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EFFECT OF POLYMER ADMIXTURES ON MECHANICAL PROPERTIES OF PREPLACED AGGREGATE CONCRETE

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ABSTRACT:

This research was carried out to study the influence of different polymer admixtures (PA) namely vinyl acetate-ethylene copolymer dispersion, styrene butadiene dispersion and styrene butadiene emulsion in preplaced aggregate concrete (PAC) on its fresh and hardened properties, and to identify the highest flexural strength of preplaced aggregate concrete using PAs. Hypothesis was established as the higher the bonding among grout and aggregate surface, the higher the flexural strength. Accordingly, aggregate-grout bond strength was studied at the introduction of various PAs by conducting pull-off tests to decide on the most effective PA at bonding and mix designs were chosen for hardened properties evaluation. Fresh properties were checked to ensure the sufficiency in flow and to fix the quantities of all the contents in the grout mix. Compressive strengths of grout and PAC were checked along with flexural strength to develop relationships on selected mix designs. A control mix design without any PA and a past researcher's mix design which gave the highest flexural strength using silica fume was considered for comparison purposes. As a conclusion, vinyl acetate-ethylene copolymer dispersion performed better than the others in all aspects and the flexural strength was almost the same with the past researcher's highest PAC strength obtained with silica fume.

KEYWORDS: Preplaced-aggregate concrete, Flexural strength, Pull-off strength, Polymer admixture

1. Introduction

Two-stage concrete (i.e. TSC) as shown in Figure 1 is a two-step activity where the coarse aggregates are placed in the formwork as the initial step and binder grout is injected on to the prepared specimen enabling the filling of voids among the coarse aggregate [1]. In ACI 116R, PAC is defined as "concrete produced by placing coarse aggregate in a form and later injecting a Portland cement-sand grout, usually with admixtures, to fill the voids". Application of PAC of special concrete in the industry began in year 1938, for a rehabilitation of a tunnel lining in Santa Fe Rail Road, California, USA [2].

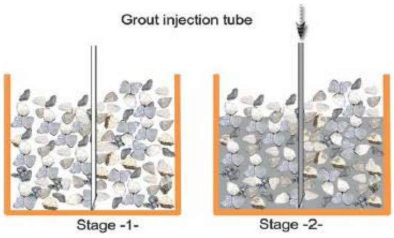


Figure 1 Two Stage Concrete [3]

While application of PAC has both great advantages and difficulties with due respect to placing conditions and limited access, it is a matter of discussion that selecting an optimum proportion for a PAC grout mixture is highly affected by the chemical and physical properties of the materials used (i.e. sand, cement, and supplementary cementitious materials) [4] and [5]. Moreover, the addition of chemical admixtures induces significant changes in fresh properties of the PAC grout [6] and [7]. A polymer (or polymeric) admixture, also called a cement modifier, is defined as an admixture which consists of a polymeric compound as a main ingredient effective at modifying or improving the properties such as strength, deformability, adhesion, waterproofness and durability of cement mortar and concrete.

As shown in Figure 2, at the introduction of water to Portland cement, the cement hydration is commenced. As a result of hydration, calcium silicate hydrate (CSH) is formed as a durable binder while free lime – Ca(OH)2 is formed as non-durable binder. Calcium ions formed by cement hydration do reacts with the polymer components and creates a more stable network [8] as shown in Figure 2. When a polymer admixture is introduced for the PAC grout, the hardened PAC will have a superior hardened property in compared to conventional cementitious composites as polymer-modified mortar and aggregates are bound by monolithic matrix phase with a network structure in which the cement hydrate phase and polymer phase interpenetrate and cement hydrates being enveloped with polymer membranes.

