Moderate Lightweight Concrete Mixed with Recycled Crumb Rubber

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Abstract

This study provided the test results on the mechanical and physical properties of lightweight concrete obtained by replacing portions of the conventional fine aggregate with crumb rubber from recycling waste tires. The mechanical properties were compressive and flexural strength. The physical properties were unit-weight, permeable voids, thermal conductivity and sound absorption. Results indicated that the unit-weight of crumb rubber concrete was lower than that of plain concrete. The decrease was found to be proportional with the crumb rubber content. In addition to the decrease in unit-weight, the crumb rubber concrete also exhibited better sound and thermal properties. However, due to the low strength and stiffness of rubber, the mechanical properties of crumb rubber concrete appeared to be lower than that of plain concrete.

Keywords : Moderate Lightweight Concrete, Crumb Rubber, Thermal and Sound Properties

1. Introduction

With a unit-weight of about 2400 to 2500 kg/m^3, concrete is quite a heavy material. That is why the self-weight of concrete becomes significant in concrete structures. In general, there are two approaches to produce lighter concrete: 1) by replacing normal weight aggregate with light-weight aggregate and 2) by inserting uniformly dispersed air bubbles into concrete (cellular or aerated concrete). The typical densities of lightweight concrete according to ACI 213R-87 are between about 300 to 1800 kg/m^3 with compressive strength ranged from 7 to 17 MPa.

This study was an attempt to produce a lightweight concrete using light-weight aggregate in the form of crumb rubber to replace fine aggregate. The project was funded by the Thailand Research Fund with an objective to produce moderated light weight concrete with density lower than 2000 kg/m^3 and having compressive strength at least 18 MPa, and also exhibiting better sound absorption and thermal properties.

The crumb rubber obtained from the recycling plant in Thailand was produced by grinding recycled vehicle tires into small particles. Two sizes of the crumb rubber were used: No. 6 (passing ASTM sieve no. 6) and No. 26 (passing ASTM sieve no. 26). The gradations of the crumb rubber were quite uniform and within the same range to that of fine aggregate.

In general, the least polluted and cheapest way to decompose wasted tires is by dumping them on empty land. However, this indirectly creates several problems, as they become fire hazards and insect or animal habitation areas (Fig. 1). During the last 20 years, several research projects have been carried out in an attempt to reuse the abandoned tires by grinding them into small particles (rubber crumb) for use in asphalt, sealants, rubber sheets or in cementitious materials like concrete.

Fig. 1 Piling Yard of Abandoned Tires in Thailand

Several studies[1-14] indicated that the presence of crumb rubber in concrete seems to lower the mechanical properties (compressive and flexural strength) as compared to that of conventional concrete. The lowering in strength is mainly due to the poor strength of crumb rubber. The decrease in strength is found to be directly proportional to the rubber content. The size of rubber crumb also appears to have an influence on the strength. Coarse grading of rubber crumbs lowers the compressive strength more than the finer grading.

Results from this study indicated that the mechanical properties of the crumb rubber concrete were lower than that of plain concrete. However, there was some improvement of other properties such as: lower unit-weight and absorption, lower thermal conductivity, better sound absorption and noise reduction coefficient.

2. Experimental Procedure

2.1 Materials

Materials used in this study consisted of Portland cement type I, 3/8"coarse aggregate, river sand, crumb rubber (Fig. 2), water and superplasticizer Type F (13 cc/1 kg of cement). Two particle sizes of crumb rubber were used: No. 6 (passing ASTM sieve no. 6) and No. 20 (passing ASTM sieve no. 20), the properties and gradation [15] of both crumb rubbers are given in Table 1 and Fig.3.

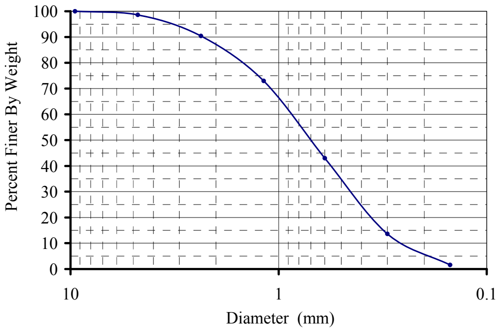
(a)

(b)

