Efficiency of Interfacial Bond Technique between Geopolymer and Portland Cement Concrete Layers on the Flexural Behavior of Slabs having a Composite Section

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Abstract - *Geopolymer concrete (GPC) is considered an eco-friendly material alternative to Portland cement Concrete (PCC). Many research works studied the fresh and the mechanical properties of the GPC based systems. However, the bond between PCC and GPC has not been covered well. This study is to investigate the influence of adding GPC overlay to substrate cement reinforced concrete (RC) slab as well as different techniques for preparing the RC substrate surfaces including, dowels with diameters 8 mm and Z shape section (Dowels-Z), carving 20 mm wide and 10 mm depth (Carv-20 mm), (painting the surface with epoxy resin (Epoxy-R), surface roughened by a stiff brush in the transverse directions (Brush-TD), surface roughened in both the transverse and longitudinal directions by a stiff brush (Brush- TL- D) and as smooth as cast (Smooth)). The investigated properties included compressive, splitting tensile and flexural strengths. Moreover, flexural behavior of substrate (RC) slab with a GPC overlay were evaluated. The first crack load, ultimate load, crack pattern, e load-deflection, load-strain curves and the interface slip responses at various stages of loading were conducted. Based on the experimental tests, the stiffness of the tested slabs is arranged in a descending order as Brush-TD, Smooth, Brush- TL-D, Epoxy-R, Dowels-Z, Control and Carv-20 mm, respectively. The energy absorption capacities of the tested slabs were improved due to surface roughened by a stiff brush, among the surface roughened by a stiff brush in both the transverse and longitudinal directions showed the best improvement in the energy absorption capacity.*

***Key Words*: Geopolymer concrete (GPC), Portland cement concrete (PCC), preparation of substrate surface, mechanical properties, flexural behavior**

1. INTRODUCTION

Manufacture of one ton of Portland cement (PC), releases about one ton of CO_2 into the atmosphere [1]. Among the greenhouse gases, CO_2 contributes about 65% of the global warming. Moreover, cement construction emissions expected to rise by 100% [2]. Comparison to ordinary (PC), the worldwide warming potential of alkali-activated concrete is 70% lesser. The energy ingesting of alkali activation system is designed to be about 60% fewer than that of PC [3].

To attain the full composite action between the overlay and substrate concrete slab, good bond strength between the two portions is a key factor to have a monolithic system [4,5].

The bond and shear strength between the interaction surfaces must be strong when no mechanical connection is provided [5]. An alternative to improve the adhesion of the two layers needs to using a bonding agent. Some submit that a passable bond can only be achieved by uniting the use of bonding agents with a proper technique to rise the substrate roughness, mostly when the substrate has a smooth surface. Others state that bonding agents are not required if the concrete substrate is dry and suitably roughened to expose its aggregates [6].

The results powerfully advise that in the case of an overlay sited in the compression zone, it is possible to develop and maintain monolithic structural action in the substrate to overlay complex. Moreover, placing the overlay in the compression zone keeps structure time and labor [7].

A statement by [8] stated that pre-wetting the surface (i.e., saturated with a dry surface) before applying the new concrete layer is the best result [8,9]

(Farnoud et al., 2015) [10] showed an experimental study to evaluate the flexural behavior of a precast concrete slab with a steel fiber concrete topping. Based on the experimental tests, ductile performance depends not only on addition the overlay layer but primarily on the kind of interface roughness. Higher energy absorption and ductility were originated in slab with steel fiber (SF) and the interface surface was roughened in the transverse direction. Comparing slabs which are diverse only in the type of roughness at their interface, a 28% development in ductility is attained when the roughness is reformed from longitudinal to transverse. The ductility factor rises by about 36% when only the interface roughness of the specimen's variations from smooth as-cast to the transverse direction and 30% when both specimens have roughness in the transverse direction and only 1% SF added in their toppings.

This research aims to investigate the flexural behavior of geopolymer concrete overlay with substrate reinforced concrete slabs with different roughness's of the substrate surface. The first crack load, the ultimate load, the crack pattern, the load-deflection and the interface slip were conducted.

2. Materials

2.1 General

Locally available materials were used for making substrate cement reinforced concrete (RC) slabs with a geopolymer concrete overlay. These materials included low-calcium fly ash and Portland cement as source materials, aggregates, alkaline liquids, water and steel.

