EXPERIMENTAL STUDY OF THE BEHAVIOUR OF INTERFACES BETWEEN CARBON FIBRE REINFORCED POLYMERS AND SC SOIL

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Abstract: *The foundation designer must consider the behavior of both structure and soil and their interaction with each other. The interaction problem is of importance to many civil engineering situations and it covers a wide spectrum of problems. These include the study of shallow and deep foundations, floating structures, retaining wall-soil systems, tunnel lining, buried structures, earth structures etc., In recent years, Fibre Reinforced Polymers (FRPs) have been introduced in the field of geo-technical engineering to solve such problems as earthen retention, unstable slopes and strengthening of foundation structures. Hence it is important to study the interfacial behavior between these materials with soil. This study conducts a series of direct shear tests to investigate the interface friction angle between Carbon Fibre Reinforced Polymer (CFRP) sheet wrapped concrete specimens to the clayey sand (SC) soil. The experimental result shows that there was a decrease in the angle of interface friction with CFRP wrapping.*

Keywords: *Direct shear test, CFRP, SC soil, Friction angle, Surface roughness.*

1. Introduction:

Soil-structure interaction studies have proven to be an effective tool for the analysis and design of geotechnical structures. Bearing capacity and load-deformation response of geotechnical structures depend on the stress-displacement behavior of interfaces in the contact area with soil. The interface behavior is based on surface roughness of construction material, composition of soil, relative density of soil, grain size distribution and shape of soil particles, moisture content of soil, magnitude of normal stress and rate of shearing. Many of the foundation structures have been found to deteriorate with time. It is essential to retrofit the deteriorated foundation structures for the better performance under external loads. In response to growing needs for strengthening and rehabilitation of structures, many researchers have considered application of Fiber-Reinforced Polymer (laminated) sheets/strips as an effective strengthening and rehabilitation method. To provide some insight into the interface behavior between CFRP and soil, an experimental study was performed to evaluate the importance of various factors. Uesugi et al. (1989) studied the friction between sand and steel by laboratory tests under repeated loading. They found that normal stress, surface roughness and sand type have remarkable influence on the interface friction. Fakharian and Evgin (1997) performed a cyclic simple shear test on sand-steel interfaces under constant normal stiffness condition. The experimental results show that maximum shear stress decreases with the increase in the number of cycles, irrespective of the magnitude of the tangential-displacement amplitude. Tan et al. (1998) studied the sand-geotextile interface shear strength by torsional ring shear tests. The experimental results show that the peak friction angle measured by the direct shear apparatus is larger than that measured by the ring shear apparatus and the peak friction occurs earlier in the direct shear test than in the ring shear test. Porcino et al. (2003) carried out laboratory tests to investigate the frictional behavior of sand-solid interfaces under more realistic boundary conditions with respect to the traditional constant normal load (*CNL*) direct shear tests. They found that normal stress and surface roughness have remarkable influence on the interface shear strength. Hammoud and Boumekik (2006) studied the interfacial shearing between cohesive soils and solid materials. The results show that the shearing resistance at the interface depends on the interface roughness, as well as on the properties of soils. Ling and Youg (2012) carried out laboratory tests to determine the interface shear strength of Palm biodiesel contaminated sand with smooth and rough steel surfaces. The experimental results show that the contribution of palm biodiesel content to interface shear strength is significant. Interface shear strength increases with the increase of palm biodiesel content. Applied normal stress and surface roughness have remarkable influence on the interface shear strength.

2. Soil characteristics:

Engineering properties of the soil is listed in Table.1. The soil was classified as clayey sand (SC) according to IS: 1498 – 1970.