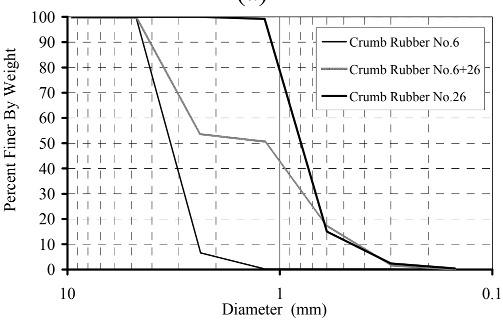
Fig. 2 Crumb rubber (a) No. 6 and (b) No. 26

Table 1 Properties of Crumb Rubber

Categories	No.6	No.26	No. 6+26
Average Bulk Specific Gravity	0.96	0.62	0.77
Average Bulk Specific Gravity (SSD)	0.97	0.62	0.78
Average Apparent Specific Gravity	0.97	0.62	0.78
Average Absorption (%)	0.92	1.05	0.95
Fineness Modulus	4.93	2.83	3.77



(a)



(b)

Fig. 3 Gradation of (a) Fine Aggregate and (b) Crumb Rubber

The mix proportion for the control specimen (no crumb rubber) was set at 1.00:0.47:1.64:1.55 (Cement: Water: Fine Aggregate: Coarse Aggregate). In the case of lightweight concrete, crumb rubber No.6, No.26 and combined No.6+26 were used to replace fine aggregates at 10%, 20% and 30% by weight. Details and assigned designations of each mix are given in Table 2.

2.2 Casting and Testing the specimen

First, the concrete was dry-mixed using a pan mixer for about 5 minutes. Then, water was added and mixing was continued for another 5 minutes. After that, it was cast into different types of specimens according to the test programs (Table 3). Six different tests were carried out: 1) Slump Test (ASTM C143-98) [16], 2) Density and Voids (ASTM C642-97)[17], 3) Compression Test (ASTM C39)[18], 4) Flexural Test (ASTM C293)[19], 5) Steady-State Heat Flux Measurement and Thermal Transmission Properties (ASTM C177)[20] and 6) Acoustics Determination of Sound Absorption Coefficient and Impedance in Impedance Tube (ISO 10534-1:1996)[21].

Table 2 Details and Assigned Designations

Designation	w/c ratio	Weight per m^3					
		Crumb Rubber (kg)		C (kg)	CA (kg)	FA (kg)	W (kg)
		No.6	No.26				
PC	0.47	0	0	479	742	784	225
6 CR 10	0.47	78	0	479	742	706	225
6 CR 20	0.47	157	0	479	742	627	225
6 CR 30	0.47	235	0	479	742	549	225
626 CR 10	0.47	39	39	479	742	706	225
626 CR 20	0.47	78	78	479	742	627	225
626 CR 30	0.47	118	118	479	742	549	225
26 CR 10	0.47	0	78	479	742	706	225
26 CR 20	0.47	0	157	479	742	627	225
26 CR 30	0.47	0	235	479	742	549	225

Table 3 Casting Schedule

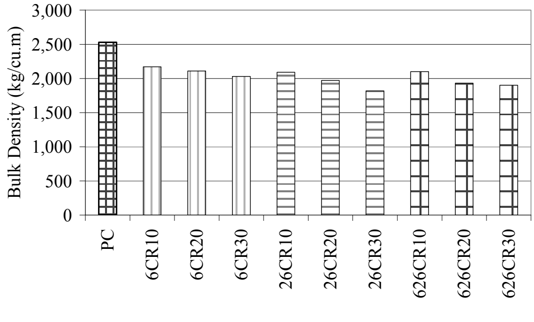
Type	Number of specimen				
	Comp	Flex	Density	Thermal	Sound
PC	3	3	3	2	8
6 CR 10	3	3	3	2	8
6 CR 20	3	3	3	2	8
6 CR 30	3	3	3	2	-
626 CR 10	3	3	3	2	8
626 CR 20	3	3	3	2	8
626 CR 30	3	3	3	2	-
26 CR 10	3	3	3	2	8
26 CR 20	3	3	3	2	8
26 CR 30	3	3	3	2	-
Total	30	30	30	20	56