2.2 Materials

2.2.1 Cement (PC)

Portland cement CEM I 42.5N was used for the production of cement concrete. The cement met the requirements of (EN 196-1:2016) [11] and ES 4756-1 [12] with fineness of 3500 cm^2/g.

2.2.2 Fly ash (FA)

commercially available class F fly ash, according to the ASTM C 618-08a [13], was used as the main source of aluminosilicate material for making geopolymer concrete in this experimental work with fineness 5000 cm^2/g. The chemical composition of FA and PC are given in the Table 1.

Table 1: Chemical composition of FA and PC

Oxides %	FA	PC
SiO_2	61.01	20.05
Al_2O_3	29.23	5.21
Fe_2O_3	4.45	3.12
CaO	1.02	64
MgO	0.4	-
SO_3	0.01	3.02
Na_2O	0.01	0.44
K_2O	0.89	0.15
TiO_2	2.08	-
P_2O_5	0.42	-
LOI	0.22	5.1

2.2.3 Alkaline liquids (AL)

A combination of sodium hydroxide (NH) solution and sodium silicate (NS) solution was used as alkaline activator for geopolymerization. NH is available commercially in flakes and pellets form. For this experimental program, NH flakes with 98-99% purity were dissolved in potable water to make NH solution. NS is available commercially in solution form. The chemical composition of NS solution supplied by the manufacturer is as follows: 14.7% Na2O, 29.4% SiO2 and 55.9% water by mass.

2.2.4 Aggregates

Coarse aggregate used was crushed lime stone with specific gravity of 2.5 and its maximum size was 10 mm. Locally available natural well graded sand of specific gravity of 2.6 was used as fine aggregate and it was sieved through sieve 4.75 mm. Coarse and fine aggregates were screened and washed to remove all the organic and inorganic compounds. Both aggregates were used in a saturated surface dry condition and were complied with the limits of ECP 203-2007[14].

2.2.5 Water

Potable water is generally considered as being acceptable. It was used for preparation of NH solution and curing of specimens which satisfies the requirements of ECP 203-2007 [14].

2.2.6 Steel

Mild steel (St. 240/350) of diameters 8 mm were used as the reinforcement in both directions of slab. The properties of the used reinforcements are tabulated in Table 2.

Table 2: Mechanical properties of the steel reinforcement according to tests

Steel type	St. 240/350
Diameter (mm)	8
Yield stress (MPa)	285
Tensile strength (MPa)	400
Elastic modulus (MPa)	2.02×10^5

3. Experimental Program

3.1 Mix proportions of Geopolymer Concrete Mixes

Molarity 16 (16M) of NH solution was used in this experimental work. FA content was 400 kg/m^3. The ratios of AL/FA and NS/NH were 0.55 and 2.5, respectively. The percentages of S/CA was 1:1.65. The Mix proportions of GPC and normal concrete NC and quantity of content in each mix is given in Table 3.

Table 3: Mix proportions for GPC mixes (kg/m^3)

Mix ID	GPC	NC
FA	400	-
PC	-	350
S	665	600
CA	1086	1200
NH	157	-
NS	63	-
W	-	175

FA= Fly ash, PC= Portland cement, S=Sand, CA=Crushed lime stone aggregate, NS=Sodium silicate, NH=Sodium W=Water

3.2 Specimen Details

The test program consisted of casting and testing of seven slabs, including a control specimen NC/RC (substrate RC with NC overlay) and six GPC/RC (substrate RC with GPC overlay) cast with the same mixes given in Table 3 and coded with Epoxy-R, Dowels-Z, Carv-20 mm, Brush-TD, Brush- TL- D, Smooth and Control, respectively. The investigated slabs were 300 mm wide and 100 mm deep in cross-section. They were 1700 mm in length and simply supported over an effective span of 1500 mm. The clear cover of the slab was 15 mm. The details of the slab specimen are shown in Figure 1.

3.3 Instrumentations and Testing Procadures

All slabs were tested after 3 months using universal testing machine of 300 kN capacity. The slabs were simply supported over a span of 1700 mm and subjected to a pair of point loads at a distance of 50 cm from both ends. The distance between the loads was 500 mm. The deflection at the mid-span and third span was observed at different loads using two dial gauges. One LVDT (Linear Variable Differential Transformer) was placed at the end of the substrate slab and overlay to measure the interface slip. To determine strain, two horizontal LVDTs and two strain gauges were installed the specimens at different depths. The overall test layout is illustrated in Figure 2. First crack load, ultimate load, deflection at mid span, crack pattern, interface slips and mode of failure were recorded during the test.