Table 1: Engineering properties of the soil used in the study

% Passing			Atterberg Limit			Dry unit weight (kN/m^3)			Type of soil (IS 1498)
4.75mm	425µ	75µ	LL (%)	PL (%)	Ip	γ_d(max)	γ_d(min)	γ_d(test)	
99	64	49	47	26	21	15.25	13.12	14.34	SC

3. Testing apparatus:

The direct shear tests for this entire study were carried out in a conventional direct shear box apparatus. The apparatus consists of a two piece shear box of 60 mm x 60 mm in cross-section rests over sliding rollers supported by a loading frame and which can be pushed forward at a constant rate by geared jack, driven by an electric motor. The gearbox with its motor is used with the step less speed control box. The speed control of the shear box is calibrated in mm/min. Test speed could be controlled by choosing the appropriate gear wheel from the gear box. The lower half of the shear box is rigidly held in position in a container and the upper half of the box butts against a proving ring. The normal stress to the specimen is by a vertical load hanger which rests on the yoke above the soil specimen, and hangs vertically downwards permitting selected weights to be held on its loading pan. The shear force was measured by means of a proving ring. The horizontal displacement of the soil specimen was measured with the help of a dial gauge.

4. Testing methodology:

For the interface frictional test, five concrete specimens of size 6cm x 6cm x 1.4 cm were prepared. The concrete specimens were prepared by first mixing the sand and cement, adding water and mixing gradually, subsequently filling the prepared boxes with concrete. The remoulded specimens were cured in water. After sufficient curing, one specimen was tested without any CFRP wrapping and remaining four specimens were wrapped with CFRP sheet. Concrete specimens wrapped with CFRP sheet in different fibre orientation as shown in figure 1. Direct shear test was conducted between these specimens with SC soil. The specimens were placed in the lower half of the direct shear box and the upper half of the shear box was filled with SC soil at predetermined density. The modified direct shear test setup is shown in figure 2. When a shearing force is applied to the lower box through the geared jack, the movement of the lower part of the box is transmitted through the specimen to the upper part of the box and hence on the proving ring. The deformation in proving ring indicates the shear force. The horizontal displacement during the shearing process is measured by mounting a dial gauge at the top of the box. Samples were sheared at 1.25 mm/min. For each tests four normal stress 0.05 N/mm^2, 0.10 N/mm^2, 0.15 N/mm^2 and 0.20 N/mm^2 were used.

Figure 1a: 0^0 CFRP wrapped specimen

Figure 1b: 90^0 GFRP wrapped specimen

Figure 1c: 45^0 GFRP wrapped specimen

Figure 1d: Bi-GFRP wrapped specimen

Figure 1e: Concrete specimen

Figure 1: Specimens used in this study

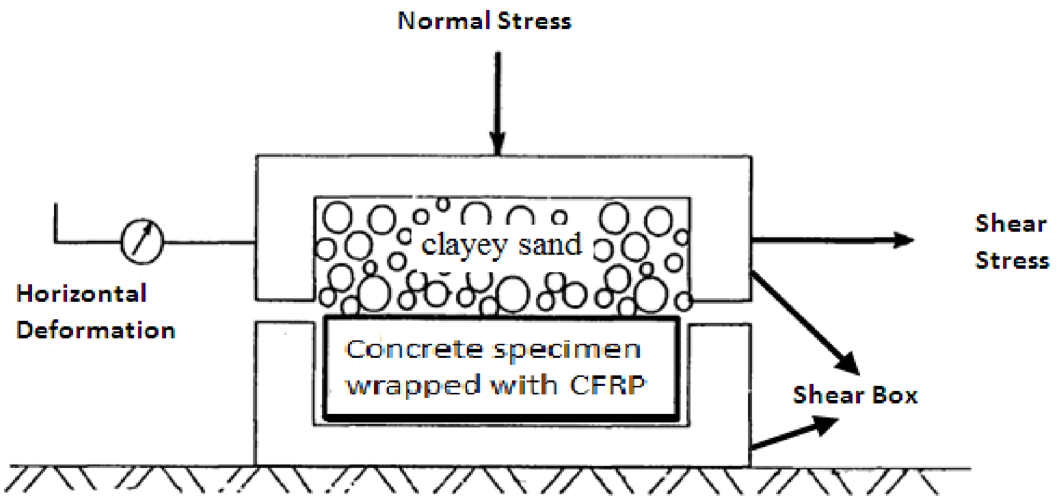

Figure 2: Test set up for interface friction measurement

ISSN 2229-5518

5. Test results and discussions:

5.1. Effect of fibre orientation on interface friction:

The results obtained for the SC soil under different normal stresses were analysed to obtain the required shear strength parameters. The obtained shear strength parameters are presented in table 2. It indicates that angle of interface friction varies with the direction of fibres to shear force. Angle of interface friction is slightly higher when the direction of shear force is perpendicular to the direction of fibres.

