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POLYMER CONCRETE TO NORMAL CONCRETE BOND STRENGTH: MOHR-COULOMB THEORY

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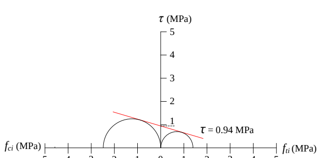
Graphical abstract



Abstract

This paper discusses an experimental study conducted to evaluate the bonding strength between polymer concrete (PC) and normal concrete (PC) bond substrate. Ground palm oil fuel ash (GPOFA) was incorporated as micro-filler in this polymer concrete (PC GPOFA) to investigate its effect on bonding strength. As comparisons, PC containing others filler were prepared, i.e., PC incorporating calcium carbonate (PC $CaCO_3$), silica sand (PC Sand), and unground POFA (PC UPOFA) filler. Two tests were conducted to investigate the bonding between two substrates through slant shear and splitting tensile test. Since the critical condition surface (smooth surface) was provided, then, effect of bonding was determined by using Mohr-Coulomb theory. The overall results indicated that PC incorporating GPOFA was improved the bond to normal concrete. This result indicates that the bonding strength PC to NC at critical condition. This was affected by self-adhesive of polymer concrete to the normal concrete. The self-adhesive characteristic such as pure shear strength of polymer concrete to normal concrete also can be found in Mohr-coulomb analysis. All-in all, the PC incorporating ground POFA could improve the bond to the normal concrete. These findings expected to bring the knowledge and information to engineers and fabricators.

Keywords: Polymer concrete, concrete to concrete bond, Mohr-Coulomb, bonding strength, pure shear strength

1.0 INTRODUCTION

Common applications such as strengthening of existing concrete member and precast concrete member with cast-in place part are always related to structural concrete-to-concrete structure and this applies to PC as well. Therefore, structural concrete-to-concrete interfaces become an area that needs scrutiny as well. The bond strength of the concrete-to-concrete interface is affected by several factors: (i) Preparation of the substrate surface. (ii) Bonding agent at the interface. (iii) Mechanical properties of both concrete substrates. (iv) Moisture content of the substrate. (v) Curing condition of both concrete substrates. (vi) Stress state at the interface. (vii) Amount of steel reinforcement crossing the interface among others.

In order to evaluate the behavior and/or the strength of concrete-to-concrete interface, there are several tests available which can be categorized according to the stress resultant at the interface in, which are axial, bending and shear tests. However, the slant shear test is the most common test done to measure the adhesion between concrete substrates. In slant shear test, the interface is subjected to both shear stress distributions at the interface. Slant shear test becomes prevalent to simplify the experimental setup and due to the high sensitivity of the test to variations parameter [1-3]. Slant shear test is applicable not only to normal/shear stress [4] but also to zero normal stress [5].

The main objective of this research is to investigate polymer concrete (PC) to normal concrete (NC) bond substrate at critical condition (smooth interface) by using Mohr-Coulomb theory. However, the bond strength between two substrates was determine beforehand proceed to analyze using aforementioned theory. Four types of PC's substrate were employed; PC incorporating ground POFA, calcium carbonate, unground POFA and silica sand and these bond substrates were bonded to NC. All types of NC to PC substrate were tested under compression and splitting tensile test purposely to investigate the bonding strength between two substrates. This finding of work expected to bring the knowledge and information about potentiality using PC incorporating palm oil fuel ash as substrate to NC substrate to improve the bonding.

