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IMPROVEMENT OF WATER PENETRATION RESISTANCE OF BOND BETWEEN CONCRETE AND STEEL BY POZZOLANIC MATERIALS AND SUPERABSORBENT POLYMER

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The weakest zone in reinforced concrete is the bond between concrete and steel. Hence, the deterioration of bond from the water penetration effect leads to the decreasing reinforced concrete structure durability. The increase in concrete performance reduces water penetration effect to bond in reinforced concrete structures, leading to longer service life of reinforced concrete structures. Pozzolanic materials such as fly ash and ground-granulated blast furnace slag (GGBFS) and superabsorbent polymer (SAP) are used as cementitious materials and water retaining agent respectively. In this experiment, the water to binder ratio of concrete was set at 0.4. Furthermore, the experiment was designed in two phases; for improving concrete performance and increasing concrete-steel bond durability respectively. For Phase-1, bleeding, compressive strength and drying shrinkage were used to evaluate the improvement of concrete performance. For Phase-2, Vickers hardness test of the interfacial transition zone (ITZ), water penetration resistance test of bond and bonding pullout test of both cases with and without water penetration effect to bond were conducted to investigate the increasing of concrete-steel bond durability. In conclusion, due to using only SAP and using both GGBFS and SAP in the concrete, the high compressive strength and low bleeding are obtained which lead to improving the microstructure of concrete-steel ITZ. Also, the small drying shrinkage of both concrete leads to reducing the possibility of concrete cracking. As a result, the water penetration resistance of concrete-steel bond improves and the durability of concrete-steel bond increases.

Key Words: *concrete-steel bond, water penetration, superabsorbent polymer, GGBFS, fly ash*

1. INTRODUCTION

Reinforced concrete has always been stated that the combination of concrete and reinforcing steel is optimal because of not only mechanical performance but also long-term performance. Theoretically, this combination should be highly durable, as the concrete cover provides a chemical and physical protection barrier to steel reinforcement. However, the effectiveness of the steel reinforcement depends on the bond between concrete and reinforcing steel bar. In the exposed environment, the ingress of liquid water from rainfall and snowfall and oxygen from the air to the steel especially through cracks occur in surrounding concrete. As a result, the steel corrosion occurs and significantly affects the durability of concrete-steel bond. This type of damage results in increase in the volume of corrosion products[2)] (i.e. rust) as shown in Figure 1. From this phenomenon, the concrete covering is broken, and also, the cross-section area of steel rebar is reduced as shown in Figure 2. These two reasons lead to decrease in durability and service life of concrete structures. Moreover, the study about the degradation of concrete anchorage performance in wind turbine foundation[1)] shows that water penetration into bond between concrete and anchor steel plate occurs because of the gaps which are created by drying shrinkage and bleeding of concrete, causing the rapid deterioration of the anchorage performance of concrete foundation. The primary cause of these two problems is the deterioration of concrete and it directly affects the durability of the bond between concrete and steel. Hence, if the concrete performance is improved, the bond durability between concrete and steel is also developed. Some researchers[7,9,10)] mention that pozzolanic materials such as ground-granulated blast furnace slag (GGBFS) and fly ash can be used to increase the durability of concrete. Also, some researchers[5,6,8)] believe that using superabsorbent polymer (SAP) as water retaining agent increases the hydration rate of cement paste in low w/b concrete (less than 0.45) and it brings about better concrete performance. However, no one comments on the performance of concrete using both pozzolanic materials and SAP in low w/b concrete. This research will investigate performance of these new types of concrete and their impact on concrete-steel bond durability.

