The Effects of Para Rubber Latex on Compressive Strength, Elastic Modulus, and Water Permeability of High Strength Concrete

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Abstract. *The objectives of this research were to study of compressive strength, elastic modulus and water permeability of high strength concrete containing low ammonia concentrated latex. The designed strength of concrete samples was 45 MPa. Some amounts of water in concrete mixtures were replaced by the concentrated latex at the percentage of 0.5, 1.0, 1.5, and 2.0 by weight. Each mixture was tested for slump, compressive strength, elasticity modulus, and water permeability. The compressive strength and elasticity modulus were observed by using concrete samples, having 10 cm in diameter and 20 cm in height at the ages of 3, 7, 14, and, 28 days of curing. The required slump was between 7.5 cm and 12.5 cm. The result showed that the increasing of concentrated latex decreased slump of the fresh concrete. The 28-day compressive strengths of the latex concretes containing 0.5, 1.0, and 1.5% of latex replacement showed a little higher than the control concrete's while the 2.0% replacement was dramatically lower. The elastic modulus varied directly to compressive strength of all mixtures. At the same time, almost all mixtures of latex concrete obviously provided lower water permeability than the control one, especially the 1.5% replacement which was about 3 times lower. Thusly, a proper amount of the concentrate latex could be used well in high strength concrete work for increasing its impervious aspect.*

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1. Introduction

Para rubber is one of the most important products to enhance the economy in Thailand. It is used to make the local products and even exported to all over the world. Unfortunately, in these last ten years, the rubber market has been oversupply causes its price has been ceaselessly decreasing. To deal with this serious issue, the government sectors, entrepreneurs, farmers and related agencies endeavor to raise its price with the intention. The Para rubber has been already used in the construction field for a while such as combination between asphalt and latex to improve durability of pavement [1], [2]. In addition, adding Para rubber latex into soil to make a better adobe brick which has a lot higher water resistance than the traditional adobe brick [3]. Moreover, a suitable amount of Para rubber latex can improve some properties of normal strength concrete, for example compressive strength and water permeability [4]. Rusting of reinforcing steel in reinforced concrete is still one of major issues that reduce concrete's useful life. There are numerous researches those tried to study for rusting causes and concrete's lifetime due to rusting [5],[6]. Since the Para rubber latex could reduce water permeability in normal concrete, it could be used in high-strength concrete in similar way. Then, occurring of rust in reinforcing steel of reinforced concrete could be reduced, consequently. However, effects of the Para rubber latex to other properties of high-strength concrete are still in need to be investigated. Hence, this research will explore the effects of Para rubber latex on compressive strength, workability, elastic modulus, and water permeability of high-strength concrete. The results could be used to design a mix proportion of high-strength concrete for expanding its lifetime, especially in severe conditions.

2. Experimental Program

The designed compressive strength for this research is 45 MPa. The required slump of fresh concrete is between 7.5 and 12.5 cm to observe its workability. The Low Ammonia-TMTD/ZnO type of Para rubber latex (LA-TZ) was used as partial replacement of water for each concrete mixture. The percentages of replacement were 0.0, 0.5, 1.0, 1.5, and 2.0 by weight of water. The compressive strength and elastic modulus of all mixtures were observed at the ages of 3, 7, 14, and 28 days whereas the water permeability was investigated only at the age of 28 days. The workability of fresh concrete of all mixtures was investigated suddenly after mixing and before molding using slump method following ASTM C143 / C143M-20 [7].

2.1 Material Preparation

All required materials must be prepared before the experiment. Both coarse and fine aggregates were washed by tap water and dried under ambient condition. The properties of coarse aggregate namely: the maximum size, unit weight, specific gravity, and water content were 20 mm, 1,550 kg/m^3, 2.70, and 0.17 percent, respectively. For the fine aggregate, the specific gravity was 2.65, the fineness modulus was 3.07, and water content was 0.18 percent. Portland cement type I conforming the ASTM C150/150M [8] was chosen for the research. The specific gravity of the Portland cement was 3.15. Furthermore, the water using for every mixtures was tap water. In addition, concentrated Para rubber latex used for the research was the Low Ammonia TMTD/ZnO type (LA-TZ) with 61.96 percent of solid content, 60.92 percent of dry rubber content, and milky white color which was taken from DS. Rubber Co., Ltd., Rayong province, Thailand. The detail of the latex is shown in Table 1. The latex was used as a partial replacement of water. The plasticizer type G was used to obtain the required workability of fresh concretes.

