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EFFECT OF CRUMB RUBBER ON CONCRETE STRENGTH AND CHLORIDE ION PENETRATION RESISTANCE

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Abstract

This paper present the effect of crumb rubber on its ability to produce concrete with structural strength when it was used directly from the plant without any treatment process. Crumb rubber was added as fine aggregates at 0%, 10%, 15% and 20% of sand volume meanwhile silica fume was added at 10% by cement weight. Three main series of concrete namely rubberized concrete with water-to-cement ratio of 50% and 35% was design and development of compressive strength was observed from day 7 until 91 days. Also, effectiveness of crumb rubber under flexural strength and splitting tensile strength was studied at 28 days curing age. Effect of crumb rubber on durability performance was done on chloride ion penetration resistance performance by migration test and by immersion in salt water. Chloride ion diffusion in rubberized concrete by migration test was carried out under steady state condition using effective diffusion coefficient, D_e meanwhile, immersion test in salt water was conducted under non-steady state condition using apparent diffusion coefficient, D_a. Results showed that compressive strength was decrease with the increasing of crumb rubber in the mixture. Even though the strength were reducing with the inclusion of crumb rubber, the reduction were less than 50% and it achieved acceptable structural strength. Chloride transport characteristics were improved by increasing amount of CR and rubberized concrete with w/c = 0.35 gave better resistance against chloride ion compared to w/c = 0.50 with more than 50% difference. Silica fume provide slightly strength increment compared to normal rubberized concrete and the same behavior was observed during chloride ion diffusion test.

Keywords: Waste utilization, crumb rubber, silica fume, strength, chloride ion penetration

Abstrak

Kertas kerja ini membentangkan keupayaan getah untuk menghasilkan konkrit dengan kekuatan struktur apabila ia digunakan secara terus dari kilang tanpa sebarang proses rawatan. Getah dimasukkan ke dalam konkrit sebagai batu baur halus sebanyak 0%, 10%, 15% dan 20% dari isipadu pasir manakala wasap silika ditambah sebanyak 10% dari berat simen. Tiga siri utama konkrit yang dinamakan konkrit bergetah dengan nisbah air-kepada-simen 50% dan 35% telah direkabentuk dan peningkatan kekuatan mampatan dipantau dari hari ke -7 sehingga 91 hari. Juga, keberkesanan getah untuk menanggung beban lenturan dan beban belahan dikaji pada 28 hari umur pengawetan. Kesan getah terhadap prestasi ketahanlasakan telah dijalankan menerusi rintangan penusukan ion klorida menggunakan ujian pemindahan dan rendaman dalam air garam. Penusukan ion klorida ke dalam konkrit melalui ujian pemindahan telah dijalankan di bawah keadaan steady state menggunakan pekali resapan yang berkesan, De manakala, ujian rendaman dalam air garam dijalankan di bawah keadaan non-steady state menggunakan pekali resapan jelas, Da. Keputusan menunjukkan kekuatan mampatan berkurang dengan peningkatan getah di dalam campuran. Walaupun kekuatan berkurangan dengan kemasukan getah ke dalan konkrit, pengurangan ini tidak lebih daripada 50% dan ia mencapai kekuatan struktur yang boleh diterima. Ciri-ciri pengangkutan klorida telah bertambah baik dengan peningkatan jumlah getah dan konkrit bergetah dengan w/c=0.35 memberikan rintangan terbaik terhadap ion klorida berbanding w/c=0.50 dengan perbezaan sebanyak 50%. Wasap silika memberikan sedikit pertambahan kekuatan mampatan berbanding konkrit bergetah normal dan tingkah laku yang sama telah dilihat semasa ujian penyebaran ion klorida.

Kata kunci: Penggunaan sisa; getah; wasap silika; kekuatan; penusukan ion klorida

1.0 INTRODUCTION

The corrosion of reinforcing steel in concrete due to chloride transport in concrete structures in aggressive environment has received increasing attention in recent years because of its wide spread occurrence and the high cost of repair. The steel in concrete is protected by an oxide passive film generated in highly alkaline environment, although the corrosion cell is fully composed: cathodic molecules such as moisture and oxygen, anode, electrolyte and electric circuit. However, a build-up of chloride at the depth of steel accompanied by a local fall in the pH of the pore solution depassivates the protection film prior to steel corrosion [1]. To prevent the chloride permeation into concrete, the use of proper material which can minimize chloride transport to steel reinforcement is introduced.