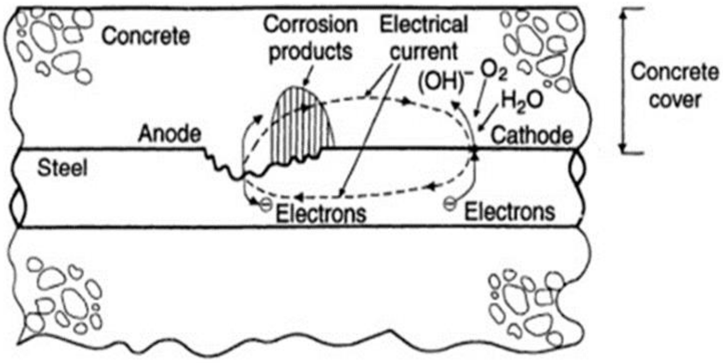

Figure 1 Electrochemical process of steel corrosion in concrete

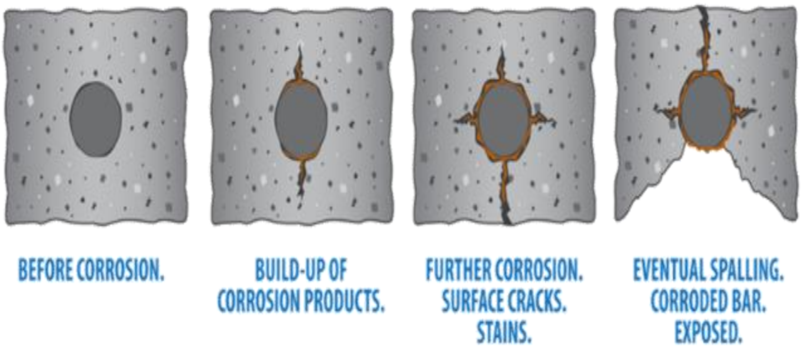

Figure 2 Process of steel corrosion in concrete

2. MATERIALS AND METHODOLOGY

2.1 Materials and mix proportion

The water-to-binder ratio of concrete in this experiment was set at 0.4. In this research, the pozzolanic materials, fly ash, GGBFS available in the market are used to replace cementitious portion by 25 and 50 percent in low w/b concrete group respectively. Also, the superabsorbent polymer was added into some mix designs by 0.11 percent of the cementitious portion. Table 1 shows the properties of cementitious materials and Table 2 present the mix designs in this research.

Table 1 Properties of cementitious materials

	OPC	fly ash	GGBFS
CaO (%)	64.04	3.17	43.67
SiO_2 (%)	20.61	54.94	33.73
Al_2O_3 (%)	5.41	28.63	13.75
Fe_2O_3 (%)	3.08	5.90	0.53
MgO (%)	1.57	1.32	6.00
Blaine fineness(cm^2/g)	3,270	3,710	6,480
Density (g/cm^3)	3.16	2.36	2.91

Table 2 Concrete mix design used in this research

	Unit weight (kg/m^3)					
Materials	M1-G1	M2-G1	M3-G1	M1-G2	M2-G2	M3-G2
Cement	428	321	214	428	321	214
Fly Ash	0	107	0	0	107	0
GGBFS	0	0	214	0	0	214
SAP	0	0	0	0.48	0.48	0.48
Sand	865	865	865	865	865	865
Gravel	853	853	853	853	853	853
Water	175	175	175	175	175	175
Superplasticizer	4.91	4.91	4.91	4.91	4.91	4.91

2.2 Experiment phase-1

2.2.1 Compressive strength test

90 cylinder specimens (100 X 200 mm.) from eight mix designs were subjected to compressive strength test following ASTM C39. Concrete specimens of 3, 7, 28, 56, and 90 day-aged were set for observation. In addition, the curing method of the concrete specimen simulated the real construction site. The specimens were covered by plastic sheet for seven days for sealed curing and then, the specimens were kept in the experiment room until the target age.

2.2.2 Drying shrinkage test

12 rectangular specimens (100 X 100 X 400 mm^3) from eight mix designs were used for drying shrinkage test following ASTM C157. 24 hours after casting concrete specimens, two pins

were attached to the surface of concrete specimens on both sides, and the distance between these two pins was set as 100 mm. For the curing method, after finishing, the specimens were submerged in water for 7 days before placing the specimens in the chamber in which temperature and relative humidity was set at 20 °C and 60% respectively. Drying shrinkage data collection started on the first day when concrete placed in the chamber. Data were collected at 2-day interval from day 1 to day 28, later on changed to 7-day interval until day 90.

2.2.3 Bleeding test

Six mix designs were used for bleeding test following ASTM C232.

2.3 Experiment phase-2

After all the tests in experiment phase-1 were finished, M1-G1, M1-G2, M3-G2 were chosen to conduct Vickers hardness test in the interfacial transition zone (ITZ), bonding pullout test and water penetration into the bond area.