Table 2: Shear strength parameters

Type of interaction	Angle of internal/interface friction
SC soil – SC soil	32.12º
SC soil – Concrete specimen	30.84º
SC soil – 0^0 CFRP wrapped specimen	26.18º
SC soil – 45^0 CFRP wrapped specimen	28.46º
SC soil – 90^0 CFRP wrapped specimen	30.12º
SC soil – Bi-CFRP wrapped specimen	28.12º

Note:

- 0^0 CFRP wrapped specimen : Fibre orientation- parallel to shear
- 45^0 CFRP wrapped specimen : Fibre orientation- 45° inclined to shear
- 90^0 CFRP wrapped specimen : Fibre orientation- perpendicular to shear
- Bi-CFRP wrapped specimen : Fibre orientation- both parallel and perpendicular to shear.

5.2. Effect of normal stress on shear strength:

Shear stress against normal stress was plotted; it indicates that the shear strength increases with increasing normal stress. Maximum shear stress against normal stress for SC soil is given in the table 3. Typical shear stress against normal stress for SC soil is shown in figure 3.

Table 3: Maximum shear stress against normal stress for SC soil

Normal stress, (N/mm^2)	Maximum shear stress (N/mm^2)					
	SC-SC	SC-Conc	SC-0^0CFRP	SC-45^0CFRP	SC-90^0CFRP	SC-Bi-CFRP
0.05	0.06542	0.05142	0.04082	0.04648	0.04948	0.04542
0.10	0.09418	0.08415	0.06215	0.07154	0.08202	0.06912
0.15	0.12826	0.11454	0.08456	0.10446	0.11246	0.10248
0.20	0.15886	0.14086	0.11546	0.12593	0.13606	0.12334

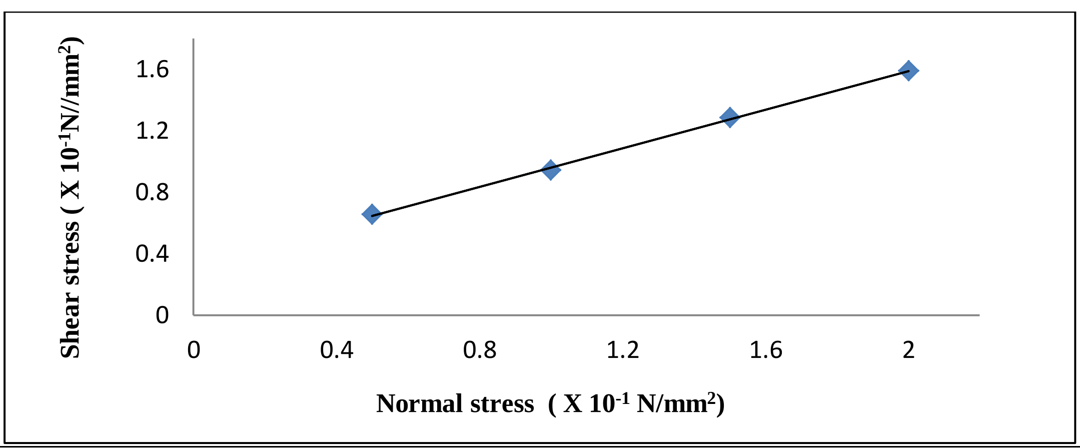

Figure 3: Shear stress against normal stress for SC soils

5.3. Effect of shear stress on horizontal displacement:

Horizontal displacement against shear stress was plotted; it indicates that horizontal displacement increases gradually with increase in shear stress until it reaches its failure shear stress. After that, further increment in horizontal displacement resulting in constant shear stress. Typical shear stress against horizontal displacement curves between SC soils and SC soil to CFRP wrapped concrete specimen (Fibre orientation- perpendicular to shear) are shown in figure 4 and 5 respectively.