One of the solution suggested is the use of waste tire rubber as partial replacement of fine aggregate. It was claimed that the addition of fibrous rubber to concrete improved shock wave abrasion, reduced heat conductivity and noise level, and increase resistance to acid rain. Moreover, the inclusion of small waste tire rubber cubes into concrete results in higher resilience, durability and elasticity. Hence, this paper proposed the use of waste tire rubber as concrete constituent namely as rubberized concrete to increase the durability of concrete structure in aggressive environment.

On the other hand, one of the major environmental challenges the world is facing now is the increasing piles of waste tires which is not easily biodegradable even after a long period of landfill treatment. If this number of waste is not controlled it will lead to environmental hazard. The accumulation of used tires at landfill sites also presents the threat of uncontrolled fires, producing a complex mixture of chemicals harming the environment and contaminating soil and vegetation. This is considered as one of the major environmental challenge the world is facing. Research has shown the utilization of these waste tires as concrete material (rubberized concrete) might improve the concrete characteristics. Study reported by G. Senthil Kumaran, Nurdin Mushule and M. Lakshmipathy in 2008 listed the advantages of rubberized concrete over ordinary concrete where it has good water resistance with low absorption, improved acid resistance, low shrinkage, high impact resistance, and excellent sound and thermal insulation

By using recycle tire rubber as concrete replacement materials; the most beneficial potential for the use of industrial by-product is the environmental values. This efforts will not only benefits to the government in reduction of providing land for disposal, but also increase the economy growth in various sectors especially amongst construction industry. Hence, the successful use of waste tire in concrete could provide one of the environmentally responsible and economically viable ways of converting this waste into valuable resource.

2.0 CONCRETE MATERIALS

The used tire rubber was classified as crumb rubber with size range between 1mm to 3mm and density of 1170kg/m^3 as shown in Figure 1. In this research, the special value of CR was that, it was used directly as received from recycled plant without any washing procedure or chemical treatment in producing structural strength rubberized concrete and good resistance against chloride ion migration and wear. Meanwhile, the 10% of silica fume, SF was added as binder in order to study the combination performance of CR with mineral admixture. Other concrete materials are presented in Table 1.

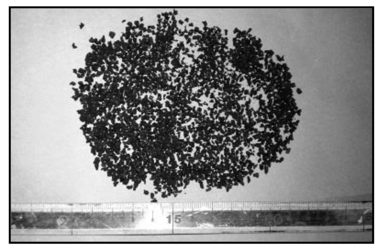

Figure 1 Crumb rubber (CR)

Table 1 Other concrete material

Component	Physical properties	
Ordinary Portland Cement	Density, kg/m^3	3160
Silica fume	Density, kg/m^3	2200
Fine Aggregate	Density, g/cm^3 (SSD condition)	2580
	Water absorption (%)	1720
	Fineness modulus	2770
Coarse Aggregate	Density, kg/m^3	2910
Ether-based polycarboxylate superplasticizer	Density, kg/m^3 at 20°C	1070
Air entraining agent	Density, kg/m^3	1040
Anti-foaming agent	Density, kg/m^3	1000

3.0 MIX DESIGN AND SPECIMEN PREPARATION AND TESTING PROCEDURES

3.1 Mix Design

CR was added in the concrete as sand replacement by volume using Equation 1 at 0%, 10%, 15% and 20%. Three (3) groups of water-to-cement ratio, w/c was prepared; Group 1 presenting w/c of 50% without SF, Group 2 was w/c of 35% without SF and Group 3 was w/c of 35% with SF as shown in Figure 2 and Table 2.

$$Percentage\ CR\ replacement = \frac{V_{CR}}{V_S - V_{CR}} \qquad \text{Eq.1}$$

Aggregates used was under surface saturated dry condition, SSD. Coarse aggregates size was divided into two (2) namely G_1 for 20mm aggregate and G_2 for 10mm aggregates. To make sure that bonding between aggregate and cement paste was in good condition, all aggregates was washed to remove impurities on aggregates surface.