2.3.1 Vickers hardness test

90 day-aged concrete cylinder specimens (100 X 200 mm) were cut by a cutting machine to the target size (35 X 35 X 20 mm), and the surfaces of specimens were made to be smooth. The load that was used in this experiment was 10 gram-force with 10-second contact time. The starting point for measuring was 10 μm away from the surface of coarse aggregate, and the other points were set in every 10 μm in the bottom direction until the distance from the surface of coarse aggregate reached 100 μm. Finally, Vickers hardness of ITZ was calculated by averaging the values from points at 10 μm to 30 μm which is original in this study and 10 μm to 50 μm away from the coarse aggregate[11)] as shown in Figure 3.

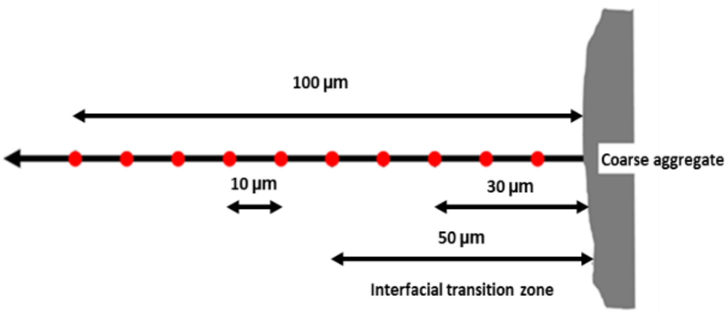

Figure 3 Measuring point of Vickers hardness

2.3.2 Bonding pullout test

This study mainly targeted the chemical bond. Therefore, the experiment was set to minimize the effect of physical bond, avoiding interlocking effect by using a round bar, and applying force in the same way for controlling friction effect. The bonding pullout test was divided into five cases which are shown in Table 5. 30 cylinder specimens (100 X 200 mm.) with a round bar (diameter 13 mm and length 1,200 mm) were used for bonding pullout test following ASTM C234. The embedded length of the round bar in concrete was 200 mm. The curing method of the concrete specimens simulated the real construction site. The specimens were covered by plastic sheet for seven days for sealed curing, and then prepared to meet each experimental case criteria in Table 3.

Table 3 Experiment cases for bonding pullout test

Case	Place specimens in room temperature	Place specimens in wet and dry cyclic tanks
B1	90 days	-
B2	140 days	-
B3	190 days	-
B4	90 days	50 days
B5	90 days	100 days

2.3.3How to set up the wet and dry cylindrical tanks

Cylindrical tanks and their caps were assembled by water resistance glue and epoxy glue in their joints. Next, the tanks were set up to be perpendicular with the floor. Then, all tanks were fastened by a chain to ensure that a group of tanks did not fall. Then, household pumps were set up to all tanks. Next, specimens of experiment Case 4 and Case 5 were inserted in the tanks. The completed setting of cylindrical tanks is shown in Figure 5. Furthermore, the wet and dry cycles in the cylindrical tanks were set to change every 2 days until 50 days and 100 days for Case B4 and B5 as shown in Figure 6.

Figure 5 Cylindrical tanks for wet and dry cyclic test

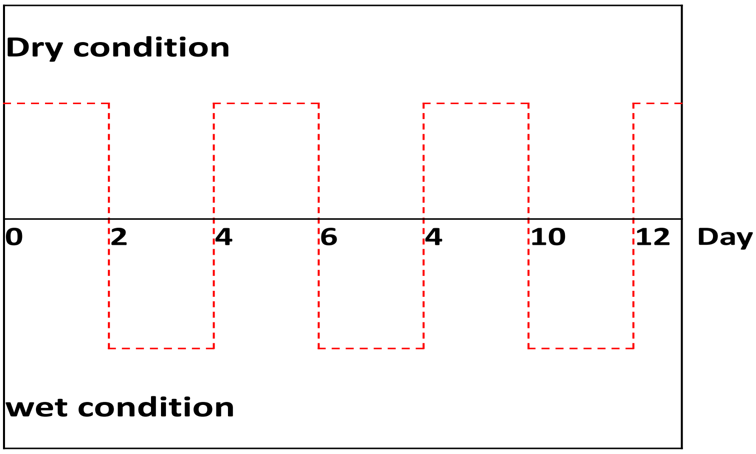

Figure 6 Wet-dry cycles for cylindrical tanks

2.3.3 Water penetration into the bond area

To check the water penetration effect in the focused area as shown in Figure 4, after bonding pullout test was finished, the concrete specimen was broken and divided into two parts. Then, the rebar in concrete was removed. Next, the moisture checking agent (Figure 5) was sprayed to observe the existence of moisture or water in the bond area.

