-Technical Paper-

STRENGTH CHARACTERISTICS AND EFFECTIVE CHLORIDE DIFFUSION COEFFICIENT OF RUBBERIZED CONCRETE

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ABSTRACT

In this study, crumb rubber was used as fine aggregate at 10%, 15% and 20% sand volume replacement to produce rubberized concrete with satisfied compressive strength. Rubberized concrete was tested on its fresh properties, mechanical strength and effective diffusion coefficient of chloride ion. In addition, silica fume as 10% of cement was added to investigate the effect on the strength and resistance against chloride penetration. Results shows mechanical strength reached to the acceptable value for satisfied strength as structural concrete and chloride ion resistance was improved with silica fume.

Keywords: Rubberized concrete, strength, air content, chloride ion diffusion coefficient

1. INTRODUCTION

The worldwide increase in used tyre which is biodegradable industrial waste is expected with increasing population of man and traffic which developed environmental problems. According to the European Association of Tyres and Rubber Producer, 3.2 millions of used tyre in 2009 were retreated and reused, recycled and used for energy production [1].

In concrete performance, utilization of used tyre as concrete components has been studied since 1990`s in terms of strength characteristics and durability. The utilization of this material is important to decrease the negative impact to the environment. On the other hand, the use of de-icing salt in cold country, could lead to penetration of chloride ion into the concrete pores which can cause a problem if it reached steel reinforcement. Corrosion of steel reinforcement makes the structure distress and high cost of maintenance and repair are required to overcome this problem. In the worst case, it could lead to the structural collapse.

Thus, this research was conducted to produce concrete with satisfied strength using simple way of materials preparation and mixing procedure. In addition, this concrete, named as rubberized concrete could give good resistance against chloride ion penetration into the concrete. This will give benefits to structure in aggressive environment such as marine environment and structure exposed to high chloride ion.

2. SPECIMEN PREPARATION AND TESTING

2.1 Crumb rubber as fine aggregates

Crumb rubber (CR) is by-product produced from used tyre of vehicles. The size of CR ranges between 1-3mm with density of 1.17g/cm^3 as shown in Fig.1. The presence of rubber in the mix cause almost 85% of strength reduction which lead to various ways to increase the strength by either washing the rubber or pre-coating the rubber [2]. Thus, in this research, the CR was used directly as received from recycled plant without any washing procedure in producing rubberized concrete.

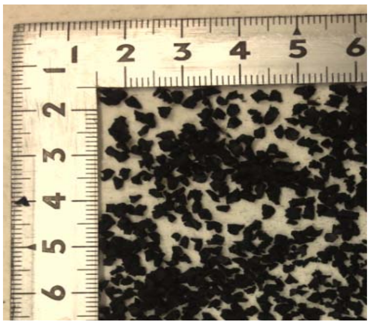

Fig. 1 Crumb rubber

2.2 Other concrete mix components

Ordinary Portland cement (OPC) was used as the main binder and silica fume (SF) was added at 10% weight of OPC in several mixes to investigate the effect on strength development. Sea sand passing 5mm sieve with density of 2.58 g/cm^3 and water absorption of 1.72 % which was less than 3.5% as stated in JIS standard was used as fine aggregate. Meanwhile, crushed stone with 20mm maximum size was used as coarse aggregate. All aggregate were prepared under surface saturated dry condition. As for workability, ether-based polycarboxylate superplasticizer was added at 0.5%-0.7% of 5% maximum allowable dosage. Air content was controlled by using air-entrained agent (to increase air content) for mixing without SF and air-modifying agent (to reduce air content) for mixing

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with SF. Table 1 shows details of physical properties of concrete mix components.

2.3 Selection of water to cement ratio

Mortar mixing was firstly conducted in order to determine suitable water to cement ratio for rubberized concrete mix. Four group of w/c of 0.25, 0.30, 0.35 and 0.40 were conducted. From mortar mixing, it was found that w/c of 0.40 achieved low compressive strength thus in further study, other w/c (0.25, 0.30, 0.35) with addition of silica fume were mixed [3].

From this initial study, w/c of 0.35 was chosen for concrete mixture in terms of fresh properties control, satisfied compressive strength and flexural strength. In addition, testing on resistance against abrasion of the mortar showed good correlation between the abrasion resistance and compressive strength for w/c = 0.35.