All concrete mixing was done in 20°C controlled room according to JIS R 5201-1997 Physical Testing Method for Cement. In the process of mixing, coarse aggregate was firstly added in the mixing drum, followed by OPC and sand. As for series with SF, SF and OPC was pre-mixed in the plastic bag before added in the mixing drum. Meanwhile, CR was added alternately with sand until all sand and CR completed added. All these materials were dry mixed and after 30 seconds water was added and continued for additional 90 seconds. Then, the mixing drum was stop for manual mixing. Finally, when all the materials were ensured well mixed, the mixing drum was finally continued for 60 seconds which makes total mixing time was 3 minutes. Fresh rubberized concrete were casted in cylindrical steel mold with size of 100mm diameter and 200mm length for 7, 28, 56 and 91 water curing days for compressive strength test, 28 days for splitting test, chloride ion migration test and abrasion test. Meanwhile, for flexural test, specimen were prepared in 100mm x 100mm x 400mm length of prism size and tested after 28 days of water curing.

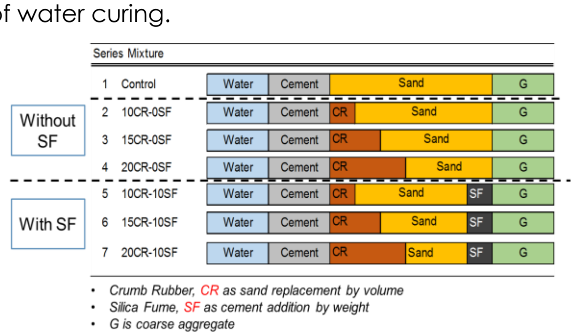

Figure 2 Series of rubberized concrete mix for water-to-cement ratio 0.35

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3.2 Chloride Ion Penetration Test

3.2.1 Chloride Ion Migration Test

For chloride ion migration test, cylindrical sample were cut into 100mm diameter x 50 mm thickness. Test was carried out according to JSCE-G571-2003; Test Method for Effective Diffusion Coefficient of Chloride Ion in Concrete by Migration to measure chloride ion migration from cathode towards the anode through the pore solution of rubberized concrete under the influence of 15V constant voltage as shown in Figure 3. When the increment rate of chloride ion in the anode side became constant, it was assumed as steady state condition and effective diffusion coefficient, D_e was calculated by using Nernst-Planck Equation[3], as in Eq. 2 and Eq. 3.

$$D_e = \frac{J_{Cl} R T L}{|z_{Cl}| F C(\Delta E - \Delta E_C)}\ x\ 100 \qquad \text{Eq.2}$$

where, D_e is effective diffusion coefficient in cm²/year, R is gas constant = 8.31 J/mol K, T is absolute temperature in K units, Z_{Cl} is charge of chloride ion = -1, F is Faraday constant = 96,500 C/mol, C_{Cl} is measured chloride ion concentration in cathode side in mol/l units, ΔE-ΔEc is electrical potential difference between specimen surfaces in V units and L is length of specimen in mm. J_{cl} is the flux of chloride ions in steady state and calculated using elow equation

$$J_{cl} = \frac{V^{II}}{A}\frac{\Delta c^{II}_{Cl}}{\Delta t} \qquad \text{Eq. 3}$$

where V^{II} is the volume of anode side in L unit, A is cross section of specimen and $\Delta c^{II}_{Cl}/\Delta t$ is rate of increase in chloride ion concentration on anode side in (mol/l)/year.

3.2.2 Chloride Diffusion Coefficient by Immersion in Salt Water

Under this testing, specimens were immersed in salt water for certain period. According to JSCE-G572-2003, Test for Apparent Diffusion Coefficient of Chloride Ion in Concrete by Immersion in Salt water [4], the submerged period can be in 3 months, 6 months, 9 months and 12 months [3]. However in this research 3 months was selected due to the time restriction. It is estimated that for normal Ordinary Portland cement concrete with w/c = 0.50 and 3 months submergence period, the chloride ion penetration depth is around 3cm to 5cm and it will decreased with the decreasing of w/c ratio.

A cylindrical concrete specimen from each mix was cut into two approximate equal heights at middle part. Basically the size of specimen was around ø100 mm x 100 mm height and were kept to dry before pretreated process. Under dry condition, specimen was coated with epoxy resin except for the one circular end face should be left uncoated.