Figure 4 Focused area for water penetration test

Figure 5 Moisture checking agent

3. RESULT AND SIMPLE DISCUSSION

3.1 Bleeding

Table 4 Bleeding of all concrete

Bleeding (%)			
M1-G1	4.5	M1-G2	3.0
M2-G1	3.3	M2-G2	1.8
M3-G1	1.0	M3-G2	0.5

3.1.1 Result

From Table 4, the bleeding of concrete with GGBFS and SAP (M3-G2) is lowest (0.5%). On the other hand, control concrete (M1-G1) presents the highest value of bleeding of 4.5%. For the concrete with fly ash and GGBFS (M2-G1 and M3-G1), the bleeding value is reduced up to 3.3% and 1.0% in comparison with that of the control concrete of 4.5%. Moreover, adding SAP in concrete (M1-G2) shows the better result of bleeding reduction compared to the control case (3.0%). Also, using both pozzolanic materials and SAP shows the higher bleeding reduction compared to concrete with only pozzolanic materials

3.1.2 Discussion

The bleeding of pozzolanic concrete is reduced because they provide greater surface area of solid particles[3)]. For SAP concrete, some excess water is absorbed by SAP during the mixing process that leads to reducing the bleeding effect of concrete. Therefore, using both pozzolanic materials and SAP in concrete influences to reduce the bleeding of concrete than the others.

3.2 Compressive strength

Table 5 Compressive strength of all concrete

	Compressive strength (MPa)				
Case	**Day-3**	**Day-7**	**Day-28**	**Day-56**	**Day-90**
M1-G1	27.7	41.4	50.5	52.8	53.4
M2-G1	23.4	31.3	47.3	49.2	50.4
M3-G1	22.4	32.4	47.3	49.6	50.5
M1-G2	32.3	43.6	53.4	55.9	56.6
M2-G2	24.7	32.2	47.7	50.6	51.2
M3-G2	24.7	37.0	51.1	54.4	55.2

3.2.1 Result

The results of the compressive strength test of all concrete are shown in Table 5. For low w/b concrete, the data indicate that concrete with added SAP (M1-G2) obtains the highest compressive strength of 3, 7 and 90 day-aged (32.3, 43.6 and 56.6 MPa respectively). On the other hand, fly ash concrete (M1-G2) has the lowest compressive strength at 3, 7 and 90 day-aged (23.4, 31.3 and 50.4 MPa respectively). The compressive strength of control concrete (M1-G1) is 27.7, 41.4 and 53.4 MPa respectively. Comparing control concrete and concrete with GGBFS and SAP (M3-G2), the strength of GGBFS concrete with SAP is lower at the day-3 (24.7 MPa) and day-7 (37.0 MPa). However, it gains more strength and be higher at later ages (51.1 MPa at day-28 and 55.2 MPa at day-90). On the other hand, concrete with combined fly ash and SAP (M2-G2) and concrete with only pozzolanic materials, fly ash (M2-G1) or GGBFS (M2-G2), shows lower strength than control concrete at all ages.

3.2.2 Discussion

Comparing concrete with and without SAP, SAP absorbs the water during the mixing process, causing reduced effective water to binder ratio. Also, SAP gradually releases the water to cement matrix for increasing degree of hydration[6)]. As a result, compressive strength increases in all stages with added SAP as water retaining agent. For pozzolanic concrete, at the earlier ages, due to the lower hydration reaction, the strength development of pozzolanic concrete is lower than control concrete[7)]. However, they either gain more strength at the later age by pozzolanic reaction between hydration products and silica (SiO_2) in pozzolanic materials, but not close to control concrete's strength. Nevertheless, due to the different chemical composition of GGBFS and fly ash, GGBFS has higher content of lime (CaO) that can react with water and creates hydration reaction with the slower rate than cement. Hence, when adding SAP as water retaining agent, it maintains and increases relative humidity inside concrete that gives an opportunity to cement and GGBFS for creating more hydration reaction at the earlier days. Moreover, GGBFS also has higher content of silica (SiO_2) that can react with Calcium Hydroxide ($Ca(OH)_2$) to create pozzolanic reaction at the later days. On the other hand, fly ash has high content of silica but low content of lime (CaO). Hence, it promotes the compressive strength only from the pozzolanic reaction at the later day.