Properties	Unit	Standard Value (ISO2004:2010)	Test result
Total Solid Content (Min.)	% by weight	61.0*	61.64
Dry Rubber Content (Min.)	% by weight	60.0	60.20
Non-Rubber Content (Max.)	% by weight	1.7	1.44
Alkalinity - on total weight (Max.)	%NH3	0.29	0.29
- on water phase	%NH3	-	0.76
pH Value at 25°C		-	10.04
KOH Number (Max.)		0.70*	0.57
Volatile Fatty Acid Number (Max.)	VFA No.	0.06*	0.0200
Mechanical Stability Time @55% TSC (Min.)	Seconds	650	900
Magnesium Content (on Solids)	ppm	-	25
Viscosity (Roto. No. 60 RPM)	cP	-	75
Color of Latex		-	White

*The number shown in table could be used as it is or making a deal between buyer and seller

Table 1 Properties of LA-TZ using in this research compared to the ISO standard values

2.2 Mix Design

The mix proportions for the control high-strength concrete was firstly designed using the required compressive strength, slump, and aggregates properties as mentioned above by following ACI 211.1-91 [9]. Consequently, all other mixtures were calculated by replacing latex to the water content of the control one at the replacement ratio of 0.5, 1.0, 1.5, and 2.0 by weight of water and shown as H-0.5, H-1.0, H-1.5, and H-2.0, respectively in Table 2. Superplasticizer content was specified by trial and error of slump of the control one. All the latex concrete mixtures used the same superplasticizer content to observe the change of slump while fresh.

Mix	Mixture proportion (kg/m^3)					
	Cement	Coarse Agg.	Fine Agg.	Water	Latex	Super P.
Control	540	915	680	215.6	-	6.8
H-0.5	540	915	680	214.6	1.0	6.8
H-1.0	540	915	680	213.5	2.1	6.8
H-1.5	540	915	680	212.4	3.2	6.8
H-2.0	540	915	680	211.3	4.3	6.8

Table 2 Mix proportion for all mixtures in the research

2.3 Mixing, Molding and Curing

A drum concrete mixer was used in this work. The latex and superplasticizer must be mixed into water following the proportion shown in Table 2 to obtain a homogeneous solution beforehand. Cylinder molds with the dimension of 10 cm diameter and 20 cm height were used for molding the test specimens. The hardened specimens were demolded after 24 hours and submerged in a water bath as curing condition. The mixing, molding, curing and preparing of the test specimens were based on the ASTM C192 / C192M [10].

3. Preparing of Test Specimen, Testing Methods, and Calculations

Slumps of fresh concrete, compressive strength, modulus of elasticity, and water permeability of each specimen were observed. Slump was tested suddenly after mixing by a drum mixer for all mixtures following the ASTM C143/C143M [7]. Compressive strength and modulus of elasticity was tested simultaneously using a universal testing machine. To prepare specimens for both tests, three specimens, at a specified age, were taken out from the water bath. All specimens were prepared in moist condition and test for their compressive strengths following ASTM C39/39M [11]. Compressive strength and elastic modulus of each mixture was the average value of those three specimens. Water permeability of concrete was tested using an in-house equipment conforming some researches which the water pressure of 5 bars was applied constantly [12]-[14]. Darcy's law was applied for water permeability calculation of all 28-day specimens. To prepare test specimens for the test, a cylindrical specimen as molded earlier was trimmed at both ends for 5 cm to avoid effects of cement paste and segregation. The rest, 10 cm, of the specimen was cut at the middle to obtain 2 test-specimen having ∅10x4 cm for the water permeability test. Non-shrink epoxy resin was applied surrounding specimen's sidewise to prevent the water leakage and allow only the water passes through from top to bottom of the specimen as shown in Fig.1. Then, the Darcy's law shown in equation 1 was used to calculate the water permeability of each specimen.

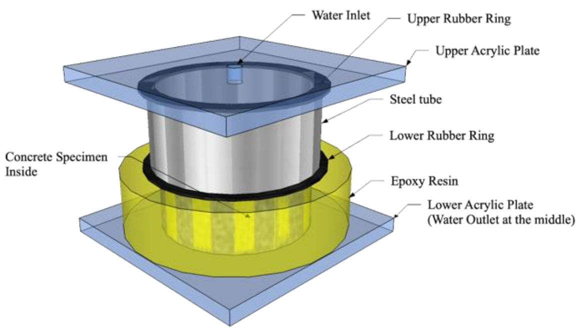

Fig. 1 Illustration of specimen installation for water permeability test

$$k_f = \frac{\rho L g Q}{PA} \quad (1)$$

where k_f is coefficient of permeability (m/sec), ρ is density of water (1,000 kg/m^3), g is gravity acceleration (9.81 m/sec^2), Q is the net flow rate of water which passes through the specimen (m^3/s), L is the height of the specimen (m), P is the absolute pressure (Pa), and A is the cross-sectional area of the specimen (m^2).