Table 1 Physical properties of materials

Component	Physical properties	
Ordinary Portland Cement	Density, g/cm^3	3.16
Silica fume	Density, g/cm^3	2.20
Crumb Rubber	Density, g/cm^3	1.17
Fine Aggregate	Density, g/cm^3 (SSD condition)	2.58
	Water absorption (%)	1.72
	Fineness modulus	2.77
Coarse Aggregate	Density, g/cm^3	2.91
Ether-based polycarboxylate superplasticizer	Density, g/cm^3 at 20^{o}C	1.07
Air entrained agent	Density, g/cm^3	1.04
Air-modifying agent	Density, g/cm^3	1.00

Table 2 Mix proportion of rubberized concrete

Series	CR/(S+CR)	SF/C	w/c	Water	Cement	Silica Fume	Fine Aggregate	Crumb Rubber	Coarse Aggregate		Chemical Admixture		
				W	C	SF	S	CR	G1	G2	Ether-based polycarboxylate superplasticizers	Air-entrained agent	Air modifying agent
	(Vol.%)	(%)		kg/m^3							%	%	%
Control	0	0	0.35	160	457	0	741	0	608	405	0.5	0.8	
10CR-0SF	10						667	34			0.5	0.8	
15CR-0SF	15						629	50			0.7	0.8	
20CR-0SF	20						594	67			0.7	0.7	
10CR-10SF	10	10	0.35	160	457	46	613	34	608	405	0.7		1.5
15CR-10SF	15						575	50			0.7		2.2
20CR-10SF	20						540	67			0.7		2.8

2.4 Mix design and specimen preparation

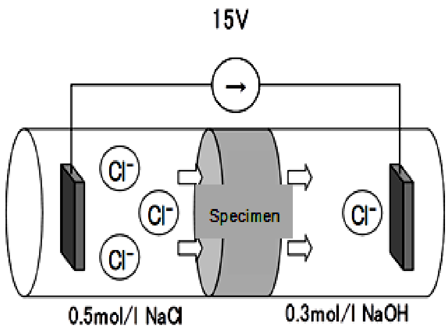
Four series of rubberized concrete without SF and three series of rubberized concrete with SF was prepared as shown in Table 2. From previous research, 50% strength reduction was the maximum strength target, thus, in this research; a simple way of mixing procedure was introduced with the target compressive strength for mixes with CR was set to be 50% with respect to the control mix in order to achieve strength under excepted structural strength.

All concrete mixing was done in 20^{o}C controlled room. Coarse aggregate was firstly added in the mixing drum, followed by OPC and sand. As for series with SF, SF and OPC were pre-mixed in the plastic bag before added in the mixing drum. Meanwhile, CR and sand were mixed sufficiently until all sand and CR completely added. All these materials were dry mixed and after 30 seconds, water was added and continued for additional 90 seconds mixing. Then, the mixing drum was stopped for the hand mixing. When all materials were ensured as well mixed, mixing drum was finally continued for 60 seconds, and then total mixing time became 3 minutes.

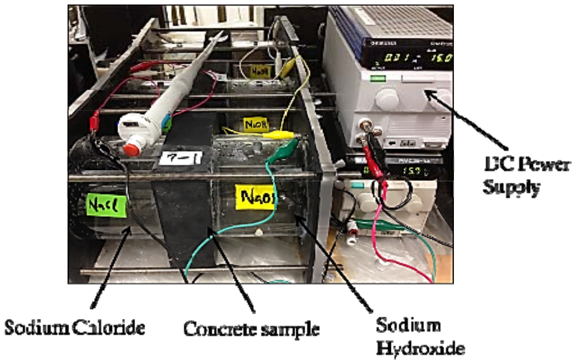
2.5 Testing procedure

In this research, air content was set as ranging from 4% to 5%. Fresh rubberized concrete were casted in cylindrical casting-metal mold with size of 100mm diameter and 200mm length, followed by water curing for 7, 28, 56 and 91 days, then compressive strength test was done. At 28 days, splitting tensile test and chloride ion migration test was prepared. Meanwhile, for flexural test, specimen was prepared in 10cm x 10cm x 40cm size prism specimen, and water cured until 28 days.

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 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 Fig. 2. When the increment rate of chloride ion in the anode side becomes constant, it is assumed as steady state



(a) Schematic diagram



(b) Experimental setup

Fig. 2 Migration cell

condition and effective diffusion coefficient, D_e was calculated by using Nernst-Planck Equation [4],

$$D_e = \frac{J_{Cl}RTL}{|Z_{Cl}|FC_{Cl}(\Delta E - \Delta E_c)} \times 100 \qquad (1)$$

where, D_e is effective diffusion coefficient in cm^2/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.

