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EFFECT OF RECYCLED PLASTIC CONTENT AS FILLERS ON MECHANICAL AND DURABILITY PROPERTIES OF CONCRETE

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ABSTRACT: This research aims to experimentally investigate the effect of recycled high-density polyethylene plastic granules as a partial replacement of fine aggregate fillers (designated as RHDPE concrete) with the mechanical and durability properties of concrete. The experimental mixtures were divided into two groups with different water-cement ratios (W/C) of 0.5 and 0.6. The influential factors studied are RHDPE contents of 0%, 20%, 40%, and 60% by weight of natural sand and W/C. The eight mixtures were tested under workability, compressive strength, modulus of elasticity, ultrasonic pulse velocity (UPV), electrical resistivity (ER), chloride penetration, and water permeability. RHDPE content has less influence on workability than its W/C. As the replacement ratio and W/C increased, the density, 28-day-compressive strength, modulus of elasticity, and UPV value are observed decreasing trends. Moreover, the high testing value of ER, chloride penetration, and water permeability were also obtained. This means that using RHDPE as partial fillers in concrete causes a reduction in mechanical and durability properties. Nevertheless, the 20 percent of fillersì replacement presented an acceptable compressive strength of Thai Industrial Standard (TIS) no. 57-2530 for compressive strength of hollow load-bearing concrete masonry units at 5.5 MPa.

Keywords: *Recycled plastic, Durability of concrete, Recycled HDPE*

1. INTRODUCTION

Since the addressing of the Sustainable Development Goals (SDGs) in 2012, interest in plastic waste usage as recycled raw material for various industries has increased significantly. To meet sustainability and profitability, lots of research has been exploiting the effect of using plastic waste for the construction materials industry, which could contribute to the mass of reducing and utilizing plastic waste. However, the application of plastic waste in structural concrete is frequently conditioned by some limitations in strength and durability. As many studies have shown, there is a decrease in compressive strength when concrete is mixed with polyethylene terephthalate (PET) [1-7]. These authors noticed that the replacement with a small amount of PET performed an acceptable strength level. Furthermore, the enhancement of using waste electronic plastic (e-plastic) in mortar and concrete was investigated by [8-9]. A significant improvement in compressive strength was obtained in concrete mixed with 12% e-plastic as coarse aggregate [8], where [10] obtained a reduction in compressive strength of concrete that involved partial polypropylene plastic waste as a coarse aggregate. While [9] found a lower value of strength in tested concrete containing a large amount (>20%) of e-plastic, a mixture of fine and coarse aggregates. Based on the study of [11] a new polymeric fine aggregate made from recycled polypropylene (PP) and polyethylene (PE) also found a decrease in mechanical properties. The large volume of replacement polyolefin waste aggregate in concrete presented a worsening in its strength [12]. The replacement of a 10% mix of rigid plastic waste engendered a relatively smaller reduction of compressive strength [13]. However, the use of waste plastic in concrete contributed to reducing thermal conductivity [14-16]. This difficulty of might is overcome using it for non-structural components of building such as facades, building isolation, and walls.

On the contrary, the replacement of electronic plastic waste, namely high-impact polystyrene (HIPS) granules, can improve the compaction of concrete [17] and provide satisfaction durability since it fills the voids in-between fine and coarse aggregates. The study of [10] observed an increase of spalling resistance of concrete mixed with polypropylene (PP) fiber in saturated surface dry. In addition, [18] and [19] obtained the improvement of tensile strength, flexural strength, and splitting strength of concrete by adding polypropylene (PP) fibers and waste metalized plastic (WMP) fiber, respectively. The incorporation of expanded polypropylene (EPP) with magnesium oxychloride cement composites contributed to some advantages of thermal resistance [20]. The study of [21] evidenced that a fiber-reinforced polymer made from plastic straw is adequate for concrete strengthening. However, most of the previous studies have mainly focused on the effects of a variety of plastic waste where the exploration of high-density polyethylene plastic waste (HDPE) in concrete was limited.