Table 2 Mix proportion of rubberized concrete

Group	CR/(S+CR)	SF/C	w/c	Water	Cement	Silica Fume	Sand	Crumb Rubber	Coarse Aggregates	
				W	C	SF	S	CR	G1	G2
	(Vol %)	(%)		kg/m^3						
Control	0	0	0.50	165	330	0	790	0	636	329
10CR-0SF	10						711	35		
15CR-0SF	15						671	53		
Control	0	0	0.35	160	457	0	741	0	608	405
10CR-0SF	10						667	34		
15CR-0SF	15						629	50		
20CR-0SF	20						594	67		
10CR-10SF	10	10	0.35	160	457	46	613	34	608	405
15CR-10SF	15						575	50		
20CR-10SF	20						540	67		

This uncoated face shall be at inner circular part of the specimen. The epoxy resin was dried in the 20^{0}C room and to ensure full epoxy hardening, JSCE-G572-2003 suggests to keep it dry for four days. After hardening, specimen was stored in container with water for at least 24 hours. Finally, it was immersed in 10% sodium chloride, NaCl solution and uncoated surface remains in full contact with the solution. The spacing between two uncoated surfaces should be at least 3 cm or more and it was placed horizontally to avoid any sedimentation of impurities on the uncoated surface. 10% of NaCl was calculated using Eq. 4 below,

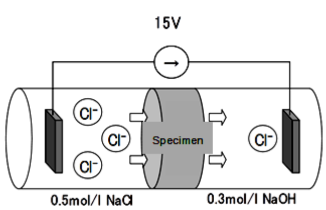
$$\frac{\text{NaCl (kg)}}{\text{Weight of solution(kg)+NaCl (kg)}} = 10\% \qquad \text{Eq. 4}$$

After three months of submergence, specimens were dried and split into two. It was then sprayed with 1/10N silver nitrate, $AgNO_3$ solution to measure the penetration depth of the chloride ion as shown in Fig. 4.8. Then, from the uncoated surface, an increment of 0.5 cm slices were cut, and five slices was obtained which makes total cutting depth was 2.5 cm. By using disk mill machine, all slices were powdered and kept in the sealed plastic bag before proceeding to the next process. Finally, this concrete powder undergoes the heating and vacuum process and the final product was in solution condition. Apparent diffusion coefficient D_{ap} was calculated using Eq. 5 and Eq.6 below

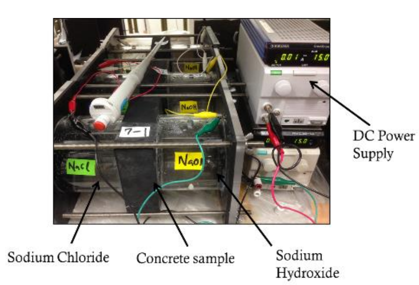
$$C(x,t) - C_i = C_{ao}\left\{1 - erf\left(\frac{x}{2\sqrt{D_{ap}\cdot t}}\right)\right\} \qquad \text{Eq. 5}$$

where, x is depth from uncoated surface to location of chloride ion content measurement (cm), t is the immersed period in year, C(x,t) is measured total quantity of chloride ion per unit mass of concrete at distance x and immersed period t (%), Ci is initial value of total quantity of chloride ion per unit mass of concrete in percentage, D_{ap} is apparent diffusion coefficient in cm^2/year and *erf* is the error function which can be calculated using Eq. 4.5 below

$$erf\,(s) = \frac{2}{\sqrt{\pi}}\int_0^s e^{-\eta^2}\,d\eta \qquad \text{Eq. 6}$$



(a) Schematic diagram



(b) Experimental setup

.**Figure 3** Migration cell

4.0 RESULTS AND DISCUSSION

4.1 Hardened Properties

4.1.1 Development Of Compressive Strength

Compressive strength for 7, 28, 56 and 91 days for both mixed with and without SF is presented in Figure 4 and Figure 5. A systematic strength increment can be seen in all mixes. At 28 days, strength for 20% CR addition without SF was more than 40N/mm^2, and when compared with the control mix which was almost 70N/mm², reduction of strength by crumb rubber was about 43%. This strength reduction became lesser when 10% and 15% of CR replacement. The mechanism of strength reduction was discussed by Moncef Nehdi [5] where three possible reasons were discussed; firstly the rubber is much softer than the cement paste, secondly rubber may be viewed as voids in concrete mix thus it gave weak bonding between the rubber particles and cement paste and thirdly due to the density, size and hardness of the aggregates. From this result, method of this rubberized concrete study can be assumed as simple way in producing rubberized concrete with satisfied strength. Meanwhile, addition of 10% SF slightly increase the mechanical strength and improve the strength reduction for about 10-15%, and, strength was kept increasing until 91 days. Meanwhile, Figure 6 presents the stress-strain curve of rubberized concrete with and without silica fume.