3. RESULT AND DISCUSSION

3.1 Fresh properties

Air content and concrete slump result are presented in Table 3. As mentioned above, the only controlled parameter in this research was the air content ranging from 4%-5%. Air content could be controlled as 4 -5%, by using air-entraining agent for mix without SF, and air-modifying agent for mix with SF.

Meanwhile, it was difficult to control the slump value in CR mixed concrete both for non SF mix and SF mix. From the previous research [5], it was predicted that the slump is decreased when CR is added, thus dosage of chemical admixture was increased up to 0.7%. The same behavior was observed in this experiment. The control of slump is still problem when mixing crumb rubber concrete.

Segregation was controlled by reducing the amount of water and increasing the cementitious materials and aggregate for w/c = 0.35. Meanwhile, the use of superplasticizer which was specially designed for the low w/c, helps to prevent segregation or drying of the mixture.

Table 3 Fresh properties of rubberized concrete

Mixture series	Air content (%)	Slump (cm)
Control	4.7	7.0
10CR-0SF	5.1	6.0
15CR-0SF	4.5	19.5
20CR-0SF	4.0	19.5
10CR-10SF	4.2	10.0
15CR-10SF	4.1	9.0
20CR-10SF	4.2	15.5

3.2 Hardened properties

Compressive strength for 7, 28, 56 and 91 days for both mixed with and without SF is presented in Fig. 3 and Fig.4. 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, on the other hand, control mix was almost 70N/mm^2 where 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 [6] 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 result of the compressive strength test, the method of mixing used in this experiment was categorized as simple way in producing rubberized concrete with satisfied strength.

Meanwhile, addition of 10% SF in all rubberized concrete slightly increased the mechanical strength and improved the strength reduction for about 10-15%. And, strength was still increased until 91 days.

Fig 5 and Fig 6 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 as with CR addition for each mixes with and without SF. It was clearly seen that the strength reduction was less than 10% compared to control mix and it was implied that this reduction was much smaller than that in compressive strength; where the reduction was more than 10%. However, substitution of 10% SF in the mixed helped to improve

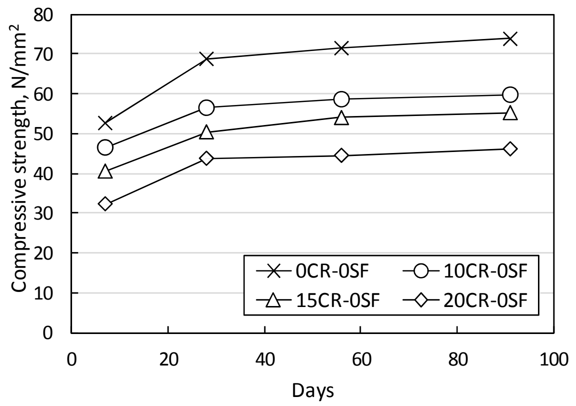


Fig. 3 Strength development of rubberized concrete without silica fume

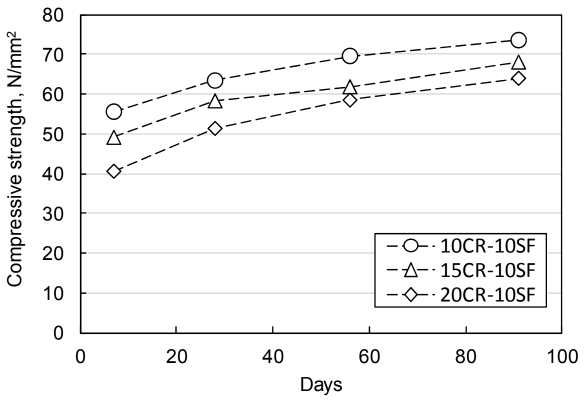


Fig. 4 Strength development of rubberized concrete with 10% silica fume

the bonding between cement paste and CR, where flexural and splitting tensile strength showed higher strength compared with control mix.

3.3 Effective chloride ion diffusion coefficient, D_e

Fig. 7 and Fig 8 shows the relationship between D_e and 28 days compressive strength of rubberized concrete for all mixes. From this figure, it was found that CR could gave benefits in providing resistance on chloride ion migration through the concrete. The same pattern can be observed when SF was added in the mixture.

The highest resistance in chloride ion migration through concrete was clearly seen when SF was used as additional binder for about 60-65% reduction compared to control mix. This may be due to the ultrafine particle of SF which allowed it to fill the voids between cement particles and aggregate particles [7]. Good filling of concrete paste lead to the reduction of porosity and provide dense concrete.