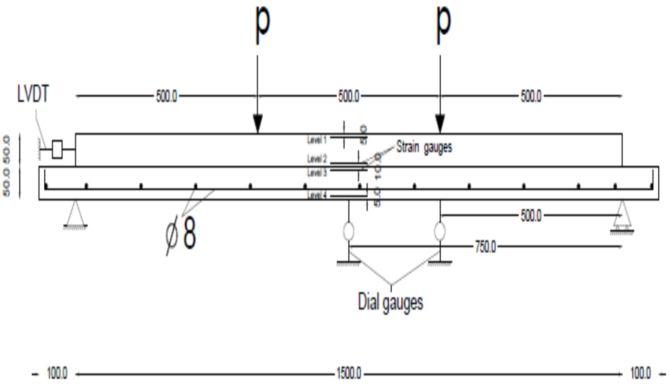


Fig. 2: Test layout

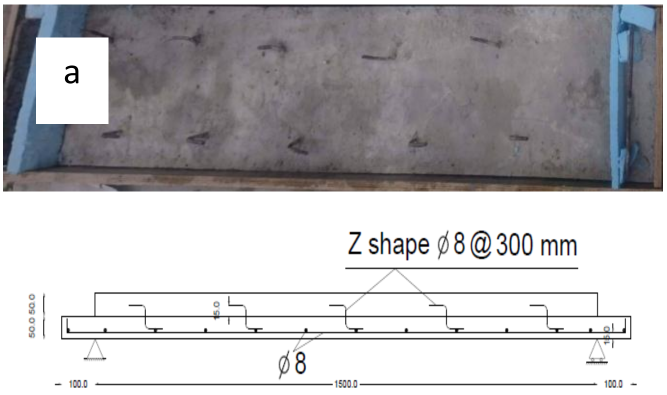
3.4 Preparation of Normal and Geopolymer Concrete Mixes

NC was mixed in a classical procedure where crushed sand and lime stone were mixed first for 2 minutes then cement was added and the dry components were mixed for about 3 minutes to obtain a homogeneous dry mix, then water was added during the mixing process which continued for another 3 minutes or until obtaining a homogeneous mixture.

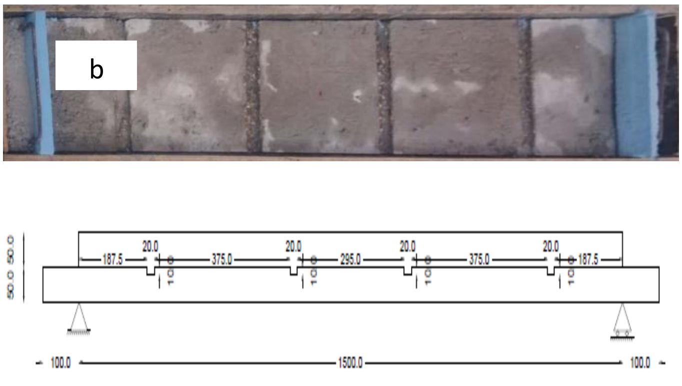
For GPC mixes, to prepare 16M concentration of NH solution, 640 grams (molarity x molecular weight) of NH flakes were dissolved in potable water and completed to form one liter of solution. The mass of NH solids in the solution varies depending on the concentration of the solution expressed in terms of M. The NH solution was prepared one day before mixing and about 2 hours before casting, the NH solution was mixed with NS gel to get the desired AL. The solid constituents of the GPC mix (FA, S and CA) were dry mixed in 100 liter capacity drum mixer for about three minutes. After the dry mixing, AL was added to the dry mix to make the mix wet until it gains homogeneous state.