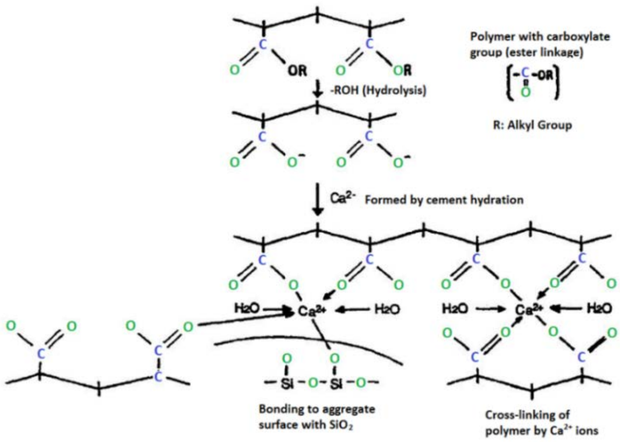


Figure 2 Networking of Cement by Products with Polymers [8]

Many researches were conducted previously to identify the properties and behavior of PAC, and subsequently a few researches on PAC with polymer admixtures. Initially, PAC was applied only for repairing works in tunnel lining, bridges and under water structures. But recently this is used for new construction works also considering economic and environmental benefits. The scarcity in researches or experiments conducted to evaluate the bond strength of aggregate-grout paste on the light of PAC, inadequate comparative details on the behavior of PAC at the introduction of various polymer admixtures and lack of comparative data regard to the influence of two or more types of polymer admixture on the bond strength and flexural strength of PAC; was considered in this study for addressing purposes.

1.1. Research Objective

This research includes the following objectives;

1. To study the effect of various polymer admixtures on fresh and hardened properties of PAC grout.
2. To study the effect of polymer admixtures on PAC grout bonding with aggregates used as substrates.
3. To study the effect of polymer admixtures on hardened properties of Preplaced-aggregate concrete

2. Materials and methodology

2.1 Selection of Materials

Table 1 llustrates the selections of materials used in this study.

Table 1 Material Selections made for this study

Cement – “High early strength Portland Cement” (Type III)	Conforming to “ASTM C150”
Fine Aggregate – Sand	Natural River Sand
Polymer Admixtures A. Vinyl Acetate-Ethylene Copolymer Dispersion B. Styrene Butadiene Dispersion C. Styrene Butadiene Emulsion	As per manufacture recommendations
Superplasticizer	High-range water reducer EN 934-2 (Brown liquid, pH value – 4.3)
Other Materials	
“Coarse Aggregate” – Limestone	“Locally available crushed aggregate – ACI 304.1 grading 2 for PAC [9]”

Aggregate Substrate – Limestone Slab	Locally available limestone boulders to be sliced and taken (through GTE Lab)
Silica fume	“Elkem microsilica (ASTM C1240)” – (Same material used by past researcher [10]

According to reference [9] “Guide for the Use of preplaced aggregate concrete for structural and mass concrete applications”, the coarse aggregate to be utilized in “PAC” has to be washed, free of surface dust and fines, and chemically stable in order to achieve a high bond with the injected grout.

2.2 Screening Experiments

Some of the past researchers [10] and [11] had worked out with a content of superplasticizer of 0.5% - 0.7% by weight of cement. The amount of polymer admixtures with other materials as shown in Table 2 were to be determined to meet fresh property requirements of grout mixes using the screening experiments.

Table 2 Data to be determined by Screening

Product	Supplier Recommended Dosage (% of cement weight)	Past Researcher’s Dosages	
		Amount	Reference
A. Vinyl acetate ethylene copolymer dispersion	10-15	-	-
B. Styrene butadiene dispersion	2-5	-	-
C. Styrene butadiene emulsion	5-15	-	-
Superplasticizer (% of cement weight)	-	0.5 - 0.7	[4] [5] [11] [10]
Sand/Cement (S/C)	-	1.0	
Water/Cement (W/C)	-	0.32	[10]
Cement (C) (kg/m^3)	-	400	[11] [10]

2.3 Aggregate Substrate – Grout pull-off test

As per the hypothesis made, it was assumed that the bond strength is directly proportional to the hardened properties, and the most effective polymer admixture to enhance the flexural strength of PAC concrete could be decided based on the bond strength. Hence, a pull-off test [12] was conducted to evaluate the bond strength between the interfaces of limestone aggregate slab with various polymer grouts. This particular task was also done in two stages where both cut surface and grinded rough surface of the aggregate substrates were used for the study independently. The design of experiment (DOE) was used for this phase of study shown in Table 3, whereby determined and developed based on the screening experimental outcomes.