In this paper, the two issues of mechanical and durability are considered and the possibility of using recycled plastic content as a fine aggregate filler in concrete is suggested. This application would substitute the currently used natural river sand as a fine aggregate. The experimental parameters were the percentage of recycled high-density polyethylene plastic granules (RHDPE) substitution and W/C. The concrete cubes and cylinder specimens were prepared with 0%, 20%, 40%, and 60% by weight of natural sand. Slump value examined the fresh property of concrete. Mechanical properties were evaluated through density, compressive strength, and modulus of elasticity. The determination of durability properties such as ultrasonic pulse velocity, electrical resistivity, and chloride penetration was also conducted to certify the reliability of its application in the building materials industry.

2. MATERIALS AND METHODS

2.1 Cement and Aggregates

In this study, ordinary Portland cement (OPC) according to ASTM C150 with a specific gravity of 3.16 was used. The fine aggregate was natural river sand according to ASTM C136 with particle size ranging from 0.6-9.58 mm, a specific gravity of 2.59, and water absorption of 2.54 percent. The coarse aggregate was crushed rock with minimum size and water absorption of up to 4.75 mm and 0.51 percent, respectively. The particle gradation of fine and coarse aggregate is given in Fig. 1. The gradation curve of RHDPE indicates that this material is classified as gap graded aggregate. RHDPE has the potential for usage as a fine aggregate replacement, as evident by its particle size.

2.1 Recycled Plastic

RHDPE was used as a fine aggregate replacement. The RHDPE were made from the collected HDPE plastic waste that was crushed, then mixed with chemical and color, heated, and molded with an injection molding machine before being cut into available size. Fig. 2 shows the RHDPE recycled granules. The specific gravity of RHDPE showed in Table 1 was 0.5.

2.2 Testing Methods

The testing conducted consisted of: (1) the fresh properties of all mixtures tested by using the slump test, (2) the hardened properties of all mixtures tested by determining the compressive strength and modulus of elasticity at 28 days, and (3) the durability properties tested by using the ultrasonic pulse velocity test, electrical resistivity test, chloride penetration test, and water permeability test.

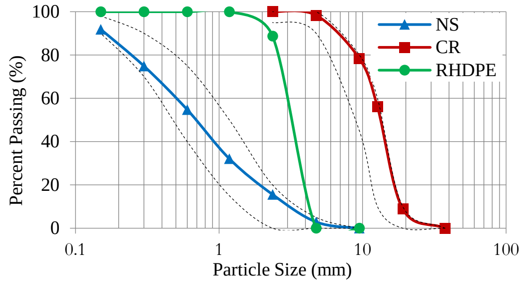


Fig.1 Gradation curve of fine and coarse aggregates

Fig.2 Recycled plastic granules

Table 1 Properties of aggregate.

	Specific gravity	%Water absorption
Natural river sand (NS)	2.59	0.79
Crushed rock	2.72	0.51
Recycled HDPE (RHDPE)	0.50	0.00

3. EXPERIMENTAL PROGRAMS

3.1 Preparation and Testing Specimens

For all the mixtures, natural fine and coarse aggregates and RHDPE were weighted and mixed with OPC in a concrete mixer. The slump test, which indicated the workability of the fresh concrete, was tested using slump test apparatus according to ASTM C143. Then, the mixtures were molded into a cylinder cast within three layers, compacting each layer. For each test with each mixture, three specimens were prepared. After casing a room temperature for 24 hours, all specimens were demolded and cured in fresh water also at room temperature. Compressive strength of concrete with 100 mm × 200 mm cylinder was used based on ASTM C39.

The ultrasonic pulse velocity test was performed on a 100 mm × 200 mm cylinder concerning ASTM C597. The pulse velocity was examined by measuring the time that pulse traveled from 54 kHz transmitter to receiver and then dividing by length path of concrete specimens as shown in Eq. (1). The setup of the UPV test is shown in Fig 3.

$$UPV = \frac{l}{t} \tag{1}$$

Where, UPV =pulse velocity (km/s), l =length path of concrete specimen (km), and t =time (s).