3.3 Drying shrinkage

Table 6 Drying shrinkage for 90 days of all concrete

Drying shrinkage (μm)			
M1-G1	-451	M1-G2	-417
M2-G1	-427	M2-G2	-402
M3-G1	-401	M3-G2	-377

3.3.1 Result

All test results of drying shrinkage are presented in Table 8. The data show that concrete with both replacements by GGBFS and added SAP (M3-G2) shows the lowest shrinkage at day-90 (-377 μm). On the other hand, the control concrete (M1-G1) shows the highest drying shrinkage value (-451 μm). Replacing cement by GGBFS or fly ash reduces drying shrinkage of concrete. For instance, at day-90, drying shrinkage of GGBFS and fly ash concrete (M3-G1 and M2-G1) is -401 μm and -427 μm respectively. Moreover, the data show that shrinkage of concrete with added SAP (M1-G2) at day-90 is -417 μm which is lower than control concrete. Furthermore, GGBFS concrete with SAP shows the lower value of shrinkage than fly ash concrete with SAP (M2-G2) at -377 μm and -402 μm. at day-90 respectively.

3.3.2 Discussion

The loss of free water causes little effect on drying shrinkage, but the loss of water from small pores (capillary pores) essentially causes large shrinkage. Hence, using pozzolanic materials whose particle size is finer than cement in concrete will fill the small pores and also reduce the voids that leads to shrinkage reduction[10)]. Comparing between the concrete with and without SAP in each case, it is clear in all cases that the drying shrinkage value obviously decreases by using SAP as water retaining agent in concrete. Because fully saturated SAP in concrete works as the water reservoir that gradually releases the water, the moisture inside the concrete in the early period is maintained, resulting in shrinkage reduction[4)]. In case of using combined pozzolanic materials and SAP in concrete, pozzolanic materials create denser concrete with the low amount of small pores and voids. Also, SAP reduces the loss of moisture and retains high relative humidity inside the concrete during the initial period. From these two reasons, drying shrinkage of pozzolanic concrete with SAP shows the significant reduction comparing to the control concrete[12)].

3.4 Microhardness of ITZ

Table 7 Vickers hardness of the interfacial transition zone

Case	HV	
	<30μm	<50μm
M1-G1	71.8	76.5
M1-G2	77.4	84.4
M3-G2	81.7	83.7

3.4.1 Result

Table 7 presents the Vickers hardness test results (HV) of the interfacial transition zone (<50 μm away from coarse aggregates surface). For low w/b cases, the results show that HV of ITZ of control concrete (M1-G1) is 76.5 which is lower than the others. Also, HV of concrete containing both GGBFS and SAP (M3-G2) and concrete with added SAP (M1-G2) are 84.4 and 83.7 respectively. However, considering the Vickers hardness test results of ITZ (<30 μm away from coarse aggregates surface), it can be seen that the HV of GGBFS concrete with added SAP presents the highest value at 81.7 that is greater than concrete containing SAP (77.4) and control concrete (71.8).

3.4.2 Discussion

For concrete with added SAP, SAP absorbs some water during mixing process, reducing effective w/b ratio. Moreover, SAP gradually releases water inside the concrete that creates more hydration reaction[5)]. From these two reasons, the ITZ microstructure of concrete with SAP is stronger. For concrete with both GGBFS and SAP, GGBFS significantly decreases the content of $Ca(OH)_2$ crystals in aggregate-mortar ITZ from the pozzolanic reaction and also has packing effect with their finer particle[3)]. Also, SAP retains the moisture inside the GGBFS concrete that leads to creating more hydration and pozzolanic reaction, improving the hardness of ITZ. As a result, ITZ in the area which is closer 30 μm from coarse aggregates surface is harder and denser.