4.1.2 Evaluation Of Compressive Strength With Pore Volume

Evaluation is made based on data collected by Rita in 2013 [6] on the relationship between compressive strength (y) and total pore volume (x) (see Figure 7). The relationship is shown as following Eq. 7.

$$y = -79.79\ln(x) + 264.26 \qquad \text{Eq. 7}$$

From this Eq. 7, total pore volume of 0CR – 0SF is calculated as 11.59% for compressive strength of 69MPa. When 10%CR is added, the strength is 56.52MPa then total pore volume is calculated as 13.51%. Replacement of 15% CR decrease the compressive strength to 50.46MPa, then corresponding total pore volume is 14.56% and strength was decreased to 43.81N/mm² with the inclusion of 20%CR, and corresponding of total pore volume of 15.86%. Here, to evaluate the compressive strength reduction of rubberized concrete, a concept of the equivalent total pore volume is adopted. Equivalent total pore volume for 10%CR is 1.92% (13.51% - 11.59%), 15%CR is 2.97% (14.56% - 11.59%) and 20%CR is 4.27% (15.86% - 11.59%).

4.1.2 Flexural Strength And Splitting Tensile Strength

Figure 8 and Figure 9 shows the 28 days of flexural and splitting tensile strength for all mixes. The presence of CR in the mixture reduced both flexural and tensile strength slightly with CR addition for each mixes with and without SF. It is clearly seen that the strength reduction was less than 10% compared to control mix and it was implied that the reduction was much smaller than that in compressive strength. However, substitution of 10% SF in the mixed helped to improve the bonding between cement paste and CR, where flexural and splitting tensile strength showed higher strength compared with control mix.

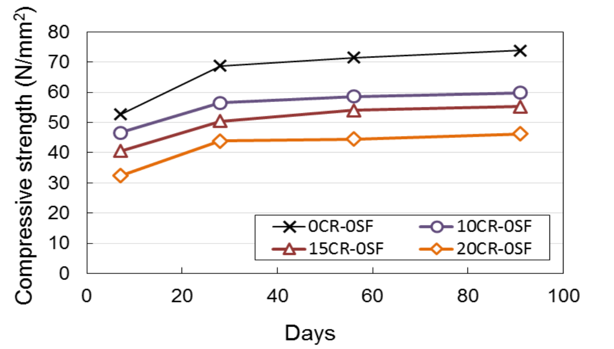


Figure 4 Strength development of rubberized concrete without silica fume

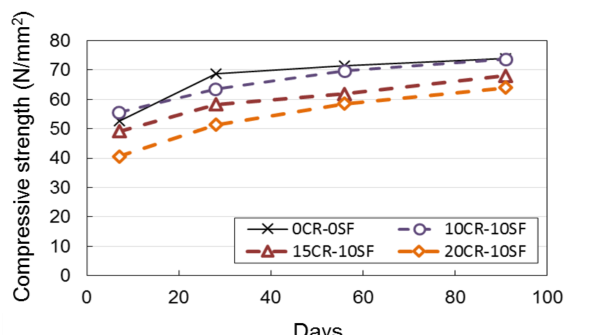


Figure 5 Strength development of rubberized concrete with 10% silica fume

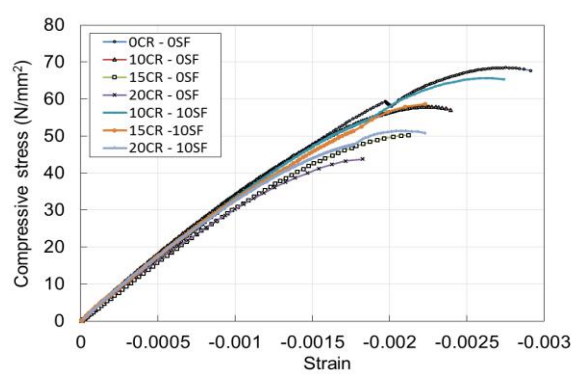


Figure 6 Stress-strain curve of rubberized concrete with and without silica fume

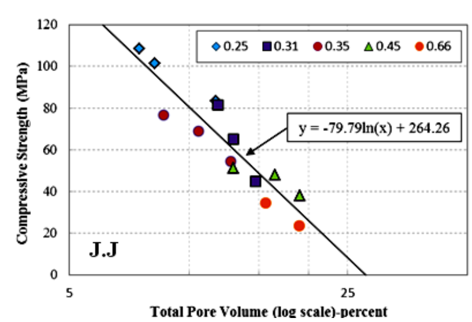


Figure 7 Relationship between compressive strength (y) and total pore volume (x)[6]