From equation 1, Q could be calculated from the drop of water level in a specific period time. The water drop could be observed from scaled plastic tube having inner diameter of 15.3 mm. Nominal height of specimen was 4 cm. However, the exact height was observed using a vernier and used for the calculation. The absolute pressure is 500,000 Pascal or 5 bar as described above. The cross-sectional area could be calculated from the exact diameter of each specimen.

4. Results and Discussion

4.1 Effect of Latex on Workability of Fresh High-Strength Concrete

Workability of fresh concrete was investigated by slump test and the results are shown in Table 3. The designed slump of the control mixture was less than 7.5 cm at first trial. From previous research, it was found that adding latex in concrete resulted in slump reduction. Hence, to keep slump of latex concretes placed in the designed slump range, superplasticizer of 1.25 percent by weight of cement was added to increase the slump of control mixture. Finally, the slump of the control mixture was 11.5 cm, which was acceptable. Hence, all designed mixtures in this research were equally added the superplasticizer content as shown in Table 1. Then, the effect of latex content on slump of fresh concrete could be observed easily as shown in Table 3.

Mixture	Control	HRL-0.5	HRL-1.0	HRL-1.5	HRL-2.0
Slump (cm)	11.5	10.2	10.0	9.6	9.0

Table 3 Slump test results of all high strength concretes in the research

According to the Table 3, it can be concluded that the Para rubber latex affected the slump of high strength concrete explicitly. This result corresponded to the study about the effects of Para rubber latex on normal strength concrete properties [4] which noticed that the more Para rubber latex adding, the lower workability. This possibly happened due to its stickiness of the latex itself comparing to water. In addition, in the latex, about 60% is dry rubber while the rest is water. Then, replacing water by latex would reduce the total water content in the mixture. Consequently, the lower slump would be observed.

4.2 Effects of The Latex on Compressive Strength of High-Strength Concrete

Fig. 2 shows the compressive strength development of all mixtures in the research. The 28-day compressive strengths of HRL-0.5, HRL-1.0, and HRL-1.5 obviously equal to 44.9, 43.1 and 41.3 MPa, respectively, which are higher than the control one of 41.1 MPa. The HRL-0.5 is clearly higher than the control one. This is because of the fact that the HRL-0.5 has a little lower w/c ratio comparing to the control mixture. In addition, the rubber particles could move with water and filled in the voids. Those rubber particles will be left in the voids while the water is used in hydration reaction. The rubber contributes a little strength to the concrete, consequently, this way. Nevertheless, the high strength concrete has a very low porosity so the rubber particles could not easily be containing in the voids [15]. Then, too much rubber particles would obstruct the binding between cement paste and aggregates [4]. Hence, the higher latex content, the lower compressive strength.

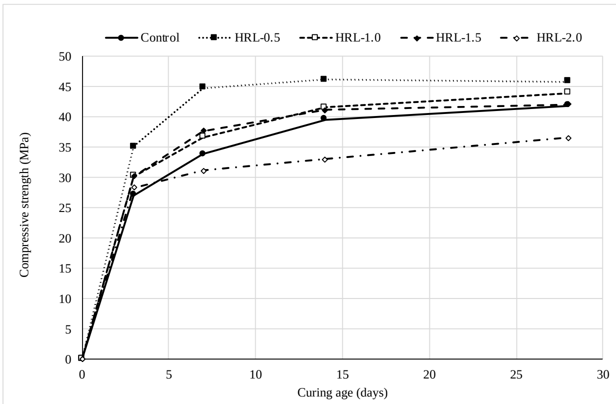

Fig. 2 Compressive strength development of all high strength concretes in the research

It could be found that HRL-2.0 has the lowest compressive strength from early stage until 28 days. The 28-day compressive strength of HRL-2.0 is 35.9 MPa or about 12.5 percent lower than the control one. The result is similar to those that found in normal strength latex concrete [4]. However, the high strength concrete has a lower and smaller voids, so the exceed latex which is the cause of compressive strength reduction found earlier in a lower replacement rate.