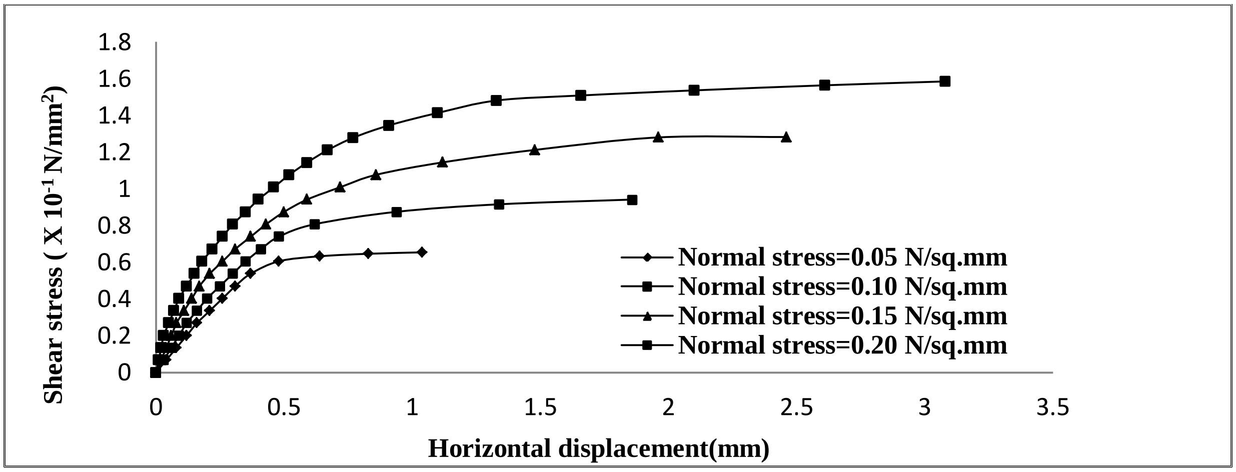

Figure 4: Shear stress against horizontal displacement curves for SC soil

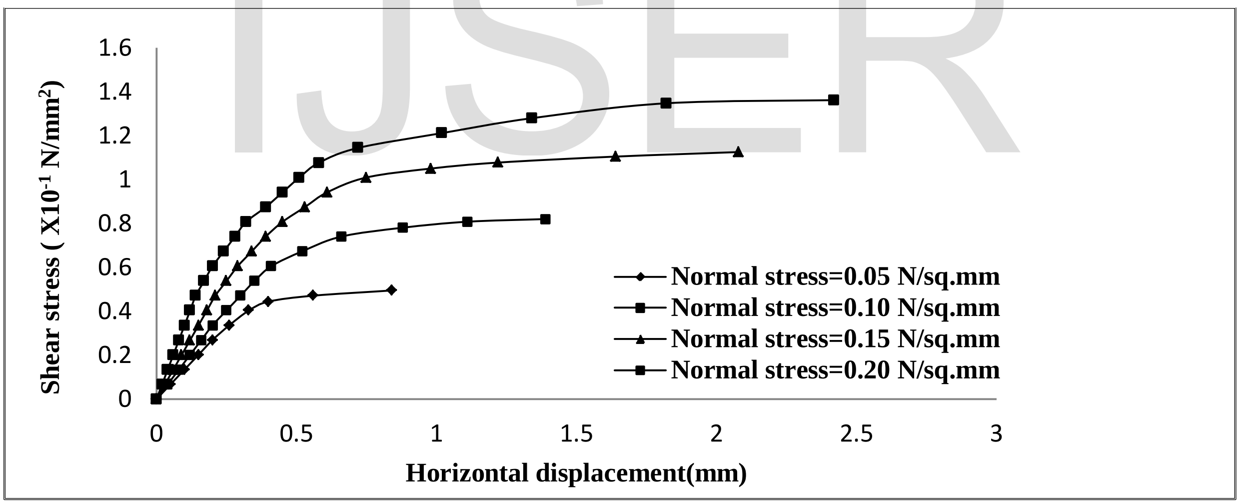

Figure 5: Shear stress against horizontal displacement curves for SC soil to CFRP wrapped concrete specimen (Fibre orientation- perpendicular to shear)