Tested specimens for electrical resistivity were the same as the UPV test with 100 mm × 200 mm cylinder at 28 days. The electrical resistivity test was performed according to the standard ASTM C1760 by measuring the applied voltage and the electrical current that flows through a specimen. Eq. (2) was used to calculate the electrical resistivity.

$$\rho = \frac{2\pi a V}{I} \tag{2}$$

Where ρ is electrical resistivity in ohm-meter (Ωm) and a is the length of specimen in meter (m). V and$I$isee the applied voltage and electrical current at 1 min in amperes. ASTM C1760 recommended the maximum electrical resistivity of 200 Ωm and above, for which the risk of corrosion of the reinforcement is very low.

Tested specimens for chloride penetration and water permeability of concrete were produced as same as compressive strength. They were prepared by cutting the 100 mm × 200 mm cylinder into a 100 mm disc with a thickness of 50 mm. Then, both ends of the disc were smoothed before being placed into the test cell and wrapped with an epoxy thickness of 25 mm, as shown in Fig.4 and Fig.5, respectively. Sodium chloride solution with 3.0% concentration (weight per volume) was filled in the test cell at the cathode and a 0.30 N solution of sodium hydroxide was added to the anode test cell compartment. After, the electric potential regulator was switched on, applying a voltage from 0 to 60 volts for 6 hours. To calculate the value of current flow in coulombs, the measure electrical current-voltage was applied by using Eq. (3).

$$Q = 900\,(I_0+2I_{30}+2I_{60}+2I_{90}+2I_{120}+\ldots+2I_{300}+2I_{330}+I_{360}) \tag{3}$$

Where Q is the current that flows through one cell (Coulombs). I_0 is electrical current-voltage (amperes). *electrical current* voltage at time t (amperes).

To confirm the durability of using RHDPE in concrete, the mixtures with acceptable results of the chloride penetration test were then investigated using the water permeability test.

Fig.3 Ultrasonic pulse velocity (UPV) test

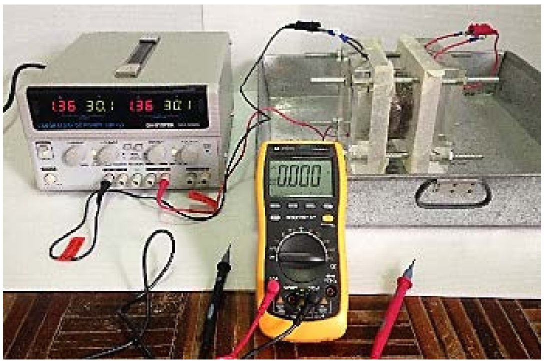


Fig.4 Chloride Penetration Test Apparatus

3.2 Description of Mixtures

The RHDPE concrete mixtures were designed having two values of water-cement ratio (W/C) of 0.4 and 0.5. The replacement content of RHDPE ranged from 0, 20, 40, and 60 percent by weight of fine aggregate and W/C. Table 2 summarizes the mixtures matrix used in this study. A total of 8 mixtures were prepared and tested. The mixture of CW-05-P0 and CW-06-P0 was used as the controlled mixture of W/C 0.5 and 0.6, respectively, which did not contain RHDPE.

4. RESULTS AND DISCUSSION

4.1 Fresh concrete properties

The slump value of the fresh concrete was measured using the slump cone test to control the quality as a convenient method. Table 3 illustrates the effect of recycled plastic on the workability of fresh concrete. For all mixtures, there were very few changes in the slump. In addition, the replacement ratio of recycled plastic granules did not affect the workability of the concrete. The factor of water-cement ratio with the CW-06 mixture contributed to a high slump value compared to the CW-05 mixture for all recycled plastic content, hence the higher volume of liquid in the cement plate.

