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Case Study of Polymer Concrete Composite for Pre-cast Product Application

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Abstract: Polymer concrete (PC) is a composite material made by fully replacing the cement binders of conventional cement concrete with polymeric binders. The property of PC is superior to cement concrete in term of curing time, higher strength, bulk modulus, acid or chemical material resistance as well as corrosion, ability to form complex shapes, and excellent vibration damping properties. The purpose of this study is to investigate strength limit of PC specimens with composition variations. In this project, experimental study has been performed on PC with variations of aggregates mixtures and resin ratio. Various composition of PC based on literatures are tested to determine the best composition for pre-cast product application. The study reveals that PC with fine aggregates and 30:70 aggregate resin ratio (AG2RT2) has the highest compressive strength (94.73 MPa) and water proof capacity (0%). Then PC with fine and coarse aggregates, fillers and chopped fibers (AG4RT2) has the highest flexural strength (12.94 MPa). The optimum PC composition specification has been applied to produce pre-cast product and field test has confirmed the product strength and durability. There are three PC pre-cast products that have been produced; plate, grating and drain trench before simple field test applied to observe the products serviceability. All products do not fail in field test within predetermined limit; static loading, free fall and water flow test. The potential to apply PC in existing pre-cast cement concrete product has been proven to enhance the product performance as well as preserving the nature by introducing polymeric resins as a replacement to cement.

Keywords: Polymer Concrete; Composite; Mechanical property; Pre-cast products

1. Introduction

Precast cement concrete can be challenging with its lack of flexibility once the structure has been built and delivered to the jobsite (Yeon, 2010). According to Bedi et.al (2014), the property of PC is superior to cement concrete in term of rapid curing, high compressive strength, high specific stiffness, high strength, resistance to chemicals as well as corrosion, ability to form complex shapes, and excellent vibration damping properties. A report from Mebarkia and Vipulanandan (1990) has shown that compressive strength, flexural strength and water absorbability of cement concrete is 10–60 MPa, 1.5-7 MPa and 4-10 % while PC has shown 40–150 MPa, 4-50 MPa and 0.5-3 % . PC is made by applying polymer resin such as polyester, vinyl ester or epoxy resins as aggregates binder which can be of gravels, granites, stones and river sands (Kumar and Venkatesh, 2018). Furthermore, cement is produced from natural resources and by initiating this project, the main concerns are to contribute toward enhancing precast cement concrete product properties and promoting sustainability by introducing renewable resources (Manda et.al, 2022). Therefore, this project proposed a solution by introducing PC to replace cement concrete to enhance product properties and preserve natural resource by using synthetic polymeric resin as matrix binders. The purpose of this study is to investigate strength limit of PC specimens with composition variations; compressive strength, flexural strength and water absorbability. Then, design and fabricate pre-cast products using polymer concrete material has been made and the test result of the load bearing capability of the polymer concrete pre-cast product has also been presented.

2. Methodology

This project presents the fundamental data on compressive strength, flexural strength and water absorption resistance of polymer concrete (PC). The experiments are performed base on ASTM standard for the entire test and thus the finding in the empirical study may be legally used for actual commercial applications (ASTM C579, ASTM C580 and ASTM D570). Figure 1 presents the methodology flow chart where section 1 describe experimental specimen preparation, section 2 describe mechanical testing and section 3 describe the fabrication of precast product based on previous section findings.