3.5 Bonding pullout test

The result of bonding pullout test is shown as an example in Figure 6. It can be seen that the bond stress curve is divided into two ranges. First, bond stress tends to increase with increase in displacement until the peak point and then, bond stress tends to decrease with further increase in displacement. For evaluating the bond performance between concrete and steel, the linear relation of the bond stress-displacement curve from 1.0 MPa to 0.85 of the maximum bond stress is selected to calculate the slope of relationship that refers to the concrete-steel bond stiffness index as shown as an example in Figure 7.

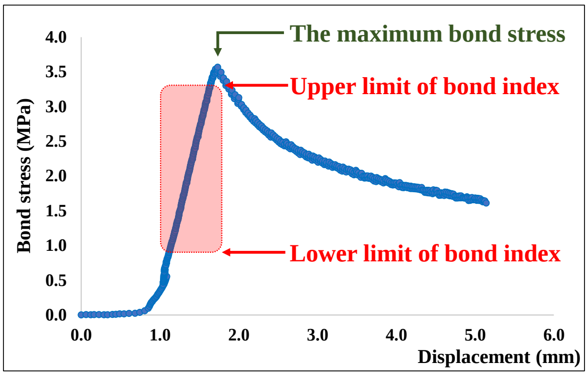

Figure 6 Test result of bonding pullout test

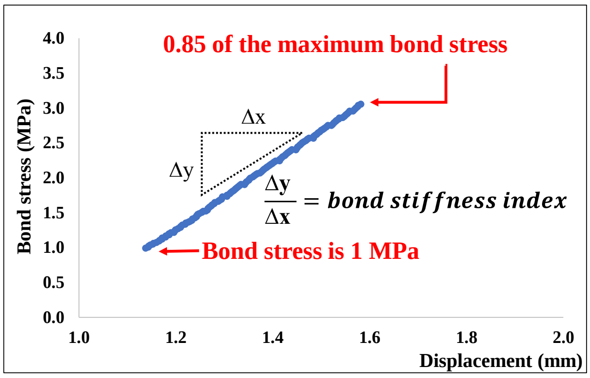

Figure 7 Concrete-steel bond stiffness index

3.5.1 Results of bond strength

Table 8 All results of bond strength

Case	Bond strength (MPa)				
	B1	B2	B3	B4	B5
Low w/b					
M1-G1	3.3	3.4	3.3	2.2	2.0
M1-G2	3.8	3.7	3.8	2.7	2.5
M3-G2	3.6	3.5	3.6	2.6	2.4

As shown in Table 8, in Case B1-B3, the bond strength of all specimens does not significantly change after 90 days. It can be seen that bond strength of concrete with SAP (M1-G2) presents the highest value between 3.7 to 3.8 MPa. Also, the bond strength of GGBFS concrete with SAP (M3-G2) and control concrete (M1-G1) are 3.5 to 3.6 and 3.3 to 3.4 MPa. On the other hand, in Case B4 and B5, comparing the bond strength of control concrete to the others, the control concrete has the lowest bond strength, 2.2 and 2.0 MPa respectively. For concrete with SAP, bond strength presents 2.7 MPa and 2.5 MPa for Case B4 and B5. For GGBFS concrete with SAP, the bond strength is 2.6 MPa and 2.4 MPa for Case B4 and B5.

3.5.2 Results of bond stiffness index

Table 9 All results of bond stiffness index

Case	Bond stiffness index (N/mm^3)				
	B1	B2	B3	B4	B5
Low w/b					
M1-G1	3.8	3.9	3.9	2.8	2.7
M1-G2	4.4	4.4	4.4	3.8	3.6
M3-G2	4.6	4.6	4.6	4.1	4.0

The results of the bond stiffness index are shown in Table 9. In Case B1 to B3, the average of the bond stiffness index of each concrete mix design remains at the same level. It can be observed that the average of the bond stiffness index of GGBFS concrete with SAP (M3-G2) shows the highest at all ages (4.6 N/mm^3). Also, the average of the bond stiffness index of concrete with SAP (M1-G2) is 4.4 N/mm^3 for Case B1 to B3. Furthermore, in case of control concrete (M1-G1), the average of the bond stiffness index is 3.8-3.9 N/mm^3. In addition, for Case B4 and B5, the control concrete has the lowest average of the bond stiffness index for both cases, 2.8 and 2.7 N/mm^3 respectively. Also, GGBFS concrete with added SAP shows the highest value (4.1 N/mm^3) for Case B4 and 4.0 N/mm^3 for Case B5. Moreover, for concrete with SAP, the average of the bond stiffness index for Case B4 and B5 is 3.8 and 3.6 N/mm^3.