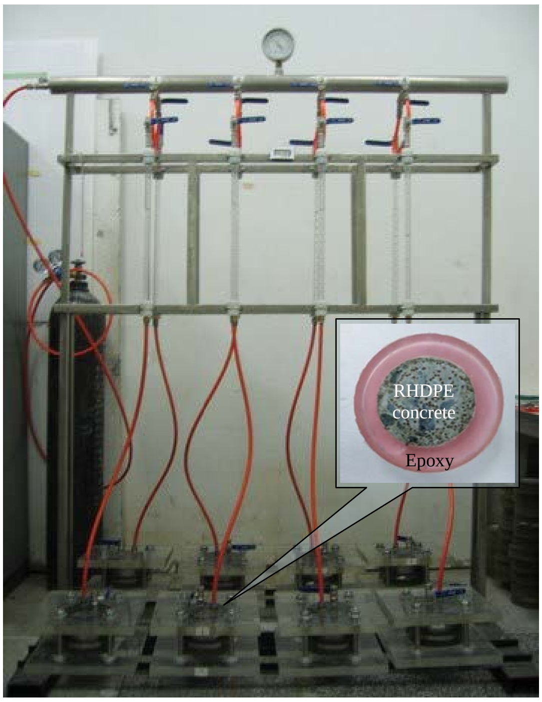


Fig. 5 Water permeability test

Table 2 Mixtures of RHDPE concrete

Mixture	Cement (kg/m^3)	Fine aggregate (kg/m^3)	%RHPDE (kg)	Coarse aggregate (kg/m^3)
CW-05-P0*	320	800	0 [0]	1200
CW-05-P20	320	640	20 (160)	1200
CW-05-P40	320	480	40 (320)	1200
CW-04-P60	320	320	60 (480)	1200
CW-06-P0**	320	800	0 (0)	1200
CW-06-P20	320	640	20 (160)	1200
CW-06-P40	320	480	40 (320)	1200
CW-06-P60	320	320	60 (480)	1200

*, **control mixtures for CW-05 and CW-06

Table 3 Slump tests of RHDPE concrete

Mixture	Slump (cm)	Mixture	Slump (cm)
CW-05-P0	13	CW-06-P0	14
CW-05-P20	13	CW-06-P20	15
CW-05-P40	12	CW-06-P40	15
CW-05-P60	13	CW-06-P60	14

4.2 Mechanical Properties

Figure 6 shows that including recycled plastic as a replacement for concrete decrease the density of concrete. The slight difference in the value of density contributed by the W/C ratio can be observed in the test samples. The calculation of the standard error reveals that the density values of RHDPE concrete are centered over the interval. They are classified as lightweight concrete and found to be lower than that for concrete mixed with PET, as studied by [1] since RHDPE has a low specific gravity than that of PET.

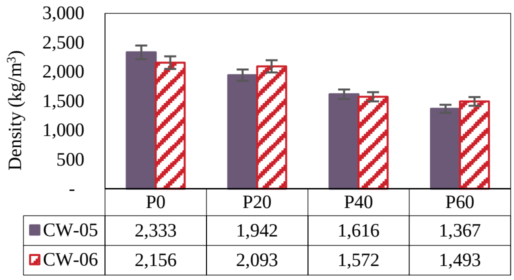


Fig.6 Density of RHDPE concrete

4.2.1 Compressive Strength

Figure 7 illustrates that the compressive strength values of the mixture P20 of CW-05 and CW-06 were lower than that of the control mixture (P0). The compressive strength values for RHDPE concrete are found to be lower than the compressive strength formerly reported by Gravina et al. [5] for a curing age of 28 days. However, the compressive strength of P20 of CW-05 and CW-06 conform to the concrete production standard of the Thai Industrial Standards Institute (TISI) 57-2530 for hollow load-bearing concrete masonry unit of 5.5 MPa. The decrease in compressive strength is attributed to the increase of recycled plastic content, which creates a decrease in the density of concrete, resulting in poor compactness. The compactness of concrete is inversely proportional to the specific density or unit weight of the concrete. Thus, an increase in recycled plastic content can lead to a reduction in compressive strength. A slightly different trend was found in the P60 mixture. This might be due to the consequence of inhomogeneous higher content of RHDPE.

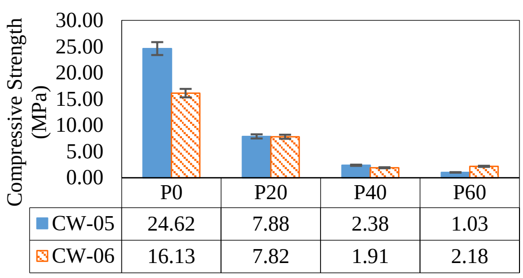
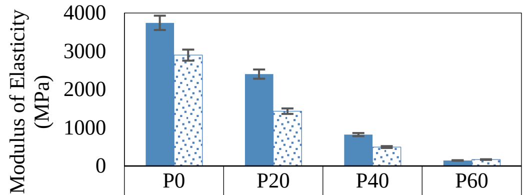


Fig.7 Compressive Strength of RHDPE concrete

4.2.2 Relation between compressive and modulus of elasticity

According to Figure 8, a significant decrease in the modulus of elasticity can be observed in the tested samples along with the percentage of RHDPE. Using the 20 percent of RHDPE granules as a natural sand replacement with a 0.5 W/C ratio produced appropriate results of the modulus of elasticity, which was shown over 2400 MPa.