Table 3 DOE for Aggregate Substrate – Grout pull-off test

2 Factors with 3 Levels (including Center Point)			
	Low Level	Center Point	High Level
Type of PA		A, B and C	
PA/C	Supplier Recommend (min)	Supplier Recommend (mid)	Supplier Recommend (max)
W/C		Fixed (0.32)	
S/C		Fixed (1.0)	

As the objective was to determine the effective polymer admixture and its dosage for comparative studies, all other materials in the grout mix was kept constant while the type and amount of polymer admixture to be used is kept as a variable. For each design of experiment, three samples were experimented to ensure the results and accordingly the performance plot was made for each case (cut surface, roughened surface) of aggregate substrate enabling the determination of decision for the best performed polymer admixture and the dosage.

Upon the determination of dosages and material content from the screening phase, the mix design for this particular experiment was developed as shown in Table 4.

Table 4 Mix Proportions for aggregate surface – grout pull-off test

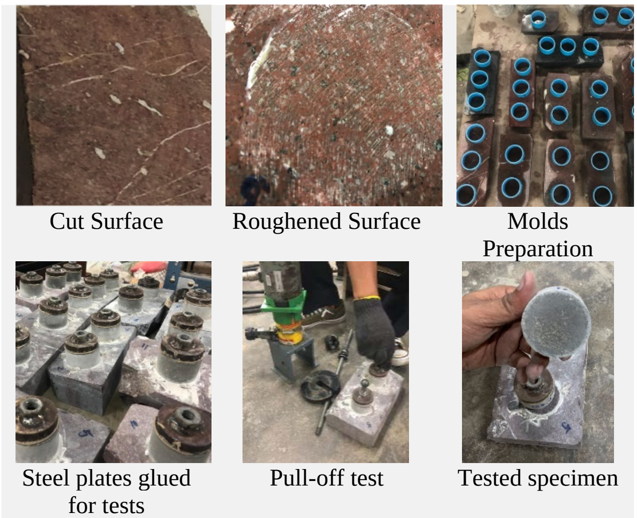
Mix Code	Cement (kg)	Sand (kg)	W/C	Polymer admixture (% of cement weight)		Silica fume
				Type	**Dose**	
Control	400	400	0.32	-	-	-

S1.W32 .BA7	400	400	0.32	A	7	-
S1.W32 .BA9	400	400	0.32	A	9	-
S1.W32 .BA11	400	400	0.32	A	11	-
S1.W32 .WA3	400	400	0.32	B	3	-
S1.W32 .WA4	400	400	0.32	B	4	-
S1.W32 .WA5	400	400	0.32	B	5	-
S1.W32 .SI8	400	400	0.32	C	8	-
S1.W32 .SI10	400	400	0.32	C	10	-
S1.W32 .SI12	400	400	0.32	C	12	-
SF	360	480	0.32	-	-	10

Initially the aggregate slabs were prepared by means of slicing the boulders obtained from the same quarry where limestone aggregates were supplied. After washing and drying the aggregate slab pieces, a PVC ring diameter of 50 mm obtained by slicing the PVC pipe with a height of 25 mm was epoxy glued on to the aggregate stone slab. Each grout was poured to the circular mold to a height of 20mm and was kept for 12 days to water cure and a circular metal disc with a diameter of 50 mm was fitted on the cleaned grout surface with epoxy glue. Since this considered both cut and roughened aggregate slab surface for experiments, the roughing was done by means of using a hand grinder for a considerable extent maintaining the uniformity in all slabs. Upon the bonded samples were left for 48 hours before being tested, specimens were subjected to the pull-off test (see figure 3). Although there could be a tendency to witness failure in other modes except for grout/aggregate interface, it was assumed that the respective test would be valid at the interfacial face failure mode only [12].