3.5 Casting of Specimens

For each mix, three cubes of size 100 mm x 100 mm x 100 mm, three cylinders of 100 × 200 mm and three prisms of size 100 mm x 100 mmx 500 mm were cast as companion specimens to find out the compressive, splitting tensile and flexural strengths, respectively at 28 days. For the reinforced slab specimens, wooden molds were used. Prior to casting, the inner walls of the molds were coat with lubricating oil to prevent adhesion with the fresh concrete. The freshly mixed concrete was placed in the molds in three layers of equal thickness and each layer was vibrated until the concrete was thoroughly compacted and the slurry appeared on the top surface of the specimens. The NC used to cast substrate layer of specimens and the substrate concrete surfaces were roughened by different techniques shown in Figure 3. The specimens were then covered by plastic sheets in order to prevent loss of moisture substrate specimens left at ambient conditions (25±2 °C, 55% RH) for 7 days up to casting GPC overlay. Then specimens were lift in the outdoor condition (25±2 °C, 55% RH) for 3 months up to the testing.



a) Dowels with diameters 8 mm and Z shape section (Dowels-Z)



b) Carving and drilling 20 mm wide and 10 mm depth (Carv-20 mm)

c) Painting the surface with epoxy resin (Epoxy-R)

d) Surface prepared with steel brush in the transverse direction (Brush-TD)

e) Surface prepared with steel brush in both the longitudinal and transverse directions (Brush- TL- D)

f) Smooth as cast (Smooth and Control)

Fig. 3: Substrate specimens with different surface preparations

4. Test results and discussion

The characteristics of the specimens and concrete properties for both the substrate and overlay concrete slab after 28 days are shown in Table 4.

Table 4: Properties of substrate and overlay concrete slabs

Mix ID	NC	GPC
Slump, mm	60	100
Bulk density, t/m³	2.37	2.36
Compressive strength, 7 days (MPa)	25	57
Compressive strength, 28days (MPa)	33	61
Splitting tensile strength, (MPa)	2.5	4.2
Flexural strength, (MPa)	4	8.5

4.1 Load Deflection Relationships

The load-deflection relationships for the investigated slabs are shown in Figure 4. Each of the load deflection relationships can be divided into two stages; first stage represents a linear relationship between the applied load and the measured mid span deflection up to a certain point (i.e., the yield load), at which the relationship starts to behave as nonlinear. The load value at which the relationship changed from linear to nonlinear varied from slab to another. In the second stage of loading a nonlinear relationship was recorded for all tested slabs up to final failure. The slope of the first part of this relationship indicates the stiffness of the tested slab. It can be simply noticed that Brush-TD showed the highest stiffness. The stiffness of the tested slabs may be arranged in a descending order as Brush-TD, Smooth, Brush-TL-D, Epoxy-R, Dowels-Z, Control and Carv-20 mm, respectively. Moreover, after steel reinforcement yielding, remarkable reductions in the flexural stiffness were observed as the mid span deflections remarkably increased with relatively constant load.

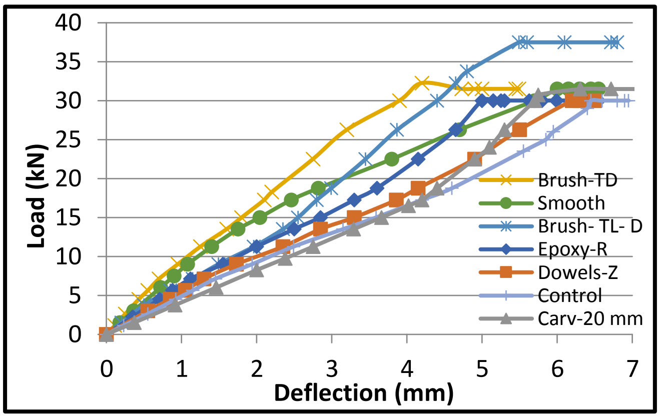


Fig. 4: Load-deflection relationships for the tested slabs

4.2 Interface slip at the end

Interface slip at every end of the specimens was measured using one LVDT and shown in Figure 5. Any movement between the two layers was viewed in the LVDT value and named as interface slip. The highest and lowest movements acquired were (4.15 mm, 3.25 mm, 2.9 mm and 2.6 mm) for slab specimens (Dowels-Z, Carv-20 mm, Brush- TL- D and Smooth) and zero for slab specimens (Epoxy-R, Brush-TD and Control), respectively.