3.5.3 Results of water penetration into the bond area

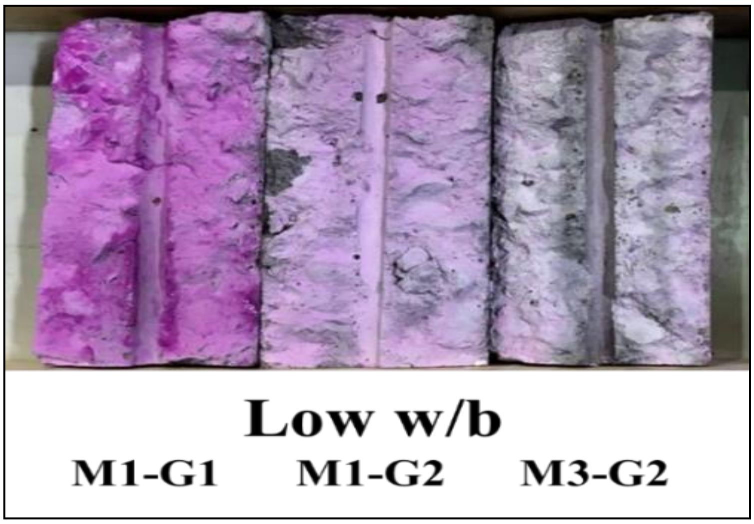

Figure 8 Results of water penetration into the bond area

As shown in Figure 8, it is clear that water penetration has effect on the bond area (rectangular boxes in Fig.8) of high w/b cases more than low w/b cases by observing the darkened shade of the indicator color. Besides, for low w/b cases, the shade of the indicator color in the bond area of GGBFS concrete with SAP (M3-G2) and concrete with SAP (M1-G2) specimens is brighter than control case (M1-G1). Moreover, the case of GGBFS concrete with SAP shows the brightest color of the indicator. This suggests that the water penetration into the bond area of GGBFS concrete with SAP and concrete with SAP is lower than control case. In addition, GGBFS concrete with SAP shows the best performance to prevent the water penetration into the bond area.

3.5.4 Discussion

As shown in Table 8-9, in Case B1 to B3, the bond strength and the bond stiffness index of each concrete mix design maintain the same level from 90 to 190 days. Moreover, it can be observed that both specimens that contain alternative materials present the greater value of both bond strength and bond stiffness index. On the other hand, comparing Case B1, B4, and B5, it is clear that water penetration to the bond area significantly affects the reduction of both bond strength and bond stiffness index. Comparing between results of each concrete mix design in Case B1 and B5, for low w/b cases, the control concrete shows the largest reduction of bond strength and bond stiffness index by approximately 40 %. For GGBFS concrete with SAP and concrete with SAP, the reduction of bond strength is 33% and 34% respectively. In case of bond stiffness index, the reduction of bond stiffness index of GGBFS concrete with SAP concrete and concrete with SAP is 13% and 18% respectively, while bond stiffness index of control case decreases by 29%. It is clear that both concrete with alternative materials presents the smaller bond strength reduction and bond stiffness index reduction than control case, increasing the bond durability. Moreover, in the water penetration test (Figure 8), it is clear that the specimens which have the brighter moisture checking agent color in the bond area show the better water penetration resistance. It can be confirmed that GGBFS concrete with SAP and concrete with SAP have better water penetration resistance in comparison with control concrete, increasing the durability of the concrete-steel bond.