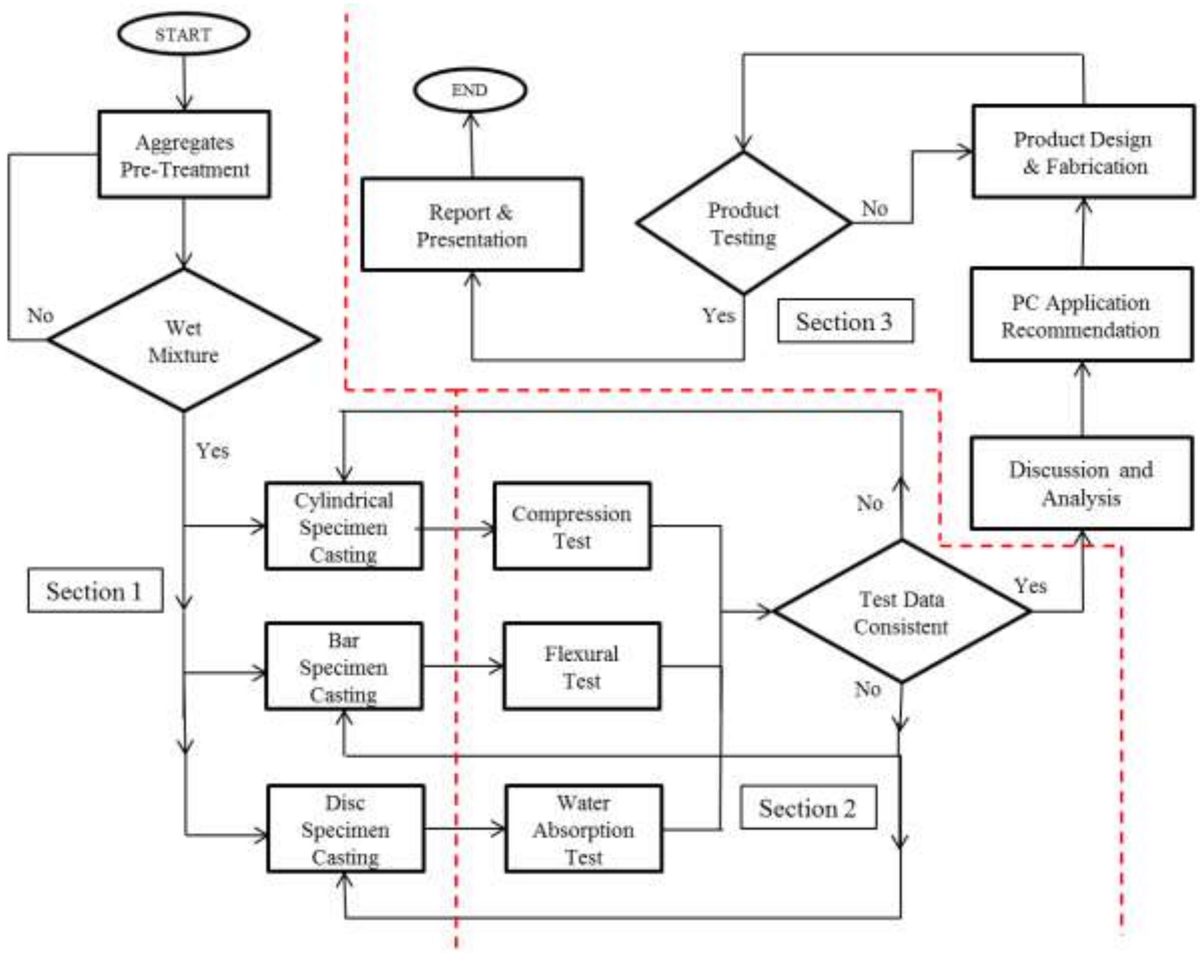

Figure 1. Flow chart of project methodology

The aggregate grading variations of the specimen have been prepared based on literatures. According to Jaafari et.al (2018) the aggregate grading of 1:1 sands and gravels has been employed. Faidzal et.al (2018) has applied uniform aggregate grading with fine sands (<1 mm). Khalid et.al (2015) has employed 18% filler, 34% coarse and 48% fine aggregates. Another variation chosen are based on Reis (2015) which has applied 17.6% filler, 33.4% coarse, 47% fine aggregates and 2% fibers.Table 1 shows the variation of specimen in aggregate grading including the specimens designation.

