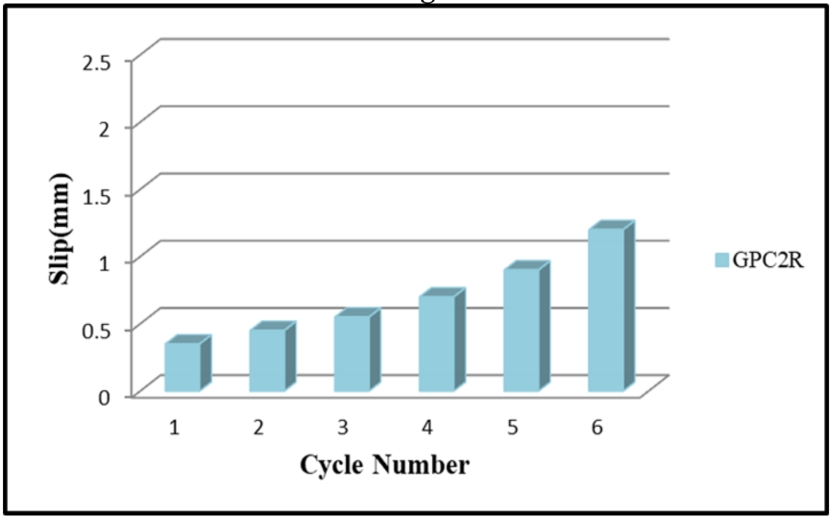


Figure 12 : Shear stress-Slip relationship for specimen GPC_{2R} with reinforcement ratio (0.45%) under repeated load group (2) geopolymer concrete

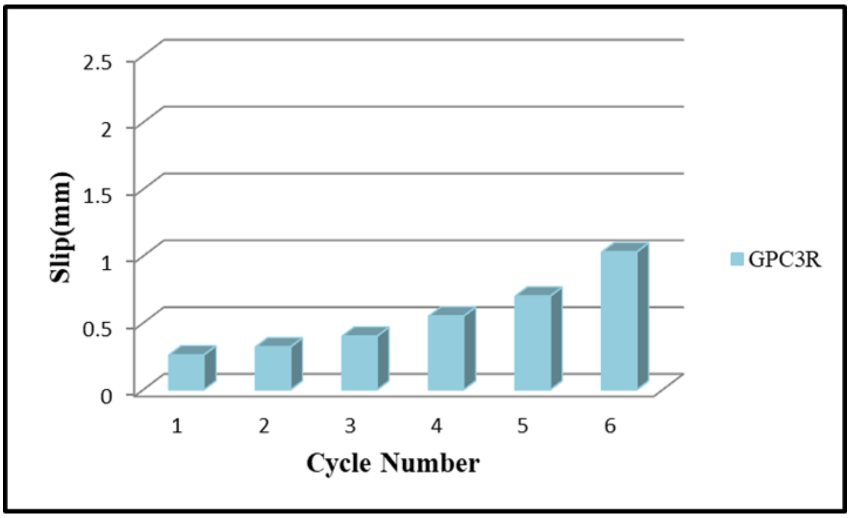


Figure 13 : Shear stress-Slip relationship for specimen GPC_{3R} with reinforcement ratio (0.68%) under repeated load group (2) geopolymer concrete

8.5 Shear Stress-Crack Width Behavior

During load increments, an average crack width in the direction perpendicular to the applied compressive load was measured using (LVDT) positioned at the beginning edge of the specimens' middle length from the back. The crack width refers to the horizontal displacement between the two portions of the L blocks in the push-off specimen. The shear stress-crack width behavior for the two groups normal strength concrete and geopolymer concrete is shown in Figures (14) through (18). In both groups (NSC and GPC), the specimens with shear reinforcement had a much smaller crack width than the specimens without shear reinforcement, according to the test results. Furthermore, specimens with a reinforcement ratio of (0.68%) had narrower cracks than specimens with a reinforcement ratio of (0.45%). Geopolymer concrete has rather lower crack width values than conventional concrete.