4.3 Effects of Latex on Elasticity Modulus of High-Strength Concrete

The results from all samples of every mixture were adopted to plot the relationship between its elastic modulus and compressive strength, one by one, as shown in Fig. 3. It could be seen that there is a relationship between those two Parameters where a multiple linear regression model could be fit the relationship as shown in equation 2. In addition, the R-squared is as high as 0.7 which reflecting a high precision of the proposed model. Moreover, a relationship between elastic modulus and compressive strength suggested by ACI 318 [16] is plotted as shown in Fig. 3. Since the proposed trendline has a different slope comparing to the ACI 318 one, so the proposed equation is highly recommended to predict the relationship between elastic modulus and compressive strength of latex concrete instead of ACI one.

$$E = 1720f_c' - 11300 \quad (2)$$

where, E is elastic modulus of concrete in MPa and f_c' is compressive strength of concrete in MPa

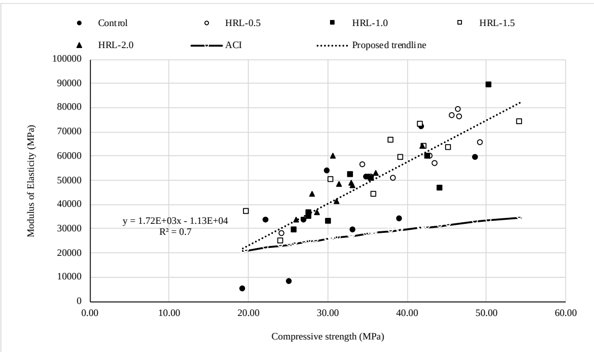

Fig. 3 Relationship between elastic modulus and compressive strength of high strength concrete containing Para rubber latex

4.4 Effect of Latex on Water Permeability of High-Strength Concrete and Relationship to the Compressive Strength

Table 4 shows the water permeability coefficient test result and normalized percentage to the control mixture. It is found that the HRL-0.5 has a little higher water permeability value than the control one. However, HRL-1.0, HRL-1.5, and HRL-2.0 have a much lower water permeability coefficient than the control high strength concrete. Especially, the HRL-1.5 that having only 1 by 3 of the control concrete. It means that the exceeding latex is the major Parameter that affects to the water permeability of latex concrete. Since the Para rubber latex is an impermeable material, higher latex content should result in lower water permeability of concrete. However, too much latex content could affect to the uniformity of fresh concrete while mixing and could obstruct the binding between cement paste and aggregates as described previously. Then, the higher water permeability was observed as found in HRL-2.0. Fig 4 shows the relationship among compressive strength, water permeability coefficient, and percent replacement of Para rubber latex. It is found that even the HRL-0.5 has a higher compressive strength but it is not the lowest permeability mixture in the test. It means that the rubber particles mostly contained in concrete's closed voids those has not much effect to the pore structures inside concrete body. Then the water could pass through the HRL-0.5 sample similar to the control concrete. In turn, HRL-1.0 and HRL-1.5 had a higher latex content resulting in higher exceeding rubber particles. Those rubber particles distributed widely inside concrete resulted in the decreasing of water permeability. At the same time, those particles obstruct the binding between cement paste and aggregates. Then, the compressive strength reduction is found. The HRL-2.0 has too much latex content which not only affects to the uniformity of fresh concrete but also obstructs the binding between cement paste and aggregates as described previously. Then several pores were created and might be connected to each other. Consequently, both higher water permeability and lower compressive strength were observed. Anyway, the water permeability of HRL-2.0 is still lower than that of the control one.

Mixture	Control	HRL-0.5	HRL-1.0	HRL-1.5	HRL-2.0
Water permeability coefficient (m/s)	1.86E-12	2.20E-12	9.72E-13	6.37E-13	1.35E-12
Normalized (%)	100.0	118.3	52.3	34.2	72.6

Table 4 The water permeability coefficient results of all high strength concretes in the research

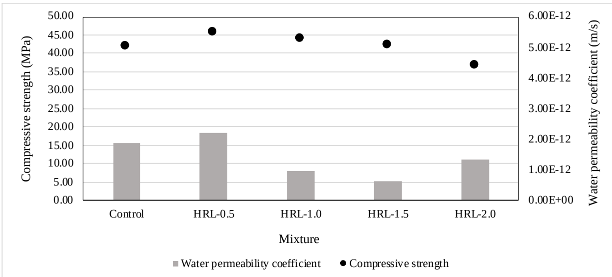

Fig. 4 The relationship between compressive strength and water permeability coefficient of high strength concretes containing Para rubber latex at the age of 28 days.