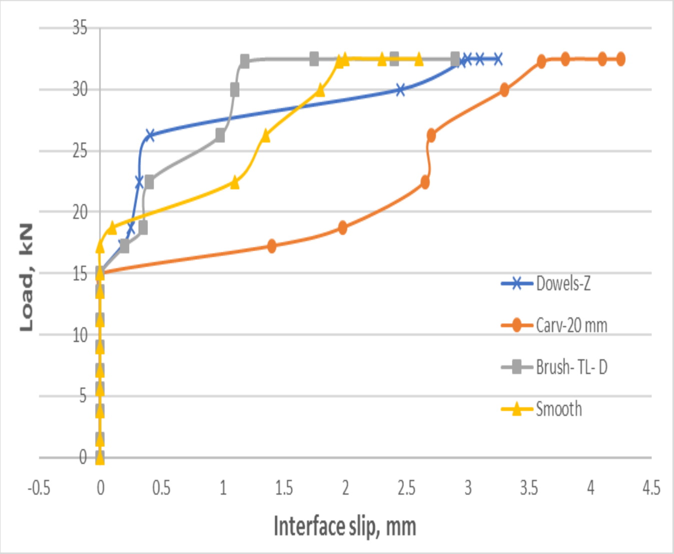


Fig. 5: Interface slip at the end of the slab

4.3 Interface slip at the mid span

Interface slip at the mid-span is measured by using a strain distribution diagram along the full depth of the specimens using the following description shown in Fig. 6.

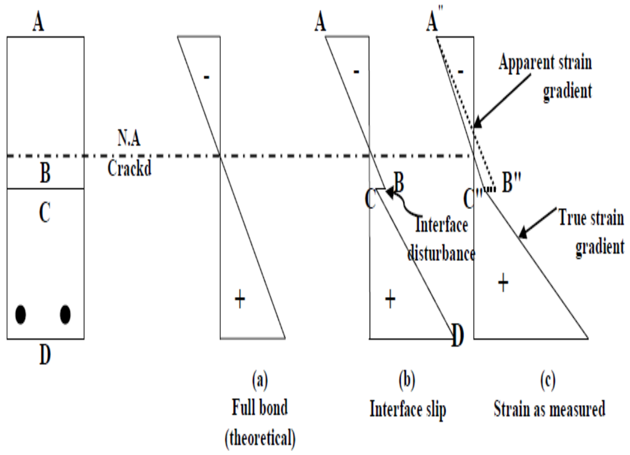


Fig. 6: Theoretical strain distribution diagram [10]

Strain distributions at full depth of the specimens were calculated with strain gauges and LVDTs and are shown in Figs. 7 to 13.