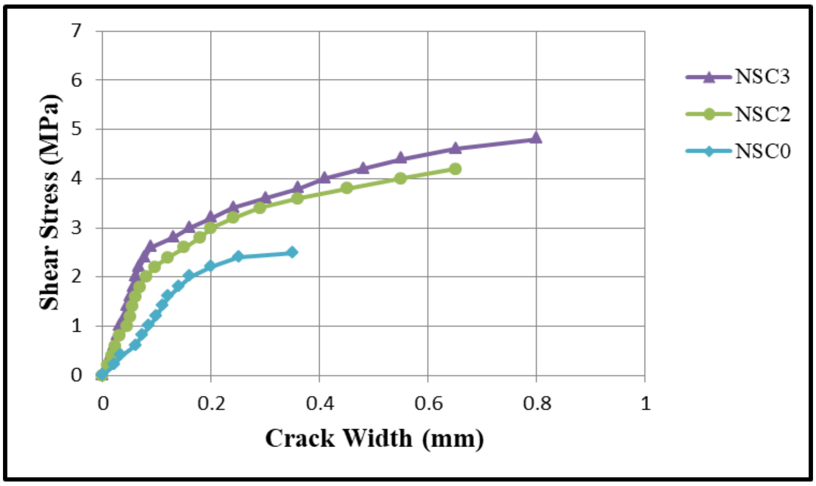


Figure 14 : Shear stress-Crack width relationship group (1) normal strength concrete

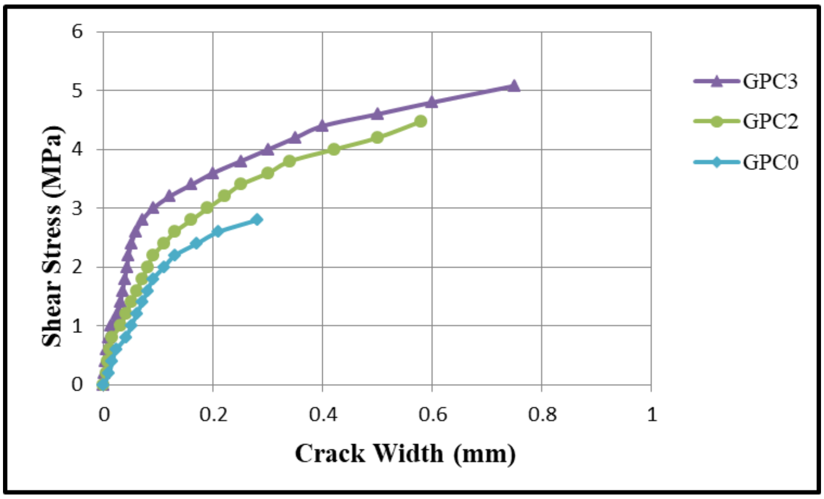


Figure 15: Shear stress-Crack width relationship group (2) geopolymer concrete

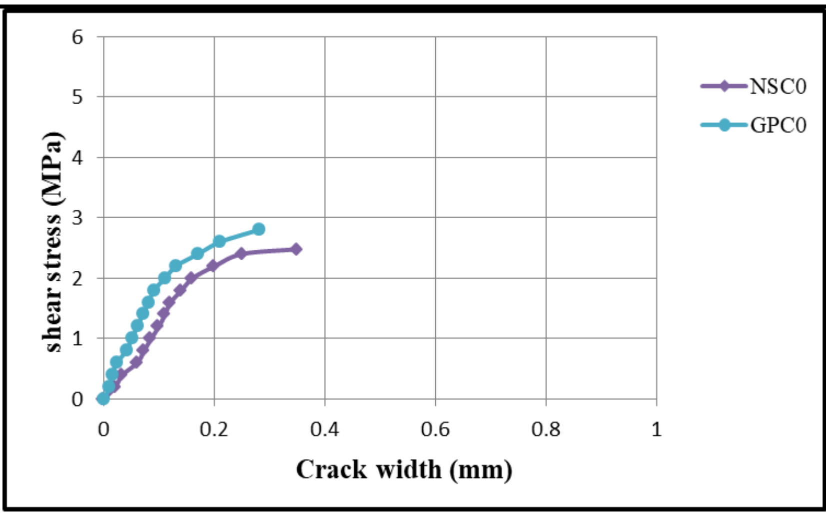


Figure 16 : Shear stress-Crack width relationship for specimens without reinforcement