2.0 EXPERIMENTAL PROGRAM

2.1 Materials and Mix Proportions

In this study, the resin was employed to produce PC was based isophthalic polyester. The optimum mix proportions of various PC were properly designed and manufactured as shown in Table 1. However, the mix proportions were limited to low binder content of about 12% of resin. The selection of low binder content is in accordance with previous researchers [6-9]. In this study, the low amount of polymer binder was able to produce PC with adequate strength at low cost. The coarse aggregates was limited to 30% for all mix proportions and the rest was the fine aggregates. Additionally, four types of fillers were used in PC's material; calcium carbonate ($CaCO_3$), ground palm oil fuel ash (ground POFA), silica sand, unground palm oil fuel ash (Unground POFA) and the properties of particle size of filler as presented in Figure 1. The general sample notations of mix proportion are as follows:

PC $CaCO_3$: PC incorporating calcium carbonate
PC GPOFA : PC incorporating ground POFA
PC Sand : PC incorporating silica sand
PC UPOFA : PC incorporating unground POFA

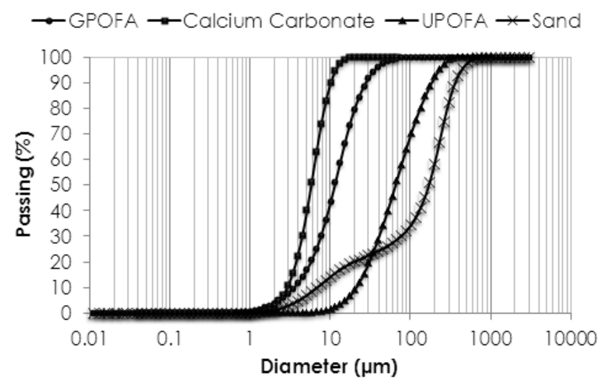


Figure 1 Particle size distribution of fine and coarse fillers

Table1 Mix Proportions of Polymer Concrete

Concrete Materials	Mix Proportions (kg/m³)			
	PC GPOFA	PC $CaCO_3$	PC UPOFA	PC Sand
Resin binder	132	132	132	132
Filler	136	270	97	258
*FA	1141	1238	1238	1238
*CA	750	750	750	750

*FA= Fine aggregate, CA=coarse aggregate

Mix proportion of normal concrete is presented in Table 2. The main materials for making normal concrete in this study were cement, coarse aggregates, fine aggregates, and tap water. The characteristics strength was design for 30 N/mm² with a slump of 30-60 mm.

Table 2 Mix Proportion of Normal Concrete

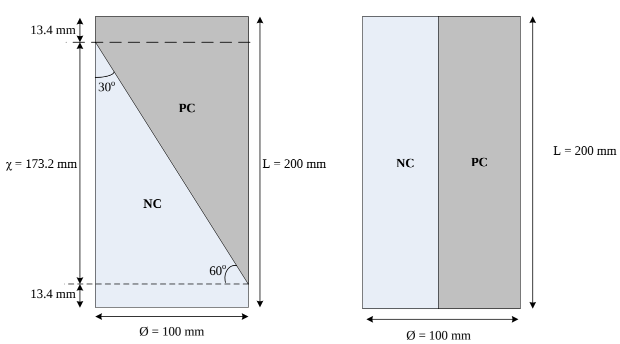
Concrete materials	Mix proportions (kg/m³)
Cement	427
Coarse aggregate	950
Fine aggregate	810
Water	213

2.2 Specimen Preparation and Bonding Test

There were two tests conducted to investigate bonding behavior between PC and NC substrate-slant shear test under compression load and splitting tensile test. In this study was limited to test the critical bonding condition. Critical bonding condition indicates a condition where the specimen has smooth surface and does not have any adhesive applied on the surface to produce bonding between two substrates. All tests strictly adopted according to BS6319 [10].

For half slant-shear specimen, the hardened normal concrete was diagonally slanted at 30° angle from vertical. According to BS6319 [10], the bond angle of 30 recommended in represents the failure stress corresponding to a smooth surface is close to the minimum stress. Dimension of slanted specimen is presented in Figure 2. A total of 20 of specimens (five specimens per PC type) were employed for slant shear test. The test was conducted using an Olsen universal testing machine with load cell of 200 kN. Half cylindrical specimen was prepared and the entire specimen was tested for splitting tensile test. While, a total of 20 specimens (five specimens per PC type) were employed for splitting tensile test. The test was conducted using Instron universal testing machine with loading rate of 3 kN/s. The dimension for bonding specimens as given in Figure 2. Figure 3 shows the test was conducted for slant shear and splitting tensile test. The general sample notations for bond substrate are given as follows:

PC GPOFA - NC	:	PC incorporating ground POFA to NC bond substrate
PC $CaCO_3$ - NC	:	PC incorporating calcium carbonate to NC bond substrate
PC UPOFA-NC	:	PC incorporating unground POFA to NC bond substrate
PC Sand -NC	:	PC incorporating silica sand to NC bond substrate



(a) (b)
Figure 2 Dimension of bond substrate

(a) (b)
Figure 3 Bonding Test (a) Slant shear under compression load (b) splitting tensile

2.3 Mohr-Coulomb Theory

Bond failure envelope can be obtained using Slant shear test (f_{ci}) results in shear combined with splitting tensile results (f_{ti}) and both of them are estimated using mohr-coulomb theory. From Mohr-Coulomb criterion, the pure shear stress (τ_o) could be obtained. This theory has been introduced previously by Santos [11] for concrete-concrete bond. Figure 4 shows the failure envelope for adhesive and cohesive failure. There are two conceivable failure mechanisms under slant shear test-adhesive and cohesion failure.Adhesive failure refers to the interface debonding and cohesive failure is about the crushing of weakest concrete [11,12]. Since smooth surface was prepared for bonding interface, therefore cohesive, failure is to be ignored in this study.

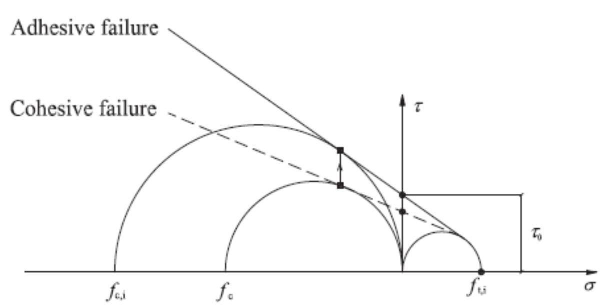


Figure 4 Failure envelope using Mohr-Coulomb theory[9, 10]

3.0 RESULTS AND DISCUSSION

3.1 Bonding Strength

Figures 5 and 6 show the average load-deflection and tensile strength for different PC to NC bond substrate under slant-shear and splitting tensile test, respectively. Under the slant shear test, the load-deflection behavior clearly showed that all materials were brittle. In terms of mode of failure, generally all specimens were broken at the interface between PC and NC substrate. This mode of failure is call as adhesive failure [11]. This showed that the materials had sufficient ability to sustain maximum test load; this allowable critical failure mode strongly reflects to the materials self-adhesive.

From the slant-shear and splitting tests, the PC $CaCO_3$ to NC bond substrate demonstrated the highest bonding strength as compared to others. The substrate could sustain high load with larger deflections since calcium carbonate has superior micro-filler characteristics On the other hand, the PC GPOFA to NC bond substrate had comparable bonding strength with the PC Sand to NC bond substrate. Additionally, it was obvious that the PC UPOFA to NC bond substrate had the lowest bonding strength because unground POFA had the high cellulose structure which may lead poor combination of materials in PC. Thus, it becomes clear that PC with ground POFA has high potential in becoming PC's substrate to the NC. This agreement was supported by previous researchers [13-18].

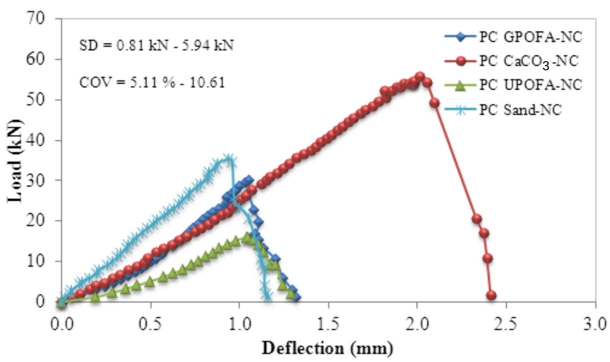


Figure 5 Average of load-deflection behavior under slant shear test for different type of bond substrate