Note: All specimens were tested at the age of 28 days

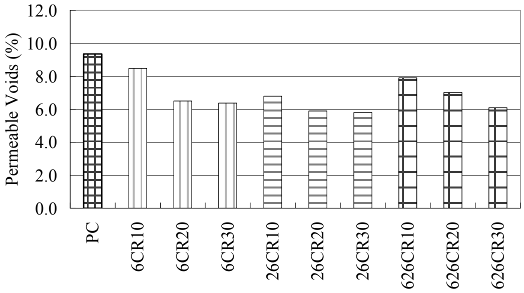
3. Experimental Results

3.1 Density, Absorption and Voids

In all cases, the bulk density of all CR (crumb rubber) lightweight concretes was found to be less than that of normal concrete (Fig. 4a). The average bulk density of CR lightweight concrete was in the range of 1800-2100 kg/m^3 depending on the rubber type and content, while the bulk density of normal concrete was about 2530 kg/m^3. Also, the bulk density appeared to decrease gradually with the increase in rubber content. Logically, since the specific gravity of crumb rubber was markedly less than that of fine aggregate, by replacing portions of the fine aggregate with crumb rubber, it resulted in concrete with lighter density.



(a)



(b)

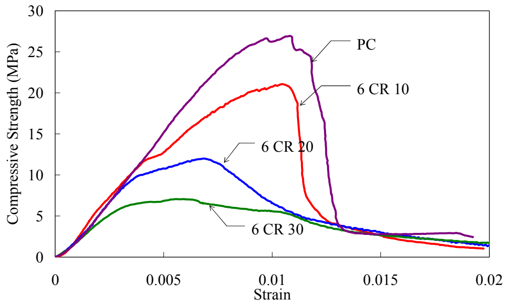
Fig. 4 (a) Bulk Density and (b) Permeable Voids

In the case of the permeable void (Fig. 4b), the effect of the crumb rubber seemed to be opposite to that of other light-weight aggregates. In general, the permeable void of the conventional light-weight aggregate concrete is substantially high because of the high porosity of the aggregates. However, when using crumb rubber, the permeable void was found to decrease slightly and progressively with the rubber content. This could be because the crumb rubber is not a porous material; in contrast, it is quite dense. Therefore, after being mixed and compacted properly, the concrete should exhibit slightly lower voids.

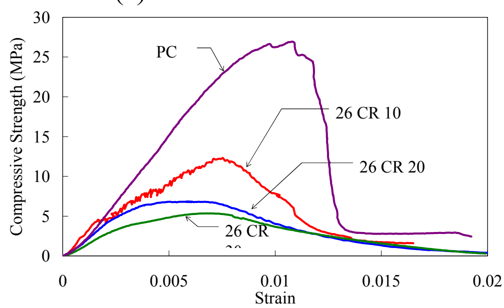
3.2 Compressive Strength and Response

Depending on the type and the content of crumb rubber, the compressive strength of all CR lightweight concrete was found to be less than that of plain concrete (Table 4). In terms of the content, the compressive strength appeared to decrease with the increase rubber content. A replacement rate of 10% seemed to be the best ratio of all three ratios with the strength ranged from 44% to 75%. At higher replacing rate (more than 20%), the compressive strength decreased significantly to about 19% to 43%. One reason is because the strength of the crumb rubber particle is far less than that of normal aggregate. By replacing the conventional fine aggregate with crumb rubber, it unquestionably provided negative effect to the strength of the CR concrete.

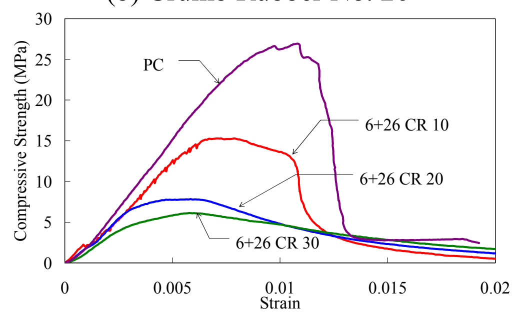
The compressive responses of both plain and crumb rubber concrete are given in Fig. 5. Results indicated that the response of concrete was, in fact, changed gradually from brittle to more flexible response as seen by the decrease in the stiffness and strength, and the longer post-peak response. This effect can be seen more clearly in the response of concrete under flexural load.



(a) Crumb Rubber No. 6



(b) Crumb Rubber No. 26



(c) Crumb Rubber No. 6+26

Fig. 5 Compressive Responses

Table 4 Compressive Strength

Type	Compressive Strength (MPa)	Percentage compared to PC
PC	28.2	100.0
6CR10	21.1	74.7
6CR20	12.0	42.5
6CR30	7.1	25.0
26CR10	12.3	43.6
26CR20	6.8	24.2
26CR30	5.4	19.0
626CR10	15.3	54.2
626CR20	7.8	27.8
626CR30	6.1	21.7

3.3 Flexural Strength

Results on the flexural strength in form of the modulus of rupture (MOR) are given in Fig. 6. Similar to the case of the compressive strength, the flexural strength of concrete was found to decrease proportionally with the rubber content. The flexural strength of CR lightweight concrete was found to be in between 29% to 65% of that of plain concrete.