2.4 Fresh and Hardened Properties

Flow cone test as per ASTM C939-10, the mini cone slump test as per EFNARC [13] and bleeding test as per ASTM C940 were conducted to determine the fresh properties of the grout at each phase [14]. PAC grout compressive strength as per ASTM C939-10, compressive strength of PAC as per ASTM C39 and three-point bending test on a loading frame to determine the flexural strength as per ASTM C78 were conducted to evaluate hardened properties [15]. As shown in Table 5, mix designs were determined for the evaluation of hardened properties based on the results obtained at the evaluation of aggregate surface – grout pull-off strength, and respecting the hypothesis made for its verification.



Cut Surface | Roughened Surface | Molds Preparation | Steel plates glued for tests | Pull-off test | Tested specimen

Figure 3 Image representation of aggregate surface and aggregate slab-grout pull-off test

Table 5 Mix Proportions for aggregate surface – grout pull-off test

Mix Code	Cement kg	(W/C)	Sand (kg) S/C	Weight	PA (dose)	Silica fume (dose)
Control	400	0.32	1	400	-	-
S.9.W34 .WA4	400	0.34	0.9	360	B - 4%	-
S1.W34. WA4	400	0.34	1	400	B - 4%	-
S1.W32. BA9	400	0.32	1	400	A- 9%	-
S1.W32. SI10	400	0.32	1	400	C- 10%	-
SF	360	0.32	1.2	480	-	10%

3. Results and Discussions

3.1 Screening Experiments

Pertaining to the experimental results shown in Table 6 below through Mix No. SC1 and SC2, 0.5% and 0.6% of that superplasticizer content were not workable enough for the PAC as their mini cone slump was even less than 30 cm. Hence, the dosage had to be fixed for 0.7% to ensure the workability.

Table 6 Screening Results

Mix No	Polymer Admixture	SP	Fresh Properties		
			Bleeding	Mini Cone Slump (cm)	Flow Time (s)
SC1	-	0.5 %	No	18	113

SC2	-	0.6 %	No	26	89
SC3	-	0.7 %	No	34.1	62.29
SC4	A – 10%	0.7 %	No	35.1	53
SC5	A – 13%	0.7 %	Yes	38.2	49
SC6	A – 11%	0.7 %	No	35.1	53.23
SC7	A – 9%	0.7 %	No	34.9	55.21
SC8	B – 2%	0.7 %	No	34	73.4
SC9	B – 4%	0.7 %	No	34.9	69.89
SC10	B – 5%	0.7 %	No	35.3	67.18
SC11	C – 5%	0.7 %	No	34	70.18
SC12	C – 10%	0.7 %	No	34.8	58.59
SC13	C – 12%	0.7 %	No	34.9	57.01

Therein, the dosages of the polymer admixtures were checked individually by using the lowest recommended dosages onward. Based on the results obtained as shown in Table 6, bleeding was observed when the supplier recommended mid dosage of polymer admixture type A was used. Past researchers by many experts have indicated that mini cone slump value within the range of 28-36 cm. and the flow time 50-105 seconds could be considered as having a sufficient flowability to use at the PAC. Hence, polymer admixture dosages beyond the supplier recommendation were considered to ensure the workability for PAC grout. Accordingly, each type of polymer admixture dosages were fixed for mid, low and high values.

3.2 Aggregate slab – Grout pull-off test

The results of the adhesion pull-off test among the aggregate slab and the grout was tabulated below in Table 7.