The results obtained from the chart in Figure 9 shows that the compressive strength of concrete has a positive correlation with the modulus of elasticity.



	P0	P20	P40	P60
CW-05	3743.11	2402.94	820.74	144.68
CW-06	2898.47	1433.44	495.4	167.79

Fig.8 Modulus of Elasticity of RHDPE concrete

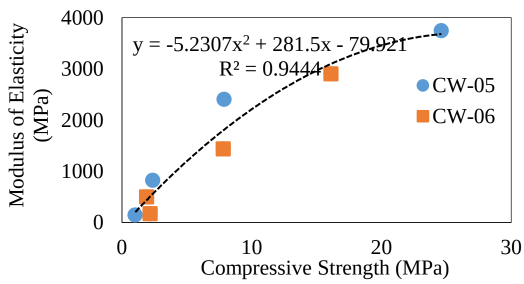


Fig.9 Compressive strength and modulus of elasticity

4.2.3 Relation between density, recycled plastic ratio, and compressive strength of concrete

Figure 10 shows the relation between the unit weight and the compressive strength of concrete aging at 28 days. It was observed that the compressive strength of all concrete containing recycled plastic was lower than that of the control concrete mixture. The results of the compressive strength test clearly showed the limitation of using recycled plastic in a concrete mixture. The trend illustrated a definite decrease in compressive capacity, as attributed to the higher recycled plastic concentrations. The percent of compressive strength was found to be decreased further when there was an increase in recycled plastic content. The compressive strength of the control mixture CW-05 was higher than that of CW-06. While the compressive strength of both mixtures containing recycled plastic content presents a similar trend until the percentage of recycled plastic content was at 60, the value of CW-06 was higher than CW-05 by almost two times. With an increase in recycled plastic content, the concrete becomes less densely spaced and may hinder the growth of microcracks within the brittle matrix, since subsequent of its smooth surface and uniformity as shown in Fig. 11.