The flexural responses of CR lightweight concrete were also more flexible as seen by the decrease in stiffness and strength, and the increase in deflection at the peak load (Fig. 7). Given that crumb rubber is a highly flexible and elastic material, the presence of crumb rubber increases the flexibility in the concrete response. However, the lack of a conventional fine aggregate was directly resulted in the loss of strength, similar to the case of the compression.

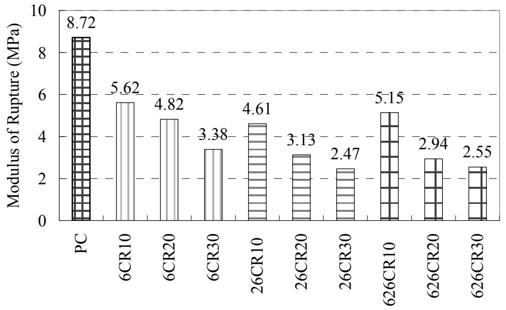


Fig. 6 Modulus of Rupture

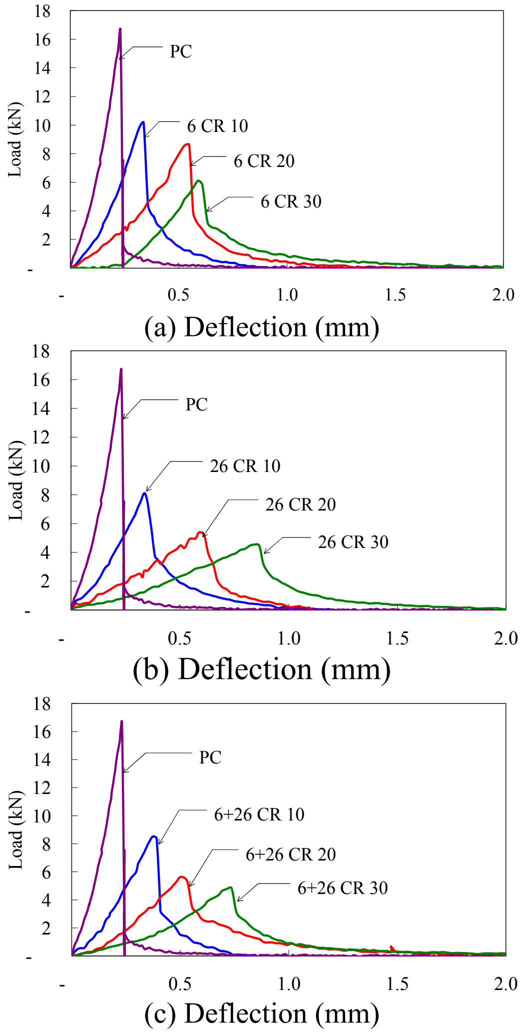


Fig. 7 Flexural Responses

3.4 Thermal Conductivity

Results indicated that the CR lightweight concrete was essentially a better thermal barrier than plain concrete as seen by the decrease of the coefficient of thermal conductivity (K-value) with the increase rubber content. Compared to the K-value of plain concrete at 0.531 W/m.K, the K-value of CR lightweight concrete ranged from 0.241 to 0.443 W/m.K (Fig. 8). Theoretically, the thermal conductivity is directly proportional to the density of the material[22]. Since the density of the CR lightweight concrete was found less than that of plain concrete, it was also expected to inhibit a smaller K-value.

Compared to Thailand Industrial Standard (TIS), The TIS specifies that the conventional lightweight concrete should have a limited K-value in the range of 0.303 to 0.476 W/m.K. The K-values of most of the CR lightweight concrete obtained from this study were found to be less than those specified by TIS.

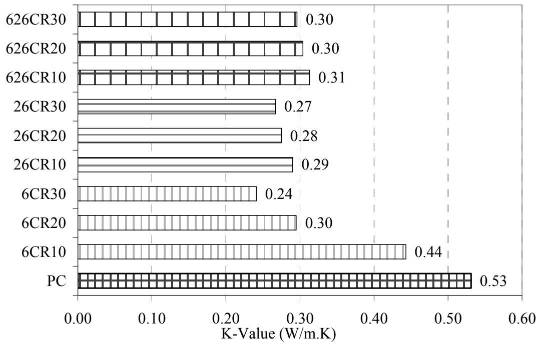


Fig. 8 Thermal Conductivity (K)

3.5 Sound Absorption

The ability of material to absorb sound can be measured in the form of the sound absorption coefficient (α). In this study, the sound absorption of the CR lightweight concrete was measured under two different ranges of frequency: 1) Low frequency (125, 250 and 500 Hz) and 2) High frequency (1000, 2000 and 4000 Hz).