Table 7 Fresh Properties and pull-off Strength Results

Mix No	Mix Code	Flow Time (s)	Mini Slump (cm)	Pull-off Strength (MPa)	
				Cut Surface	Grinded Rough Surface
1	Control	62.29	34.1	0.664	0.941
2	S1.W32.BA7	58.11	34.6	0.993	-
3	S1.W32.BA9	55.21	34.9	0.499	0.839
4	S1.W32.BA11	53.23	35.1	0.732	-
5	S1.W32.WA3	72.51	34.3	1.02	-
6	S1.W32.WA4	69.89	34.9	1.113	1.140
7	S1.W32.WA5	67.18	35.3	0.794	-
8	S1.W32.SI8	61.12	34.6	0.451	-
9	S1.W32.SI10	58.59	34.8	0.522	0.771
10	S1.W32.SI12	57.01	34.9	0.608	-
11	SF	103.21	28.0	1.069	1.207

Previous researcher [10] experimentally concluded that the PAC with the same mix design used for Mix No. 11 in this study, was giving a high flexural strength of 6.018 MPa (with type 1 Portland cement) at 28 days; compared to all other mix designs used at his study with/without other supplementary cementitious materials. The experimental results obtained through this study showed that Mix No. 11 with silica fume gave high pull-off strength, endorsing the hypothesis made.

Moreover, Mix No. 6 with polymer admixture type B was also giving high pull-off strengths, whereby a prediction was made that the same mix would also give high flexural strength as per the hypothesis. Flow time and mini cone slump of all mix designs used in this study was showing that they fell in the recommended workability range for PAC. Visual images of the tested specimens are shown in Figure 4.

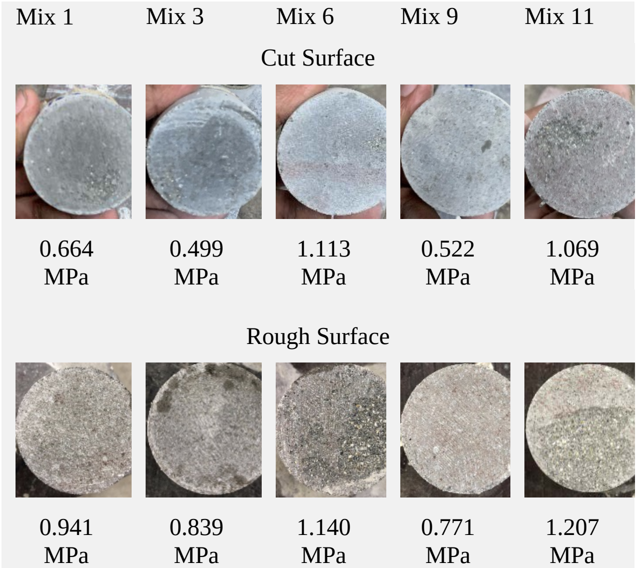


Figure 4 Visual Images of Tested Specimens

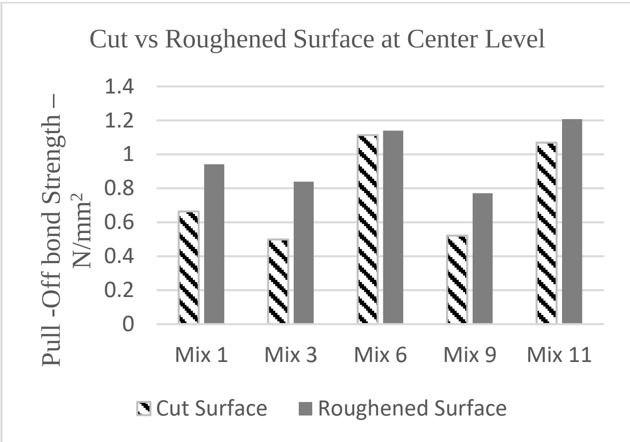


Figure 5 Visual Images of Tested Specimens

When the specimens were visually observed, a direct conclusion was made as all specimens failed from the interface zone between the grout and aggregate slab [16]. In comparison to the results obtained from the both cut and roughened surface specimens, it was evident that Mix No. 6 with polymer admixture type B was performing better in all levels of dosage. All the mixes were showing an increment in pull-off strength at the roughened surface experiments. At this stage, it was also noted that past researcher's [10] mix design (i.e. Mix No. 11) which gave the highest flexural strength with silica fume was also providing high bond strength similar to Mix No. 6 as shown in Figure 5.