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4. discussion

Table 10 Results of compressive strength, bleeding and Vickers hardness of ITZ

Case	Compressive strength (MPa)	Bleeding (%)	Vickers hardness of ITZ (<50µm)
M1-G1	53.4	4.4	76.5
M1-G2	56.6	3.0	84.4
M3-G2	55.2	0.5	83.7

The relationship between compressive strength for 90 days, bleeding and Vickers hardness (HV) of ITZ is shown in Table 10. It can be observed that HV value becomes greater with higher compressive strength and lower percentage of bleeding. Comparing between control concrete (M1-G1) and the others, the concrete with SAP (M1-G2) has the lower percentage of bleeding because SAP takes some part of mixing water during the mixing process. Moreover, it has the higher degree of hydration and also lower effective w/b ratio. From these three reasons, ITZ becomes denser. Similarly, using GGBFS and SAP in concrete (M3-G2), the bleeding reduces by water absorption of SAP and compressive strength increases both slow hydration reaction and pozzolanic reaction. Moreover, the finer particle of GGBFS reduces the porosity of ITZ by filler effect[3)]. From these three reasons, the ITZ becomes stronger.

Table 11 Results of Vickers hardness of ITZ and drying shrinkage and moisture checking agent color in the bond area

Case	Vickers hardness of ITZ (<50µm)	Drying shrinkage (µm)	Moisture checking agent color in the bond area
M1-G1	76.5	-451	
M1-G2	84.4	-417	
M3-G2	83.7	-377	

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The relationship between Vickers hardness of ITZ, drying shrinkage and moisture checking agent color in the bond area is shown in Table 13. It is clear that color of moisture checking agent in the bond area becomes brighter with greater HV and smaller drying shrinkage. From test results, both SAP concrete (M1-G2) and GGBFS concrete with SAP (M3-G2) show the higher HV value that impacts on increasing the bond performance and smaller drying shrinkage that reduces the opportunity for water penetration to bond than control concrete (M1-G1). From these two reasons, the water penetration resistance of bond increases by using SAP and both GGBFS and SAP, which is confirmed by the brighter shade of moisture checking color in the bond area.

Table 12 Results of bond strength reduction, bond stiffness reduction and moisture checking agent color in the bond area

Case	Bond strength reduction (%)	Bond stiffness index reduction (%)	Moisture checking agent color in the bond area
M1-G1	40	29	
M1-G2	34	18	
M3-G2	33	13	

The relationship between bond strength reduction, bond stiffness index reduction and moisture checking agent color in the bond area is shown in Table 14. It can be observed that bond strength reduction and bond stiffness index reduction become smaller with brighter shade color of moisture checking agent in the bond area. Comparing control case (M1-G1) to the others, both SAP concrete (M1-G2) and GGBFS concrete with SAP (M3-G2) show smaller percentage reduction of both bond strength and bond stiffness index after water penetration effect to bond than control case. This suggests that using SAP and both GGBFS and SAP in concrete improves water penetration resistance of bond, leading to the increase in concrete-steel bond durability.

4. CONCLUSION

- Due to the finer particle size of GGBFS and the absorption capacity of SAP, GGBFS concrete with SAP and concrete containing SAP show the lower percentage of bleeding in comparison with control concrete.

- Concrete with SAP and GGBFS concrete with SAP obtain the higher compressive strength than control concrete. In case of concrete with SAP, the compressive strength is improved by the reduction of effective w/b ratio and the increase in hydration degree. In case of GGBFS concrete with SAP, the compressive strength is improved by the increase in hydration degree and pozzolanic reaction.

- Using GGBFS influence to reduce drying shrinkage and adding SAP to concrete decreases the loss of moisture inside concrete. From these reasons, the GGBFS concrete with SAP presents the lowest drying shrinkage comparing to others. Also, comparing concrete with and without SAP, the concrete with SAP shows the smaller drying shrinkage.

- Due to the decrease in the percentage of bleeding and the increase in compressive strength, Vickers hardness of ITZ in concrete with SAP and GGBFS concrete with SAP is higher in comparison to control case. From this reason, it is clear that the ITZ microstructure of both concretes with alternative materials is denser and stronger than control concrete.

- The improvement of ITZ microstructure and the reduction of drying shrinkage by using only SAP and both GGBFS and SAP in concrete has a strong impact on increasing the bond performance and reducing the possibility of concrete cracking. From these reasons, the water penetration resistance of concrete-steel bond improves and the durability of concrete-steel bond increases.

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