Referring to the literature, both strength and chloride transport characteristics are linked to the pore structure of the rubberized concrete [8]. 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.

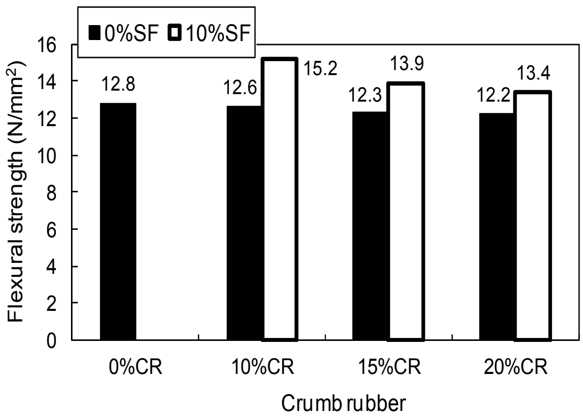


Fig. 5 Flexural strength of rubberized concrete at 28 days

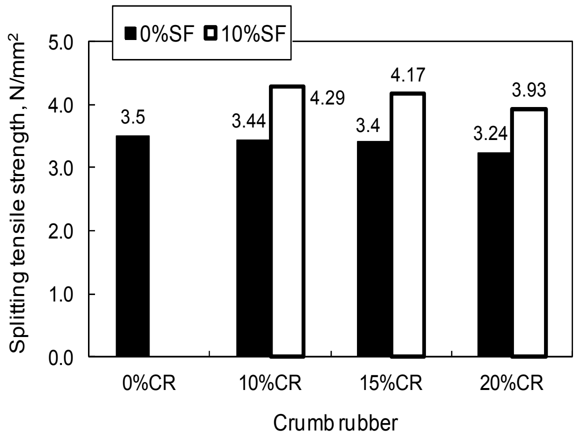


Fig. 6 Splitting tensile strength of rubberized concrete at 28 days

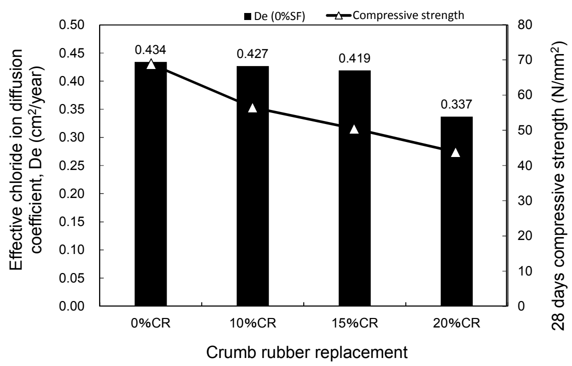


Fig. 7 Relationship between effective chloride ion diffusion coefficients and compressive strength at 28 days of rubberized concrete without silica fume

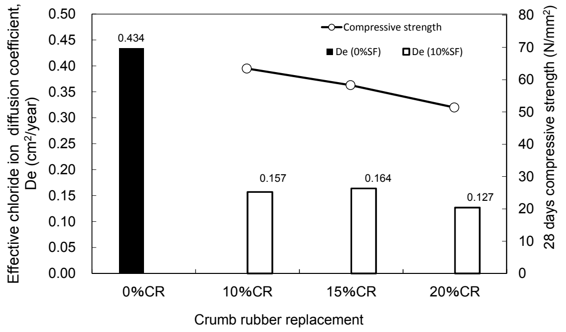


Fig. 8 Relationship between effective chloride ion diffusion coefficients and compressive strength at 28 days of rubberized concrete with silica fume

4. CONCLUSION

From this research, several conclusions can be drawn as follows,

1. Addition of CR and silica fume in the mixture makes air content control in concrete very difficult. Thus, selection and usage of air-modifying agent was important to make air content in concrete as 4-5%.
2. Increment of crumb rubber in the mixture decrease the workability behavior for both rubberized concrete with and without silica fume.
3. Due to the low density of crumb rubber, compressive strength reduction of 43% was observed in 20% crumb rubber mixed without silica fume and this reduction was improved when silica fume was added.
4. Addition of 10% SF improved the resistance of rubberized concrete against chloride ion. And also CR addition reduced chloride ion migration coefficient of concrete.
5. Chloride transport characteristics were improved by increasing the amount of CR due to the fact that CR has the ability to repel water.

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