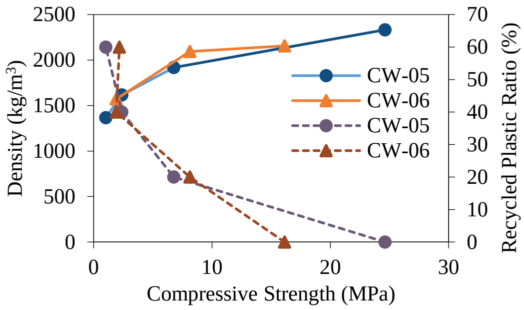


Fig. 10 Relation between compressive strength density and recycled plastic ratio

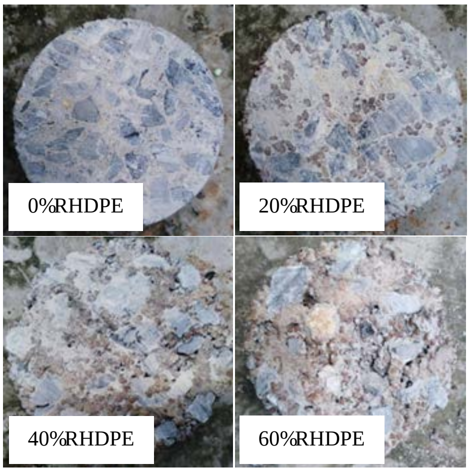


Fig.11 Cross-sectional area of RHDPE concrete

4.3 Durability Properties

4.3.1 Ultrasonic pulse velocity (UPV) Test

The results found from the ultrasonic pulse velocity (UPV) test are shown in Fig. 12. The addition of RHDPE decreases the UPV value of concrete. At the same time, the W/C ratio presents a random trend of the UPV value. For the W/C ratio of 0.5, the substitution rate of 20%, 40%, and 60% decreases the UPV value by almost 13%, 65%, and 100%, respectively, when compared to the control mixture. A similar effect of different amounts of RHDPE can be obtained from another mixture of W/C ratios of 0.6. In comparison to the IS 13311(1): 1992 standard, that classified the concrete quality as doubtful, medium, good, and excellent for the UPV value ranges from below 3.0 km/s, 3.0-3.5 km/s, 3.5-4.5 km/s, and above 4.5 km/s, respectively, the UPV value of concrete with the addition of 20% RHDPE can be categorized as good quality concrete due to its appropriate high density, while the rests of the mixtures were doubtful. The appropriate content of RHDPE mixed with concrete is less than 20 percent.

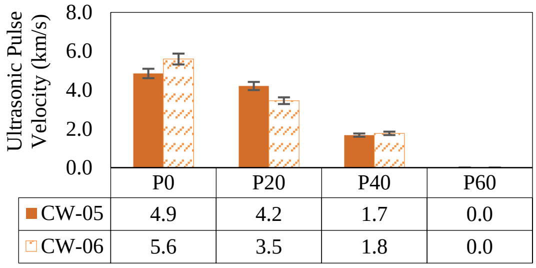


Fig.12 Ultrasonic pulse velocity of RHDPE concrete

4.3.2 Electrical Resistivity Test

The electrical resistivity (ER) of concrete was measured according to ASTM C1760 and Eq. (2). Figure 13 shows that the value of ER was a random trend as the replacement of RHDPE increased, as similar as the increase of W/C ratio fluctuated the ER value. The ASTM C1760 categorized the value of conventional concrete resistivity in four types: <50 Ωm, 50-100 Ωm, 100-200 Ωm, and >200 Ωm, which is very high, high, low, and very low corrosion risk, respectively. Compared with that concrete grading, the ER value of all mixtures ranged from 120-1090 Ωm, which were grouped as low and very low risk of corrosion. It highlights that the amount of RHDPE at 40% has a strong positive impact on the expansion of ER to the highest value of 820 Ωm and 1090 Ωm for W/C ratio of 0.5 and 0.6, respectively. This finding is in agreement with those obtained by [22]. These can be attributed to the properties of RHDPE that have a high electrical resistivity ranging from 5×10^{17} - 1×10^{21} $\Omega mm^2/m$.

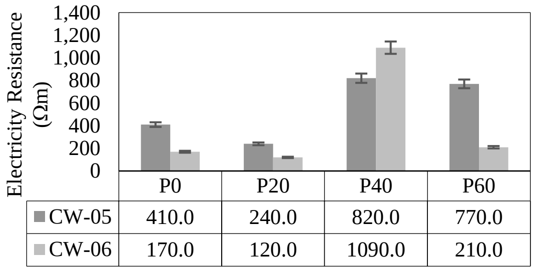


Fig. 13 Electrical Resistivity of RHDPE concrete

4.3.3 Chloride Penetration Test

As shown in Figure 14, the charge passed a value of RHDPE concrete is found to be higher than the penetration of chloride ions in concretes ranging from 3070 to 4183 coulombs, as previously reported by Bhogayata and Aror [23] for a curing age of 28 days. A remarkable increase of charge passed as the percentage of RHDPE increased indicated that there was a low degree of homogenous in the tested concretes. Compared to the ASTM standard C1202, the chloride permeability value of all RHDPE concrete is classified as high chloride permeability. It was noted that the inclusion of RHDPE in concrete led to a decrease in durability for all mixtures [24].

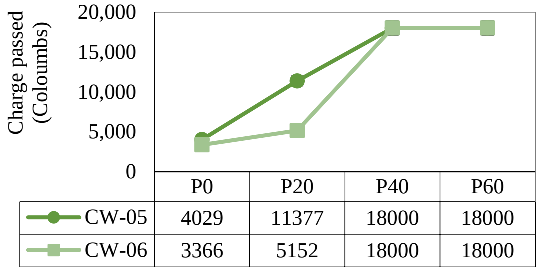


Fig.14 Chloride Penetration of RHDPE concrete

4.3.4 Water Permeability of Concrete

From the test results of the chloride penetration test, mixture CW-05 and CW-06 with 40% and 60% RHDPE presented a slightly higher value of charge passed. Thus, to evaluate the feasibility of using RHDPE with 20%, the water permeability was conducted. It is worth noting that the values of water permeability coefficients of the mixture CW-05-P20 are lower than CW-06 P20 values, as shown in Fig. 15. This confirms the low value of W/C of RHDPE concrete enhances the adequate value of water permeability significantly.