3.3 PAC Hardened Properties

Upon completion of the adhesion pull-off test among the aggregate slab and the grout, PAC grout compressive strength, PAC compressive strength and PAC flexural strength at both 7 and 28 days was evaluated to study the hardened properties of PAC using the UTM and the respective results are furnished in Figure 6-8. Mix designs for these hardened property evaluation were chosen due respect to the adhesion pull-off test results obtained as shown in Table 7 and the screening experimental results.

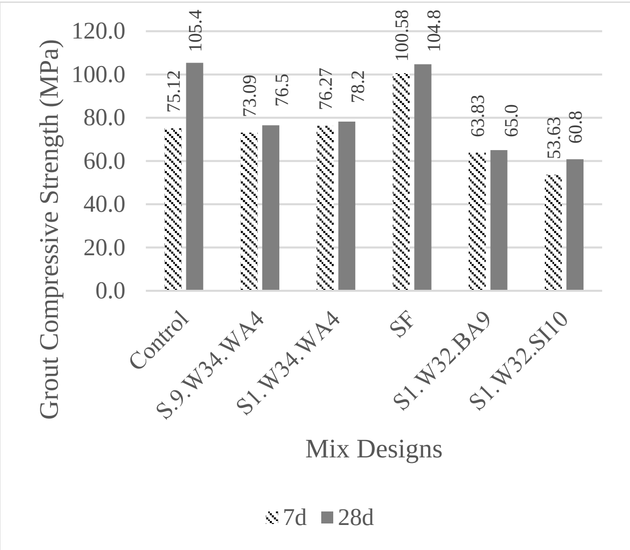


Figure 6 PAC Grout Compressive Strength

PAC Grout compressive strength of control mix has given an utmost higher result compared to other mixes at 28 days with a rapid growth since 7 days. At the presence of polymer admixtures in PAC grout, no significant growth of PAC grout compressive strength was observed and the strength was falling in the range of 50-80 MPa. In comparison, the mix design which included silica fume was achieving a PAC grout compressive strength above 100 MPa both at 7 and 28 days.