Table 1. Aggregate grading and specimen designation

Designation	Aggregate grading	Study
AG1	1:1 sands and gravels	Jaafari et.al (2018)
AG2	Sands only	Faidzal et.al (2018)
AG3	18% filler, 34% coarse and 48% fine	Khalid et.al (2015)
AG4	17.6% filler, 33.4% coarse, 47% fine and 2% fibers	Reis (2005)

Polyester resin (P5909) has been employed as matrix binder in this study due to its relatively low cost and wide availability (Manda et. al., 2022). Resin manufacturer recommendation is also applied by using 2% Methyl Ethyl Ketone Peroxide (MEKP) mixture with resins as catalyst and minimum 3 days of curing time at room temperature. The aggregate to resin ratio has been referred to literatures. Leornadi et.al (2019) has applied 20:80 while Faidzal et.al (2018) introduced 30:70 ratios. Other than that, Khalid et. al. (2015) has applied 12:88 ratios. Table 2 presents the ratio and the designation for resin to aggregate ratio.

Table 2. Matrix binder to aggregate ratio and specimen designation

Designation	Resin: Aggregate	Study
RT1/ C1	20:80	Leonardi et.al (2019)
RT2/ C2	30:70	Faidzal et.al (2018)
RT3/ C3	12:88	Khalid et.al (2015)

Specimen shape and size has been cast according to ASTM 579 for compression test specimen, ASTM 580 for flexural test specimen and ASTM D570 for water absorption test specimen. Table 3 summarizes the specimen specification and designation.

Table 3. Specimen specification and designation

Designation	Specimen shape and dimension	Standard
S1	Cylindrical (25 mm diameter x 25 mm height)	ASTM C-579
S2	Square bar (25 mm x 25 mm x 250 mm length)	ASTM C-580
S3	Disc (50.8 mm diameter x 6.35 mm height)	ASTM D-570

Compression and flexural test has been performed using Shimadzu UTM AGX 50 kN. Water absorption test apparatus includes water container for specimen submersion and weight scale for weight measurement. All test apparatus are in compliance with ASTM standards. The calculation to obtain mechanical properties has also been adapted from ASTM recommendation standards for compression testing (1), standards for flexural testing (2) and standards for water absorption test (3). The symbols represent compressive strength (σ), flexural strength (σ_f), maximum load (W), specimen diameter (D), maximum load (P), span length (L), specimen width (*b*) and specimen depth (*d*).

$$\sigma = \frac{4W}{\pi D^2} \quad (1)$$

$$\sigma_f = \frac{3PL}{2bd^2} \quad (2)$$

$$Water\ Absorption\ (\%) = \frac{Wet\ weight - Dry\ weight}{Dry\ weight}\ x\ 100 \quad (3)$$

3. Result and Discussion

Table 4 presents mechanical testing results for all of the testing (compressive strength, flexural strength and water absorption percentage). Test results show that AG2RT2-S1 specimen give the highest compressive strength (94.73 MPa). AG2RT2-S1 composed of uniform fine aggregates from sands only. The aggregate to resin ratio for AG2RT2-S1 is 70:30 and the specimen shape is cylindrical with 25 mm diameter and height. The results for three point bend test has shown that AG4RT2-S2 composition provide the best flexural strength for polymer concrete (12.94 MPa). AG4RT2-S2 composed of 17.6% filler, 33.4% coarse, 47% fine and 2% fibers. The aggregate to resin ratio for AG4RT2-S2 is 70:30 and the specimen shape is 25 mm x 25 mm x 250 mm square bars. Another experimental test is water absorption test which employ disc shape specimen with 50.8mm diameter x 6.35mm height. The specimens has been measured for dry weight and submerge for at least 24 hours before the wet weight is measured to determine percentage of water absorb by every specimens. The results from Table 4 indicated that AG2RT2-S3 specimen provide 0 % water absorption compared to others. AG2RT2 composed of uniform fine aggregates from sands only. The aggregate to resin ratio for AG2RT2 is 70:30. All of the test results are in the range of PC property as report by Mebarkia and Vipulanandan (1990) which shown that compressive strength, flexural strength and water absorbability of PC are 40–150 MPa, 4-50 MPa and 0.5-3 %. However, water absorbability of AG2RT2 in this study has performed better than the estimated range.