4.4 Microstructural Inspection

Figure 16 shows the microstructural photo of the mixture. It can be seen that the homogeneity of the control (ordinary concrete) was visible, while the numerous micro-cracking surrounding the RHDPE can be noticed. The replacement of fine aggregate with RHDPE, which has a round shape and slightly smooth surface, reduced the bond between fine aggregate and cement paste compared with that of natural sand.

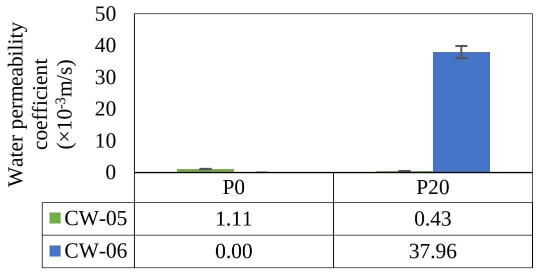


Fig.15 Water permeability of RHDPE concrete

5. CONCLUSIONS

Based on the experimental investigation obtained from the experimental programs, the following conclusions can be drawn:

1) According to the test results obtained in this study, with the increase in replacement of RHDPE, a lower unit weight was observed from the concrete. The replacement of RHDPE with 20%, 40%, and 60% in concrete decreased the unit weight by about 10, 29, and 36 percent when compared with the control mixture, respectively.
2) As the replacement of RHDPE in concrete increased, the compressive strength and modulus of elasticity decreased. The highest decreasing value of compressive strength and modulus of elasticity were around 92 and 95 percent, respectively.
3) UPV values of concrete decreased as the RHDPE containing rate increased. The UPV values of the mixtures containing 20% RHDPE were in the range of 3.5-4.5 km/s, which can be categorized as a good quality of concrete. In comparison, the doubtful quality of concrete can be shown with a replacement rate of up to 40%.
4) Electrical resistivity of all HDPE mixtures was beyond 200 Ωm and was classified as very low corrosion risk, except the mixture CW-06-P20 that was observed as a low corrosion risk. The increase in the RHDPE replacement rate increased electrical resistivity. These may be attributed to the low electrical conductivity properties of RHDPE.
5) A sharp increase of the chloride penetration rate was visible from beyond 20% RHDPE replacement in the concrete mixture, except for the mixture CW-06-P20. The values of chloride permeability of these were up to 4000 coulombs and were considered as high chloride permeability rate. This is because of the inhomogeneity of concrete with RHDPE.
6) The water-cement ratio, whereas, had no significant effect on the unit weight of concrete. But the increase in the W/C ratio resulted in the decrease of compressive strength and modulus of elasticity. As the W/C ratio increased, there were no patterns of W/C ratio influence on UPV value, electrical resistivity, and chloride penetration rate.

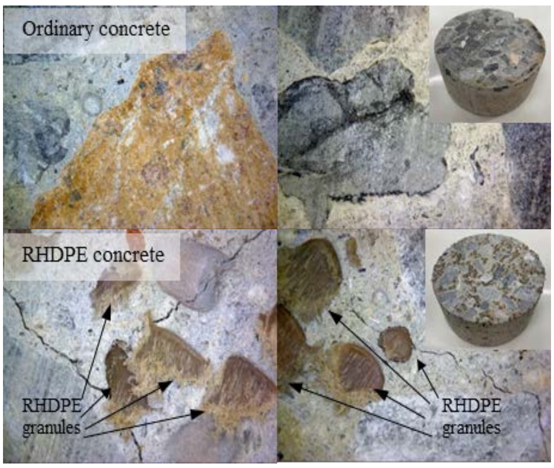


Fig. 16 Microstructural Inspection of RHDPE concrete granules

6. ACKNOWLEDGEMENTS

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