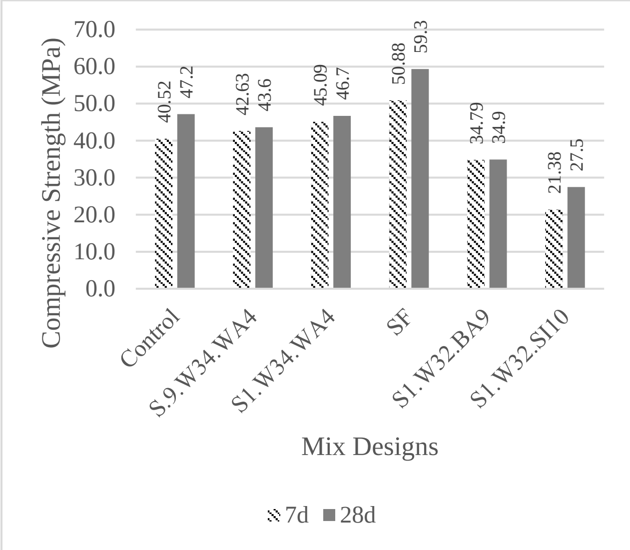


Figure 7 PAC Compressive Strength

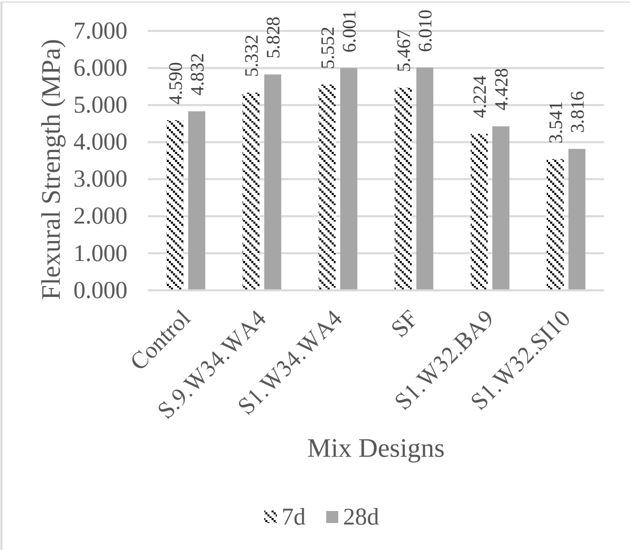


Figure 8 PAC Flexural Strength Results

The PAC compressive strength at the presence of vinyl acetate-ethylene copolymer was similar to the control mix and was falling in the range of 40-50 MPa, while the PAC compressive strength at the presence of styrene butadiene based polymer was falling in the range of 20-35 MPa at both 7 and 28 days. All of the polymer added PAC compressive strength was showing only a minor gain (less than 2 MPa) of strength at 7 to 28 days but, styrene butadiene emulsion added PAC showed a strength gain of 6 MPa similar to control mix and silica fume added mix. In comparison, the mix design which included silica fume was achieving a PAC compressive strength above 50 MPa both at 7 and 28 days.

The PAC flexural strength at the presence of vinyl acetate-ethylene copolymer with 1:1 sand to cement was showing a strength result of 5.552 MPa at

7 days and 6.001 MPa at 28 days. But the PAC flexural strength at the presence of Styrene Butadiene based polymer was only falling in the range of 3.5-4.5 MPa at both 7 and 28 days. In comparison, the referred past researcher [10] achieved 6.018 MPa from the same SF mix using Type I Portland cement at 28 days while this experiment had reached almost same strength of 6.010 MPa at 28 days using Type III Portland cement, very much similar result to the PAC flexural strength result obtained at the presence of vinyl acetate-ethylene copolymer. Visual observation of tested flexure specimens are shown in Figure 9.

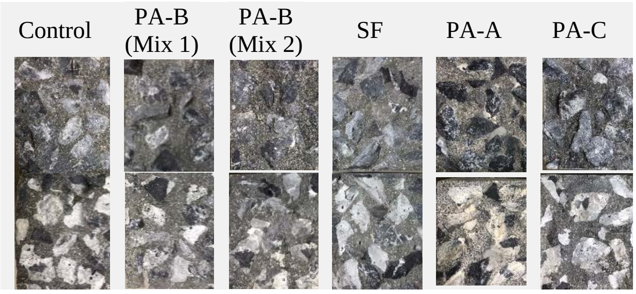


Figure 9 Visual Observation of Tested Flexure Specimen

When the failure modes of the flexure specimens were visually examined, the majority of the sectional area had failed on interfacial transition zones (ITZ) as a past researcher [17] stated, and few aggregate failures were also visible on a random distribution. The flexure strength of the PAC concrete would have been increased if quality aggregates were used. The hypothesis made was validated by the flexural strength results as they were directly proportional to the pull-off strength between grout and limestone aggregate substrate.

4. Conclusions

- Introduction of polymer admixture to PAC grout increased its slump and flow time similar to the effect given by superplasticizer while the introduction of silica fume decreased the same. However, suitable polymer admixture dosage is to be determined within the recommended range as there was a threshold limit of dosage to be used for optimum workability to avoid bleeding effects.
- PAC grout compressive strength at the presence of polymers does not show any rapid strength gain from 7 to 28 days similar to the control mix (strength gain of 30 MPa) nor shows a very high strength above 100 MPa at both 7 and 28 days similar to the mix with silica fume. Instead, all polymer added PAC grout compressive strength was falling in the range of 50-80 MPa with a strength gain as low as 1-7 MPa from 7 to 28 days.
- Vinyl acetate-ethylene copolymer dispersion added PAC grout performed better in bonding (67% and 84% respectively at cut and roughened surfaces of limestone aggregate substrate), compared to the addition of styrene butadiene dispersion/emulsion liquids in PAC grout.
- Introduction of vinyl acetate -ethylene copolymer dispersion for PAC resulted on a quick strength gain compared to others and it performed as good as a mix with silica fume at compressive strength and flexural strength evaluation.

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