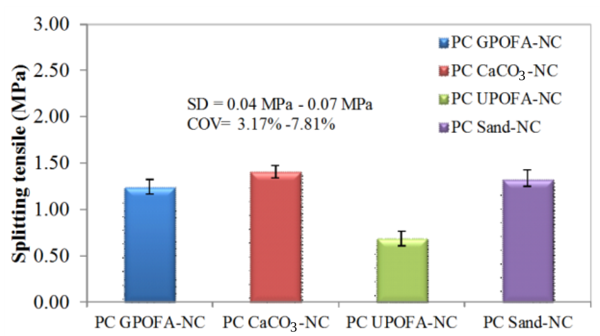


Figure 6 Average of load-deflection behavior under splitting tensile test for different type of bond substrate

3.2 Mohr-Coulomb Theory

Slant shear and splitting tensile results were combined together to proceed the analysis using Mohr-Coulomb theory. Tables 3 and 4 present the summary of desired parameter to be considered in Mohr-coulomb analysis. However, since adhesive failure was occurred in this study, therefore only the interface slant shear strength in compression (f_{ci}) and tensile strength (f_{ti}) were used. The nomenclature was used in this summary was given as follows:

F_c : Compression maximum load in kN
F_{ci} : Shear compression load in kN (angle of 60° divided to cos 30°)
A_c : Compression area in mm^2
A_{ci} : Shear Area in mm^2 (compression action)
f_c : Concrete compressive strength in MPa (slant shear action)
f_{ci} : Interface compressive strength in MPa
F_t : Tension maximum load in kN
F_{ti} : Shear tensile load in kN
A_t : Tension area in mm^2
A_{ti} : Shear Area in mm^2 (tension action)
f_t : Concrete tensile strength in MPa (tensile splitting action)
f_{ti} : Interface tensile strength in MPa
τ : Pure shear strength in MPa

Table 3 Summary of desired parameter to be considered and used in Mohr-Coulomb analysis under slant-shear results

Type of bond substrate	F_c (kN)	F_{ci} (kN)	A_c (mm²)	A_{ci} (mm²)	f_c (MPa)	f_{ci} (MPa)
PC GPOFA-NC	27.2	34.6	7862.5	14152.5	3.5	2.5
PC $CaCO_3$-NC	56.0	64.7	7862.5	14152.5	7.1	4.6
PC UPOFA-NC	15.8	18.5	7862.5	14152.5	2.0	1.3
PC Sand-NC	35.4	40.4	7862.5	14152.5	4.5	2.9

Table 4 Summary of desired parameter to be considered and used in Mohr-Coulomb analysis under splitting tensile results

Type of bond substrate	F_t / F_{ti} (kN)	A_t (mm²)	A_{ti} (mm²)	f_t (MPa)	f_{ti} (MPa)
PC GPOFA-NC	39.0	7862.5	20000	1.2	2.0
PC $CaCO_3$-NC	44.0	7862.5	20000	1.4	2.2
PC UPOFA-NC	21.7	7862.5	20000	0.7	1.1
PC Sand-NC	41.5	7862.5	20000	1.3	2.1

Figure 7 shows the adhesive bond failure envelope which estimated using Mohr-Coulomb theory. The bonding strength between NC and PC at critical condition (smooth surface) influenced by pure shear strength. Pure shear strength in this study indicates that PC had materials self-adhesive to the NC. It means, PC $CaCO_3$ had superior self-adhesive as compared to others with pure shear strength, τ 1.58 MPa. However, PC GPOFA and PC Sand had comparable self-adhesive to NC with pure shear strength, τ 0.94 MPa and 1.22 MPa, respectively. Utilizing of POFA was improved the NC to PC bond but only the ground POFA was qualified to be used as micro-filler in PC substrate. This evident was found when the PC UPOFA to NC bond substrate had very small of pure shear strength, τ with 0.60 MPa. This situation gives insight that NC to PC UPOFA substrate had very poor bond and this PC had worst self-adhesive to the NC. Additionally, the highest bonding strength gives the pure shear strength between PC and NC, vice versa. However, PC GPOFA to NC bond substrate improved about 57% of bonding strength as compared to PC UPOFA to NC bond substrate.