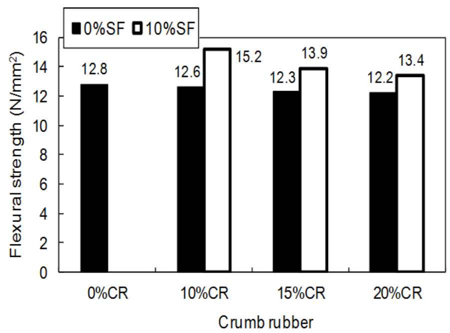


Figure 8 Flexural strength of rubberized concrete at 28 days

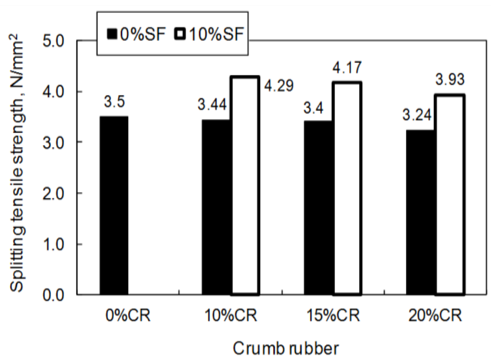


Figure 9 Splitting tensile strength of rubberized concrete at 28 days

4.2 Chloride Ion P0enetration

4.2.1 Effective Diffusion Coefficient Of Chloride Ion Under Steady State Condition, D_e

Results of chloride ion migration in concrete are shown in Figure 10, Figure 11 and Figure 12. In all mixes, D_e reduction was clearly seen where mixture with CR produced lower D_e compared to mixture without CR. Additional SF as the binder gave extra advantages in minimizing the amount of chloride ion to migrate from cathode to the anode side. By replacing some portion of sand volume with CR in the mixture for w/c of 0.50, almost 50% of D_e reduction was observed. In contrast to the mix having w/c of 0.35, D_e was decreasing but slightly small in comparison with normal concrete. The same pattern can be seen in mix with silica fume. In addition, the amount of the binder in the mixture plays an important role in providing resistance against chloride ion. This was presented in w/c of 0.50 and w/c of 0.35 where the D_e was 1.538cm^2/year and 0.434cm^2/year respectively for normal concrete. This show it decreased more than 50%. As for compressive strength, even though it decreased with the increasing amount of CR in the mix, results gave good durability showing that the amount of porosity percentage was small hence producing durable concrete against chloride ion attack.

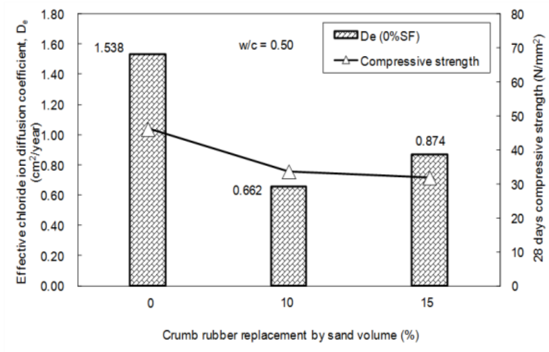


Figure 10 Effective chloride ion diffusion coefficients and compressive strength at 28 days of rubberized concrete (w/c = 0.50)

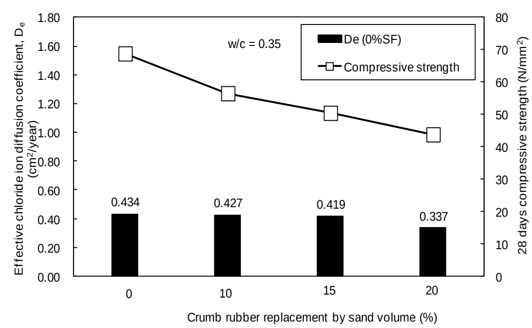


Figure 11 Effective chloride ion diffusion coefficients and compressive strength at 28 days of rubberized concrete (w/c = 0.35 without silica fume)