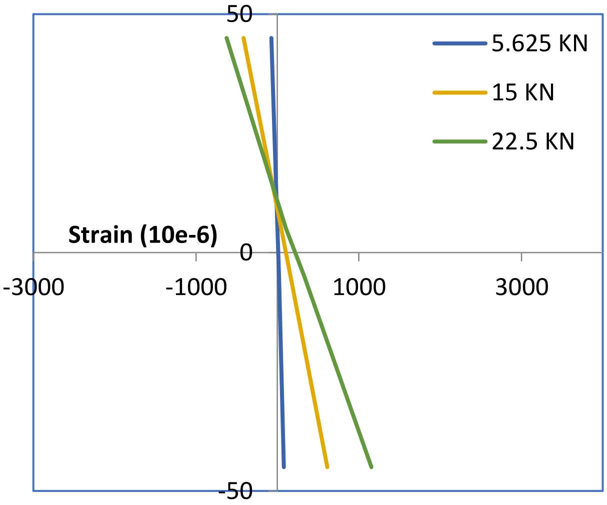


Fig. 7: Strain distribution for slab Epoxy-R

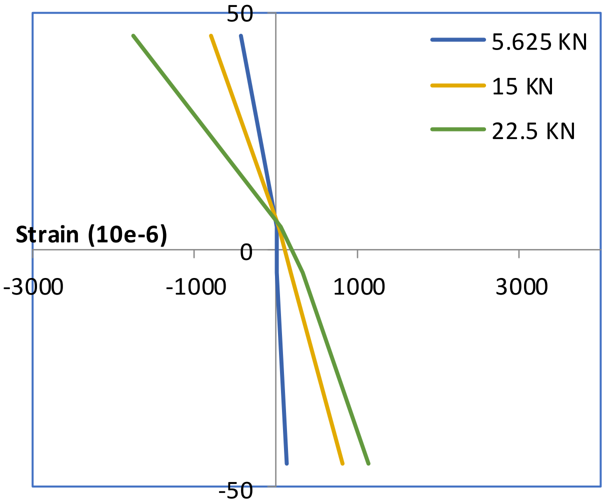


Fig. 8: Strain distribution for slab Dowels-Z

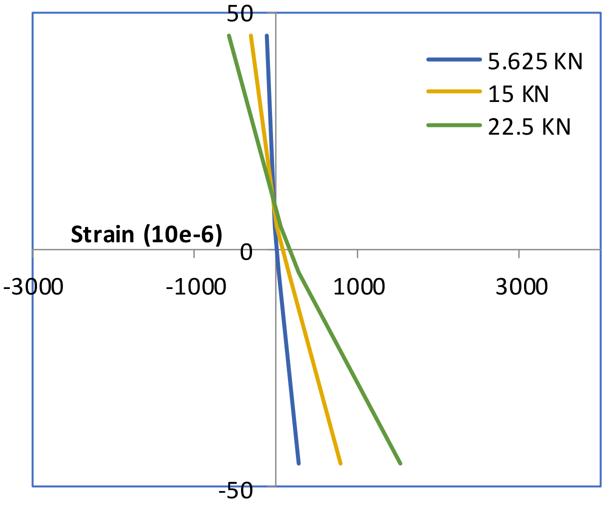


Fig. 9: Strain distribution for slab Carv-20 mm

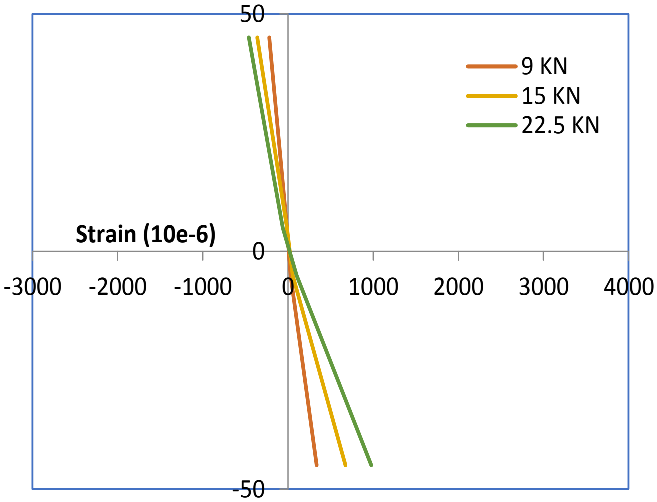


Fig. 10: Strain distribution for slab Brush-TD

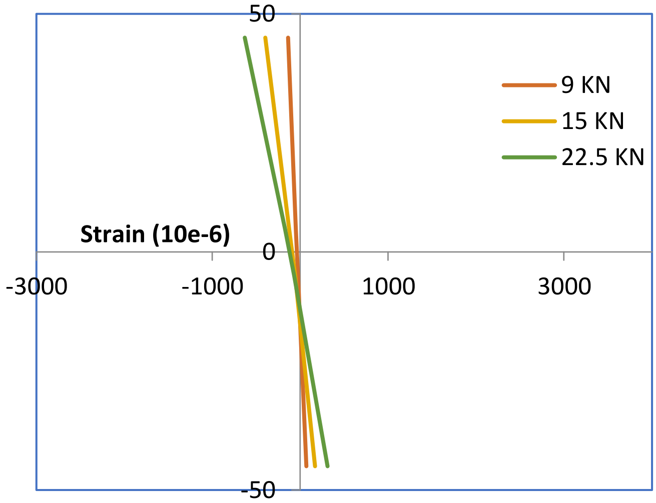


Fig. 11: Strain distribution for slab Brush- TL- D

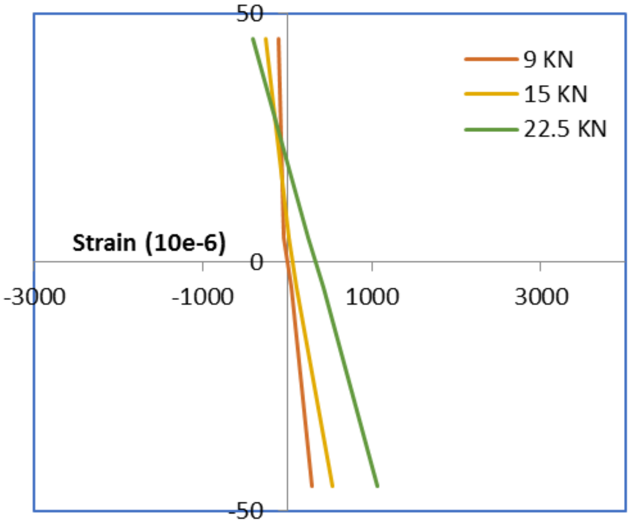


Fig. 12: Strain distribution for slab Smooth

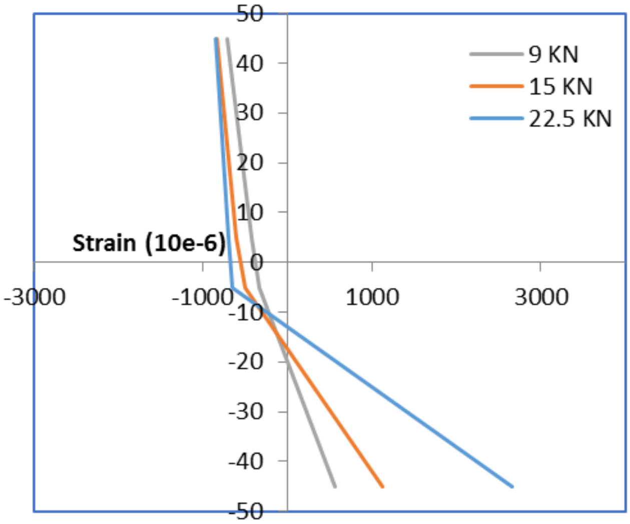


Fig. 13: Strain distribution for Control slab

Interface slip for all specimens is shown in Fig. 14. The slip at the interface is a mark of poor bonding between the topping and substrate concretes. The biggest slip happened for slab control at 0.25mm, signifying poor bonding strength at the interface. This result proves that the normal concrete is estimated to setback overlay debonding. Slab Brush- TL- D, with zero mm of slippage, showed the best interface slip. Interface slippage was showed at all of the specimens; however, only slab failed at the interface was slab Dowels-Z. R.M. Farnoud [10] observed that the biggest slip occurred for smooth as cast slab.