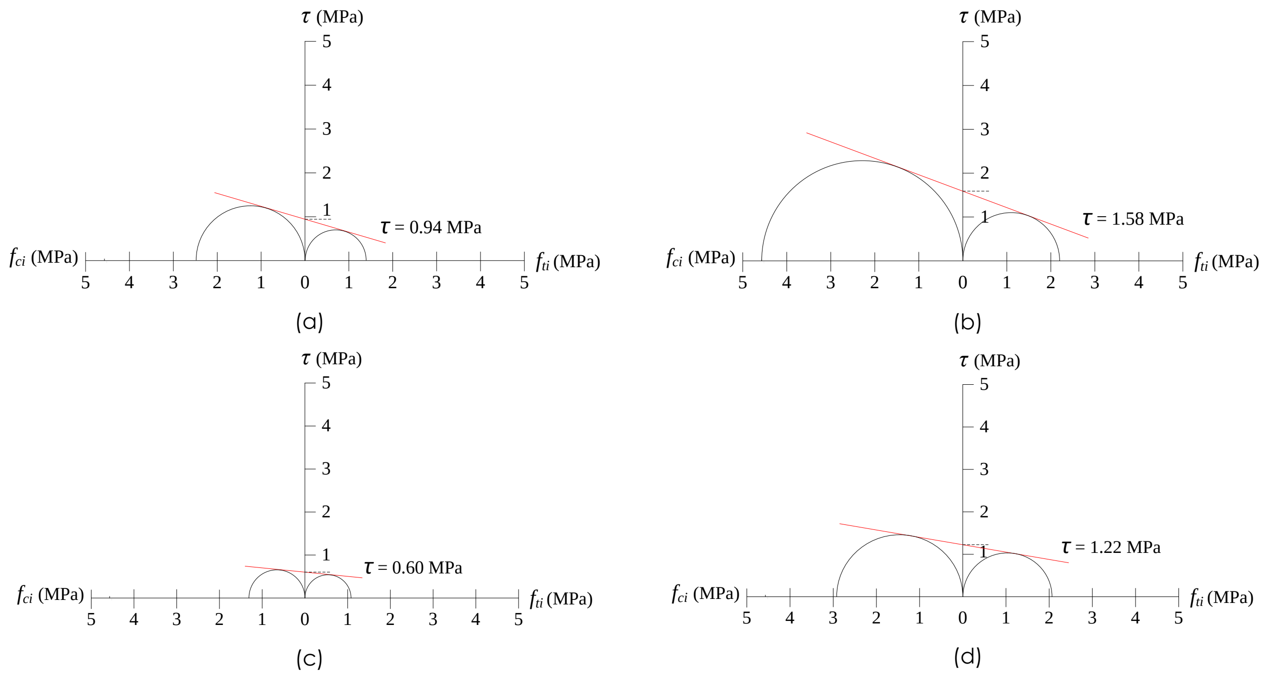


Figure 7 Adhesive bond failure envelope using Mohr-Coulomb theory (a) PC $CaCO_3$-NC (b) PC GPOF -NC (c) PC Sand-NC (d) PC UPOFA-NC

4.0 CONCLUSION

The following conclusions have been drawn from the present study:

1. PC $CaCO_3$ to NC bond substrate had superior bond strength as compared to others. But, the NC to PC GPOFA and NC to PC sand had comparable bond. And, the NC to PC UPOFA had worst bond strength. However, PC GPOFA to NC bond substrate improved about 57% of bonding strength as compared to PC UPOFA to NC bond substrate.
2. PC incorporating palm oil fuel ash was improved the bonding to normal concrete. However, only PC incorporating ground POFA was improved the bonding as compared to PC incorporating unground POFA.
3. The bonding strength was influenced by the pure shear strength. The highest bonding strength gives the highest pure shear strength.
4. Pure shear strength was found in this study indicates that PC had self-adhesive to NC at the critical bonding condition.

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