5.4. Effect of surface roughness on interface friction:

Surface roughness of the material is one of the important factors that influence the shear strength parameters. Generally, Absolute roughness (R_a) is considered for calculating interface friction between two different materials. It is a measure of the surface roughness of a material. This roughness is generally expressed in units of length as the absolute roughness of the material. Surface roughness of materials used in the study is given in the table 4. Interface friction angle against surface roughness of concrete specimens is shown in figure 6. It indicates that interface friction angle increases with the increment of the surface roughness of the material used in this study. The highest peak shear strength is achieved when the surface is rough..

Table 4: Surface roughness

Type of interaction	Surface roughness, R_a (μm)
Concrete specimen	0.88
0^0 CFRP wrapped concrete specimen	0.51
45^0 CFRP wrapped concrete specimen	0.69
90^0 CFRP wrapped concrete specimen	0.84
Bi-CFRP wrapped concrete specimen	0.65

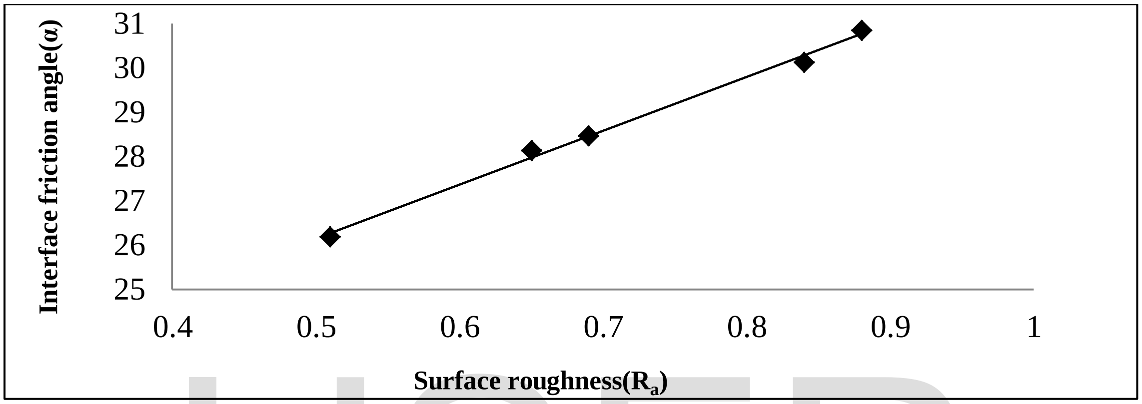

Figure 6: Interface friction angle against surface roughness of concrete specimens

6. Conclusion:

Direct shear tests were conducted to investigate the interface friction angle between SC soil with CFRP wrapped concrete specimens. The tests were performed under four values of normal stress 0.05 N/mm^2, 0.10 N/mm^2, 0.15 N/mm^2 and 0.20 N/mm^2. Examining the data obtained from direct shear test, it could be seen that, in general, there was a decrease in the angle of interface friction with CFRP wrapping. The shear strength at the interface increases with increase in surface roughness of the CFRP wrapped concrete specimens. The shear strength increases with increasing normal stress.

- Angle of interface friction between SC soils with 0^0 CFRP wrapped concrete specimen was 15.11 % lower than concrete specimen without CFRP wrapping.
- Angle of interface friction between SC soils with 45^0 CFRP wrapped concrete specimen was 7.72 % lower than concrete specimen without CFRP wrapping.
- Angle of interface friction between SC soils with 90^0 CFRP wrapped concrete specimen was 2.33 % lower than concrete specimen without CFRP wrapping.
- Angle of interface friction between SC soils with Bi-CFRP wrapped concrete specimen was 8.82 % lower than concrete specimen without CFRP wrapping.

7. References:

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