Table 4. Summary of mechanical testing results

Spec.	Max. Load (N)	Comp. Strength (MPa)	Spec.	Max. Load (N)	Flexural Strength (MPa)	Spec.	Dry Weight (g)	Wet Weight (g)	Water Absorption (%)
AG2RT2-S1	*48000*	*94.73*	AG2RT2-S2	1770	9.35	AG1RT2-S3	51	55	7.84
AG2C2-S1	5900	11.64	AG2C2-S2	340	1.80	*AG2RT2-S3*	*45*	*45*	*0*
AG2RT1-S1	39600	76.15	AG2RT1-S2	1590	8.40	AG1C2-S3	72	78	8.33
AG2RT3-S1	4800	9.47	AG2RT3-S2	620	3.27	AG2C2-S3	46	52	13.04
AG1RT1-S1	45000	88.8	AG1RT2-S2	1820	9.61				

AG4RT2-S1	20600	40.65	AG3RT2-S2	1040	5.49
			AG4RT2-S2	*2450*	*12.94*

Results from experimental were then employed to produce pre-cast product innovation based on the best composition with specific application. Pre-cast PC plate has applied AG2RT2 composition due to optimum compressive strength compared to other composition. Then, pre-cast grating has applied AG4RT2 composition due to optimum flexural strength as experimental results. Finally, pre-cast drain trench has applied AG2RT2 composition due to minimum water absorption percentage compared to other composition. Figure 2 presents the drawing and finished PC pre-cast product innovation.

Evaluation on the pre-casts products has been performed using simple field test on each product. Table 5 simplified the field test and observation results. In static loading test, five different people has stand on the products to observed if any sign of crack or fracture occur. However, all products successfully passed the test as they remain intact after the test. Then for free fall test, the products are elevated to 2 m, 4 m and 6 m high and dropped. The fallen products were observed for a sign of crack or chips. Similarly, all of the products successfully passed the test as all products still remain intact. The final field test was applied only to drain trench to observe their effect of water flowing through them. According to Table 5, the drain allows smooth water flow no matter how much of the flow rate capacity.