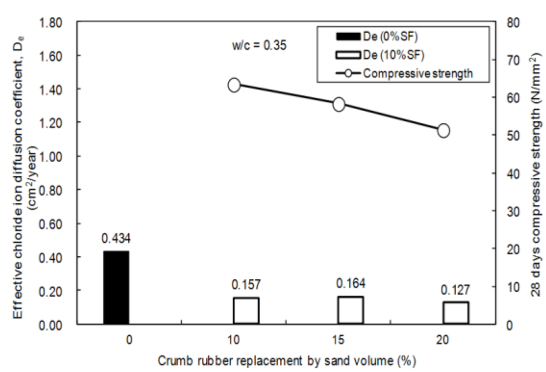


Figure 12 Effective chloride ion diffusion coefficients and compressive strength at 28 days of rubberized concrete (w/c = 0.35 with silica fume)

4.2.2 Apparent diffusion coefficient of chloride ion under non-steady state condition, D_a

Chloride ion profile at every 50mm depth is presented in Figure 13, Figure 14 and Figure 15. Basically, chloride content is larger at the nearer uncoated surface and it begins to reduce when it is getting deep. This behavior was observed in all mixture with and without CR in the mix. As for mixture with w/c = 0.50, chloride ion content ranging between 18 kg/m^3 to 20kg/m^3 at 0.50cm from the surface and it reduced to around 8-6kg/m^3 at 1.0 cm depth. Meanwhile for mixture with w/c = 0.35, chloride ion content is between 14kg/m^3 – 12kg/m^3 and addition of silica fume reduced the chloride ion content to 12kg/m^3 – 10kg/m^3.

Apparent diffusion coefficient, D_a result is presented in Figure 16. A clear behavior of D_a can be seen from this figure. Water-to-cement ratio of 0.50 has larger D_a compared to 0.35 water-to-cement ration and the reduction was almost 70%. When 10% of CR was added in the mixture, value of D_a is decreasing slightly. The presence of silica in the mixture provides low apparent diffusion coefficient.

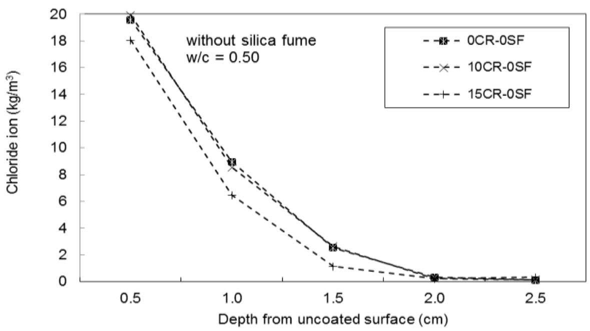


Figure 13 Chloride ion versus depth from surface for w/c = 0.50

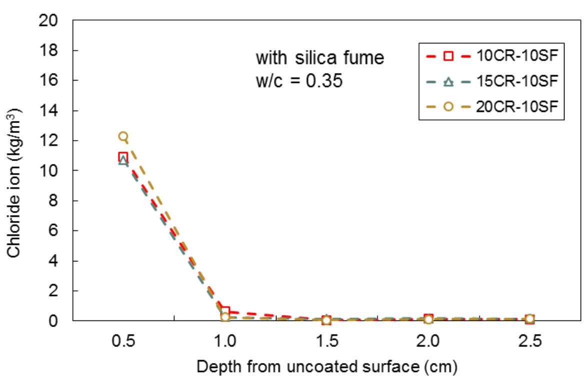


Figure 14 Chloride ion versus depth from surface for w/c = 0.35 (without silica fume)

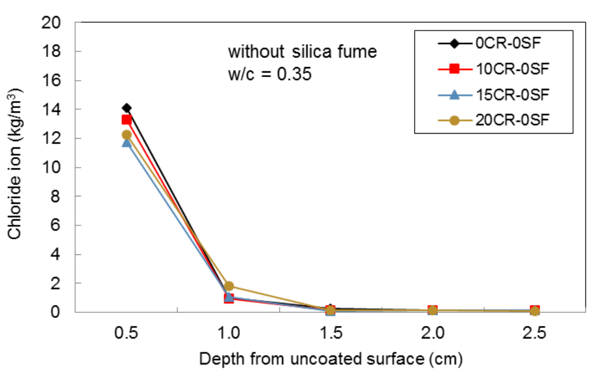


Figure 15 Chloride ion versus depth from surface for w/c = 0.35 (with silica fume)