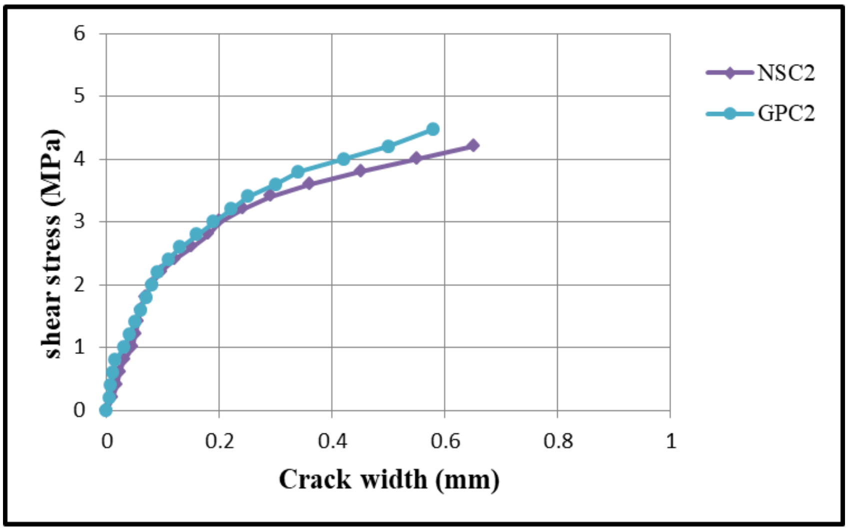


Figure 17 : Shear stress-Crack width relationship for specimens with reinforcement (0.45%)

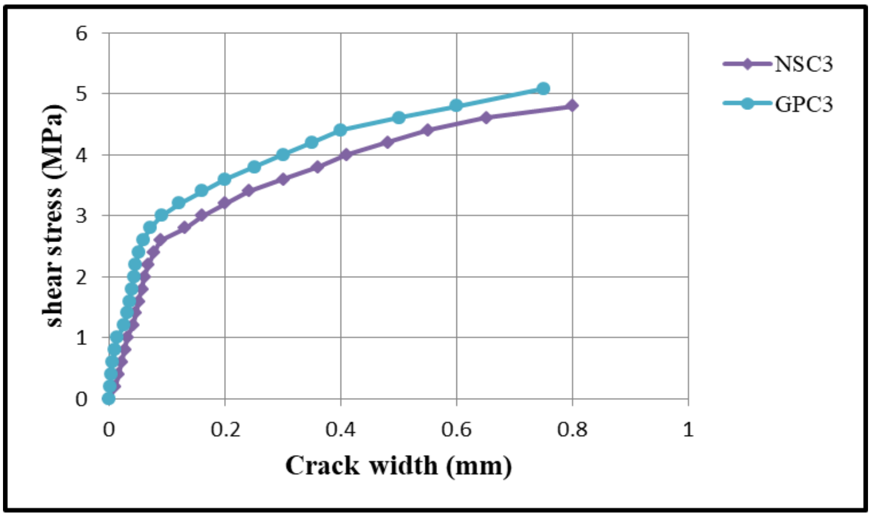
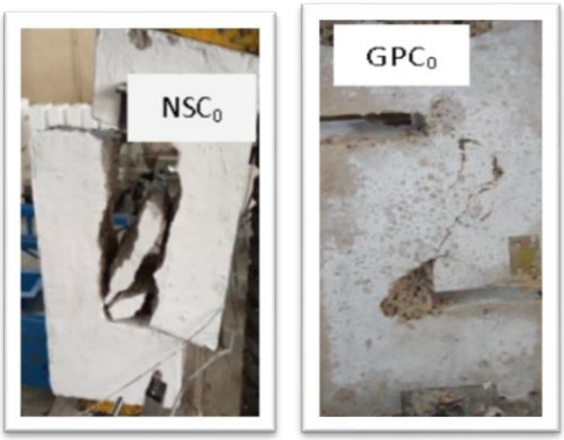


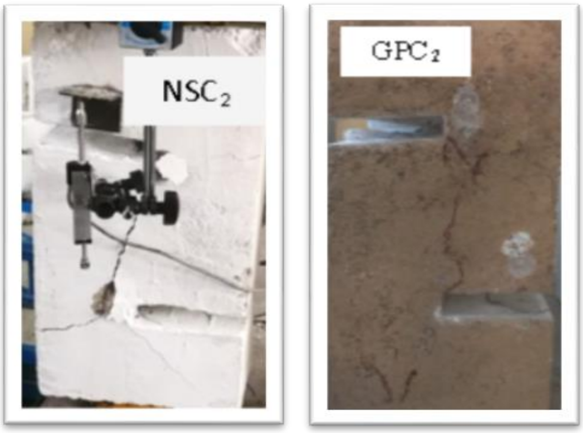
Figure 18 : Shear stress-Crack width relationship for specimens with reinforcement (0.68%)