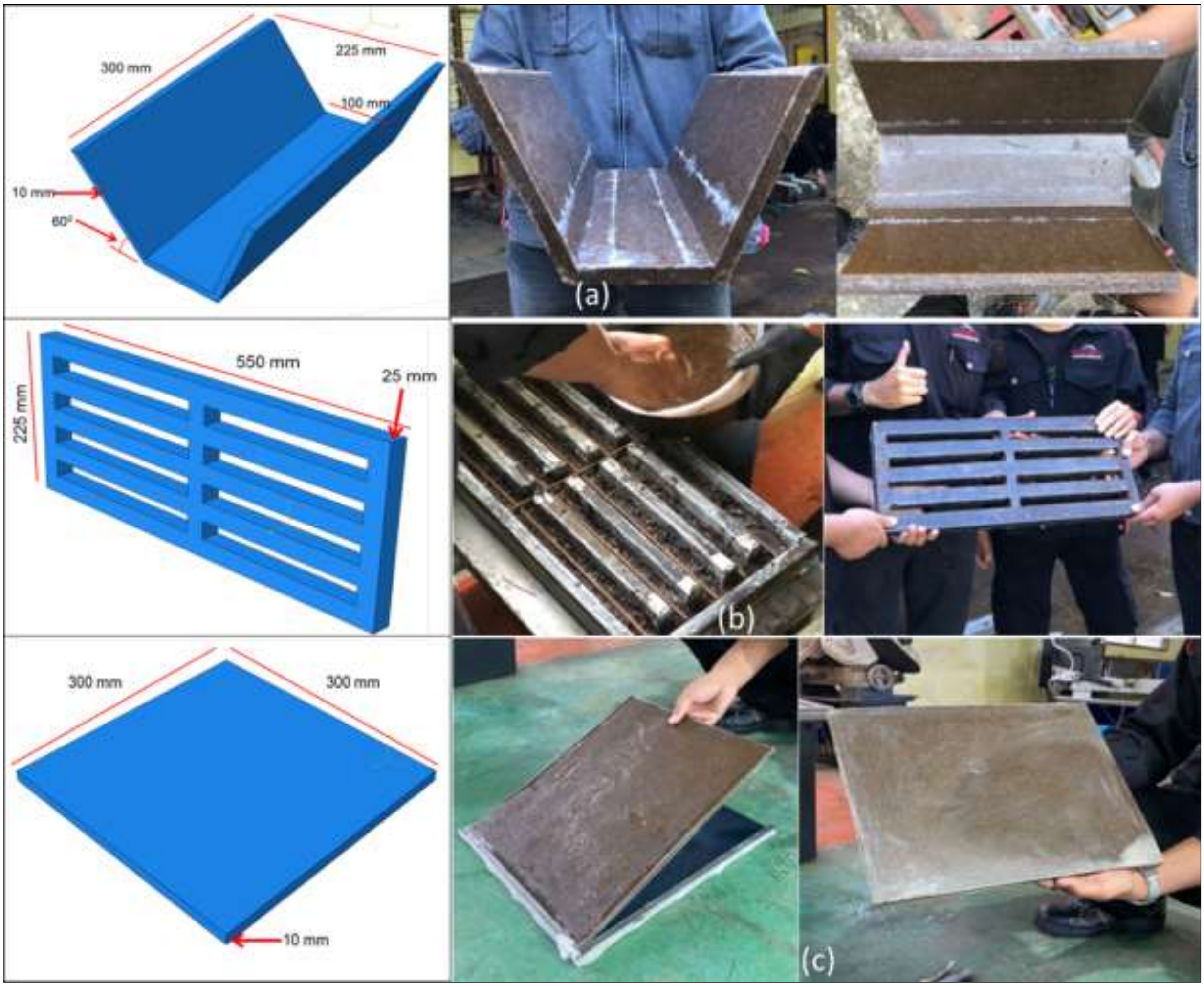

Figure 1. Drawing and finished PC pre-cast product (a) Drain trench, (b) Grating, (c) Plate

Table 5. Summary of field test and observation results

Field Test 1	**Persons**	**Mass (kg)**	**Drain trench**	**Grating**	**Plate**
Static Loading Test	A	48	*Intact*	*Intact*	*Intact*
	B	52	*Intact*	*Intact*	*Intact*
	C	77	*Intact*	*Intact*	*Intact*
	D	104	*Intact*	*Intact*	*Intact*
	E	110	*Intact*	*Intact*	*Intact*
Field test 2	**Elevation**		**Drain trench**	**Grating**	**Plate**
Free Fall Test	2 m		*Intact*	*Intact*	*Intact*
	4 m		*Intact*	*Intact*	*Intact*
	6 m		*Intact*	*Intact*	*Intact*
Field test 3	**Water flow capacity**		**Drain trench**	**Grating**	**Plate**
Water Flow Test	Slow		*Smooth flow*	*N/A*	*N/A*
	Moderate		*Smooth flow*	*N/A*	*N/A*
	Fast		*Smooth flow*	*N/A*	*N/A*

4. Conclusions

All of the experimental findings and product innovation fabrication outcome has been revealed successfully based on project methodology and objectives. This project has contributed to novel findings in the application of fundamental data from previous research through experimental validation and pre-cast polymer concrete products fabrication. The potential to apply PC in existing pre-cast cement concrete product has been proven to enhance the product performance as well as preserving the nature by introducing polymeric resins as a replacement to cement.

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