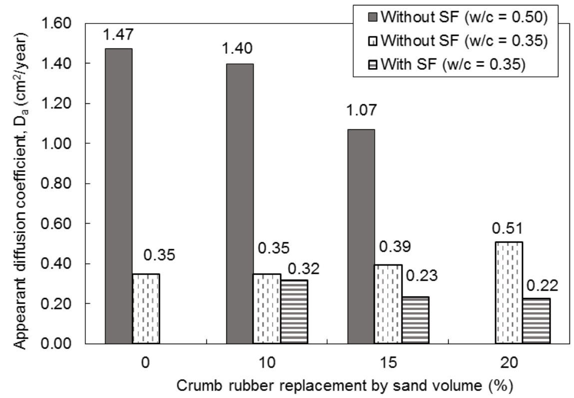


Figure 16 Apparent diffusion coefficient, D_a by percentage of crumb rubber replacement

4.2.3 Effect of crumb rubber and silica fume on chloride ingress, and relationship between D_a and D_e

The highest resistance of chloride ion migration through concrete was clearly seen when SF was used as additional binder for about 60-65% reduction compared to control mix (referring to mix with w/c = 0.35). This may be due to the ultrafine particle of SF which allowed it to fill the voids between cement particles and aggregate particles [4]. Good filling of concrete paste lead to the reduction of porosity and provide dense concrete. This was agreed by Omar S. Baghabra Alamoudi et al. on their studies that the significant reduction of chloride ion ingress in concrete in silica fume cement concrete may attributed to the formation of secondary calcium silicate hydrate (C-S-H) by the pozzolanic reaction. This reaction reduces the pores, leading to a dense microstructure and therefore reducing the amount of diffusion of chloride ion into concrete [5]. It was great practical importance to learn due to this reduction which it may gave positive response to the corrosion of embedded reinforcement.

In terms of crumb rubber, the ability of crumb rubber to repeal water has improved the chloride ion transport characteristics even though the strength was reducing. By referring to the literature, both strength and chloride transport characteristics are linked to the pore structure of the rubberized concrete [6]. Thus, this relationship shows that even though the strength was reduced, the positive improvement in chloride ion migration resistance indicates that the pore structure of the rubberized concrete was still under accepted level. This behavior was clearly seen when 10% SF was added in the rubberized mixed

Figure 17 shows the relationship between D_a and D_e for all rubberized concrete mix. When line of equity is constructed, it is clearly seen that D_a was larger than that D_e. This may due to the longer exposed period of specimen with chloride ion during D_a test. For three months of immersion in salt water, chloride ion penetrated into the concrete and the larger amount of chloride accumulated on the uncoated surface. This chloride ion then form as compound when react with ongoing hydration process. Meanwhile, as for D_e test, chloride is penetrated directly into the two uncoated surface from cathode towards anode. During the test, chloride ion did not reacts with the hydration process thus it provides smaller chloride ion compared to D_a test. However, it can be observed that there was no difference between D_a and D_e for mix with w/c = 0.35 without SF.

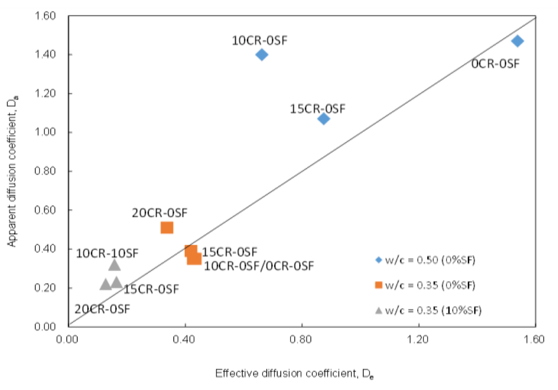


Figure 17 Relationship between D_a and D_e

5.0 CONCLUSION

Due to the low density of crumb rubber, compressive strength reduction of 43% was observed in 20% crumb rubber. Compressive strength reduction was improved 10-15% when 10% silica fume was added. From the strength result, it can be concluded that by using simple mixing method, structural strength can be achieved and it indicates the success of the objective. As for chloride ion penetration test, crumb rubber has good potential in improving the chloride ion ingression resistance into concrete. Strength reduction is certainly negative property when crumb rubber is added in the concrete, however positive effect was observed on chloride ion transportation into concrete indicates that concrete pores was under acceptable range. Chloride transport characteristics were improved by increasing amount of CR due to the fact that CR has ability to repel water. Addition of 10% silica fume improved the resistance of rubberized concrete against chloride ion penetration due to the dense cement matrix hence reducing the pore of cement paste. Mix with w/c = 0.50 gave larger chloride ion diffusion coefficient value compared to the mixture with w/c = 0.35. Rubberized concrete can be designed for some structure with normal compressive strength and can provide good resistance against chloride ion penetration.

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