5. Conclusion

From the research it can be concluded that the concentrated Para rubber latex controls workability of fresh concrete. Higher latex content, lower slump found. Moreover, concrete containing the latex content of 0.5, 1.0, and 1.5 percent by weight of water show the higher compressive strength than the control high strength concrete for about 10, 5, and 0.5 percent, respectively. The compressive strength of latex concrete has a relationship to its elastic modulus in which the ACI 318 cannot fit suitably. This research proposes an equation having R-squared of 0.7 that fit for the high strength latex concrete. Furthermore, the concentrated Para rubber latex could reduce the water permeability of high strength concrete. The latex concrete with percent replacement of 1.5 shows a water permeability coefficient value of 1 by 3 of the control one. Hence, the Para rubber latex could be used as an ingredient for high strength concrete to increase compressive strength and reduce water permeability. Especially, for the replacement of 1.0 and 1.5 percent those have higher compressive strength and lower water permeability simultaneously.

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References

[1] T. Koichi, and H. Walter, "Polymer network formation in the pavement using SBR latex modified asphalt emulsions", *Studies in Surface Science and Catalysis*, vol. 132, pp. 271-274, 2001.

[2] P. Sharvin, R. M. H. Mohd, and P. J. Ramadhansyah, "Impacts of recycled crumb rubber powder and natural rubber latex on the modified asphalt rheological behavior, bonding, and resistance to shear", *Construction and Building Materials*, vol. 234, pp. -, 2020.

[3] J. Wongpa, and P. Thongsanitgarn, "Effect of Para rubber latex and coir on compressive strength, water absorption and volumetric change of adobe brick", *International Journal of Agricultural Technology*, vol. 14(7), pp. 2229-2240, 2018.

[4] J. Wongpa, S. Koslanant, W. Chalee, and P. Thongsanitgarn, "Effects of Para rubber latex on workability, compressive strength and water permeability of normal strength concrete", *Mahasarakham International Journal of Engineering*, vol. 7(1), pp.61-66, 2021.

[5] A. Moreno Bazán, J. Galvez, E. Reyes, and G. L. Lamuela, "Study of the rust penetration and circumferential stresses in reinforced concrete at early stages of an accelerated corrosion test by means of combined SEM, EDS and strain gauges", *Construction and Building Materials*, vol. 184, pp. 655-667, 2018.

[6] P. Cady and R. Weyers, "Chloride penetration and the deterioration of concrete bridge decks", *Cement, Concrete and Aggregates*, vol. 5(2), pp. 81-87, 1983.

[7] ASTM International. ASTM C143 / C143M-20: Standard Test Method for Slump of Hydraulic-Cement Concrete. *ASTM International*, 2020.

[8] ASTM International. ASTM C150 / C150M-20: Standard Specification for Portland Cement. *ASTM International*, 2020.

[9] ACI Committee 211. Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1-91) Reapproved 2002. *American Concrete Institute*, 2020.

[10] ASTM International. ASTM C192 / C192M-19: Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. *ASTM International*, 2019.

[11] ASTM International. ASTM C39 / C39M-21: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. *ASTM International*. 2021.

[12] W. Sanawung, T. Cheewaket, W. Tangchirapat, and C. Jaturapitakkul, "Influence of palm oil fuel ash and W/B ratios on compressive strength, water permeability, and chloride resistance of concrete", *Advances in Materials Science and Engineering*, vol. -, pp. -, 2017.

[13] N. Kakhuntodd, P. Chindaprasirt, C. Jaturapitakkul, and S. Homwuttiwong, "The investigation of water permeability of high volume pozzolan concrete", *Journal of Science and Technology Mahasarakham University*, vol. 31(5), pp. 563-570, 2012.

[14] J. Wongpa, K. Kiattikomol, C. Jaturapitakkul, and P. Chindaprasirt, "Compressive strength, modulus of elasticity, and water permeability of inorganic polymer concrete", *Materials and Design*, vol. 31, pp. 4748-4754, 2010.

[15] J. Bu, and Z. H. Tian, "Relationship between pore structure and compressive strength of concrete: Experiments and statistical modeling", *Sãdhanã*, vol. 14(3), pp. 337-344, 2016.

[16] ACI Committee 318. Building Code Requirements for Structural Concrete (ACI 318-95) and Commentary (ACI 318R-95). *American Concrete Institute*, 1995.

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