7.6 Modes of Failure

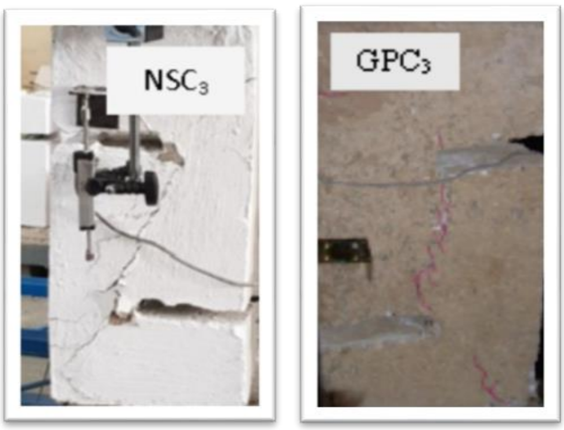
The GPC and NSC push-off specimens had failed due to the interface cracking. The failure occurred rapidly in specimens without reinforcement throughout the interface, whereas apparent cracking along the shear plane was seen at around 65percent of the ultimate stresses in reinforced interfaces. None of the specimens have failed early owing to flexure in the horizontal or vertical arms of the push-off specimen due to the provision of adequate reinforcement in both halves of the push-off specimen. As shown in Figure (19).



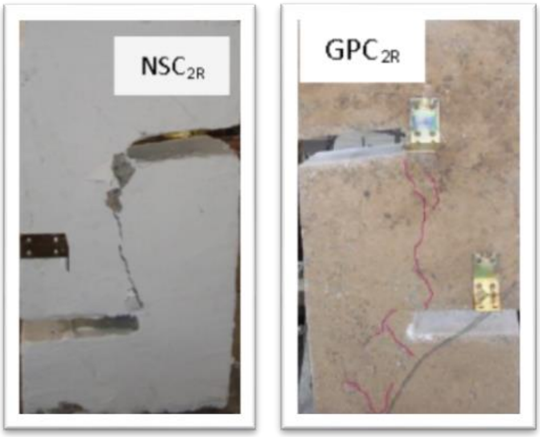
a-Specimens without reinforcement



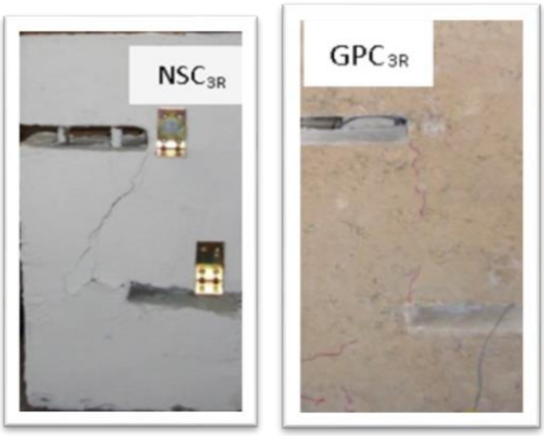
b-Specimens with reinforcement (0.45%)



c-Specimens with reinforcement (0.68%)



d-Specimens with reinforcement (0.45%)
under repeated load



e-Specimens with reinforcement (0.68%)
under repeated load

Figure 19 : Failure mode for all specimens

9. Conclusions

- When a specimen produced of geopolymer concrete is equated to a specimen made of conventional strength concrete, the shear strength of the concrete for the specimen without transverse reinforcement improves by (12.9%). For specimens with transverse reinforcement ratios of 0.45% and 0.68%, respectively, shear strength improved by 6.67% and 5.83%.
- In normal strength concrete, the inclusion of transverse reinforcing steel in the shear plane with a ratio of (0.45% and 0.68%) enhanced shear strength by (69.35% and 93.5%, respectively) when compared to the specimen without shear reinforcement.
- In geopolymer concrete, the inclusion of transverse reinforcing steel in the region of the shear plane with a ratio of (0.45% and 0.68%) enhanced the shear strength by (60% and 81.4%, respectively) when compared to the specimen without shear reinforcement.
- The failure load capacity for specimens of normal strength concrete with transverse reinforcement reduced by 33.3% and 31.6%, respectively, when the type of loading was changed from (monotonous) to (repeated). While specimens of geopolymer concrete with transverse reinforcement ratios of 0.45 and 0.68 percent decreased by 33.1% and 33.62%, respectively.

- In the shear plane, lateral reinforcement lowers slip and horizontal displacements by around (30 to -50%).
- The tested specimens all showed the same failure pattern, with a crack emerging in the shear plane, followed by vertical movement and crack expansion, and transverse reinforcement deformed, despite of the concrete mixture types.
- In specimens with no reinforcing across the interface, failure happened suddenly, whereas evident cracking along the shear plane was detected in reinforced interfaces at (50 to 70%) and (70 to 80%) of the ultimate loads, respectively, for normal strength concrete and geopolymer concrete.

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