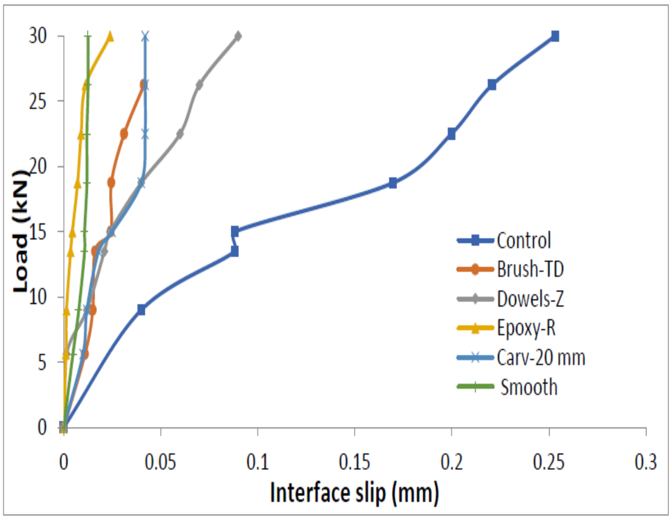


Fig. 14: Interface slip at the mid-span

4.4 Energy Absorption Capacity

Usually, the energy absorption capacity of a given material could be attained from the area under the load deflection curve. Concrete is effective in resisting the load until the deformation of the first crack. At this phase concrete is reassured of its tensile stress and steel converts effective at the cracked section. The area under the load-deflection curve of all slabs representing energy absorption capacity was estimated and publicized in Fig. 15.

From Fig. 15, it can be observed that the energy absorption capacity increased significantly due to surface roughened by a stiff brush. The increases were up to 20.625%, 3.83%, -5%, -7.18%, -9.58% and -18.75% in the energy absorption capacities Brush-TL- D, Brush-TD, Control, Carv-20 mm, Epoxy-R, Smooth and Dowels-Z specimens, respectively when compared to Control slab.