The ability to absorb sound at both frequency ranges of both plain and CR concrete are given in Fig. 9 and 10. Apparently, the CR lightweight concrete seemed to have superior sound absorption properties to that of plain concrete, though this could not be seen clearly at the low frequency range. As seen in Fig. 10, at the lowest frequency ranges of 125 and 250 Hz, both plain and CR concrete exhibited similar α-values. However, at the top frequency of the low range (500 Hz), the CR concrete began to show slightly higher α-values. This was the first indication of the CR concrete as a better sound absorber at the high frequency range. At a frequency higher than 1000 Hz, the ability to absorb sound at this range of all CR lightweight concrete was found to be much better than that of plain concrete (Fig. 10).

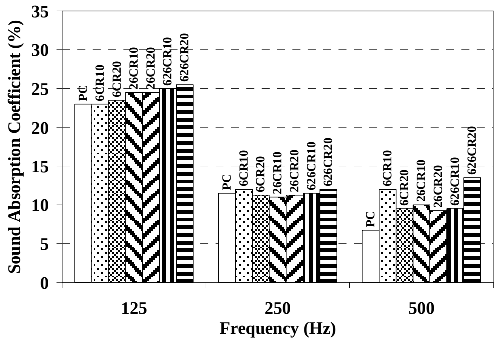


Fig. 9 Sound Absorption Coefficient at Low Frequency

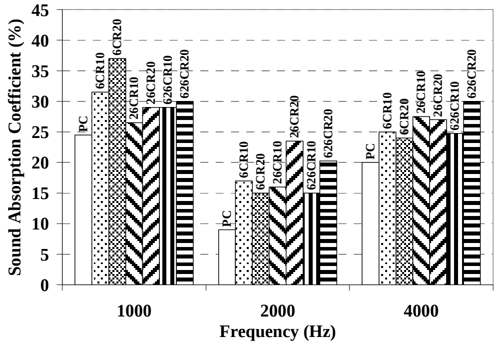


Fig. 10 Sound Absorption Coefficient at High Frequency

However, indicating the sound properties of materials using the α-values at different range of frequency could be complicated sometimes because it involved several numbers at different frequency range. To simplify this, the ability of material to absorb sound can be indicated using one single value called the noise reduction coefficient (NRC). The NCR can be calculated using the following formula.

$$NCR = (\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000})/4$$

Results from the calculation shown in Fig. 11 clearly indicated that CR concrete, in fact, had better sound properties than plain concrete. The average noise reduction was about 36% higher.

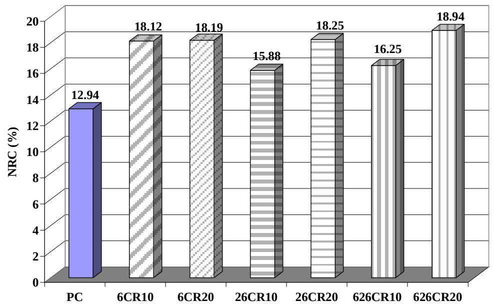


Fig. 11 Noise Reduction Coefficient

4. Conclusions

1. There is a possibility to produce a structural lightweight concrete by replacing fine aggregate with crumb rubber with a compromise between the mechanical properties (compressive and flexural strength) and other properties such as the unit-weight, the thermal and sound absorption. However, the ratio of replacing should not excess 10%; otherwise the strength would become too low.
2. By replacing conventional fine aggregate with crumb rubber, the unit-weight of concrete can be reduced from 14% up to 28% depending on the type and the content of the crumb rubber.
3. The lack of conventional fine aggregate and the presence of the crumb rubber appear to downgrade the mechanical properties of concrete, as seen by the decrease of both compressive and flexural strength. The decrease is varied from 25% to 81%.
4. The CR concrete exhibits superior thermal and sound properties compared to plain concrete, as seen by the decreased thermal conductivity coefficient (K) and the increased sound absorption coefficient (α) and noise reduction coefficient (NRC).

5 Acknowledgement

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