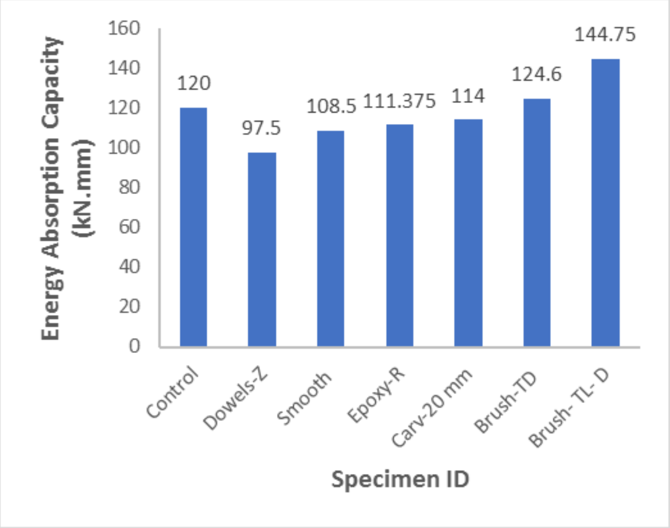


Fig. 15: Energy absorption capacity of the tested slabs

4.5 Crack Patterns and Mode of Failure

The crack patterns and mode of failure for the investigated slabs are shown in Fig. 16. It can be observed as given in the figure and from the test follow up that the cracks started with a limited number in the tension zone of the slabs. With increasing of the applied load, the number of cracks were increased and extended to the compression zone in addition to the neutral axis moved from tension to compression zone until the failure occurred. The cracks were vertical and in the middle of the slab. It can be seen from the cracks at failure, especially for slabs that surface roughened by a stiff brush (Brush-TD) and (Brush- TL- D) slabs have smaller numbers cracks and lesser crack width in comparison to other slabs.

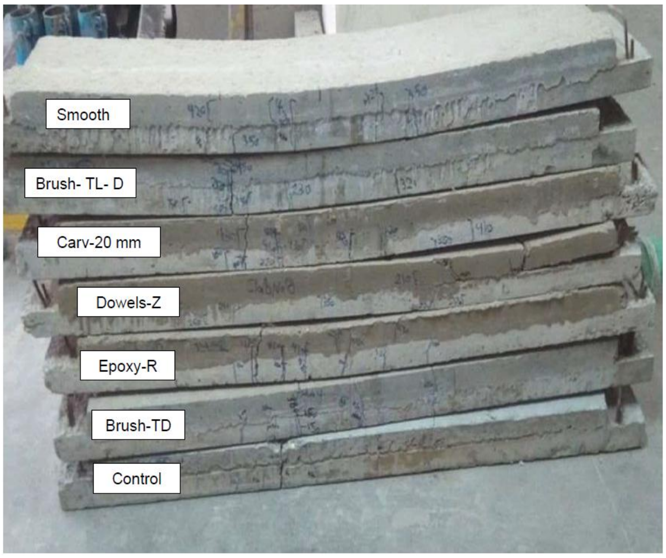


Fig. 16: Crack pattern and failure mode of the tested slabs

5. CONCLUSIONS

This study is directed to investigate the flexural behavior of overlaid geopolymer concrete (GPC) slabs with substrate reinforced concrete (RC) with different techniques for preparing the RC substrate surfaces including, (painting with epoxy resin on the surface (Epoxy-R), dowels 8 mm -Z section (Dowels-Z), carving 20 mm width and 10 mm deep (Carv-20 mm), surface roughened in the transverse directions by a stiff brush (Brush-TD), surface roughened by a stiff brush in both the transverse and longitudinal directions (Brush- TL- D) and as smooth as cast (Smooth)). Based on the experimental results and discussions, the following conclusions are drawn:

1. Ductile performance of slab depends not only on adding GPC to the topping but mainly on the type of interface roughness.

2. The stiffness of the tested slabs may be arranged in a descending order as Brush-TD, Smooth, Brush- TL-D, Epoxy-R, Dowels-Z, Control and Carv-20 mm, respectively.

3. Surface roughened by a stiff brush in both the transverse and longitudinal directions (T&L) D showed the best performance in the energy absorption capacity

4. The interface slips at every end of the specimens acquired were (4.15, 3.25, 2.9 and 2.6) mm for slab (Dowels-Z, Carv-20 mm, Brush- TL- D and Smooth) and zero for slab (Epoxy-R, Brush-TD and Control), respectively.

5. Surface roughened in the transverse directions by a stiff brush reduced the cracks width and enhanced the failure mode to a more ductile one.

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