Concrete Pedestrian Block Containing Crumb Rubber from Recycled Tires

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Abstract

In this study, the properties of concrete pedestrian block mixed with crumb rubber were investigated. Crumb rubber or reclaimed wasted tires particles have been studied widely for the last twenty years on several applications such as asphalt pavement, waterproofing systems, membrane liners etc. For this study, the crumb rubber was used as aggregate (to replace portions of coarse and fine aggregates at 10% and 20% by weight) in the manufacturing of concrete pedestrian block. Results from the laboratory indicated that the obtained crumb rubber concrete blocks were more skid resistant, more flexible and able to absorb more energy, and thus, able to provide softness to the surface (reduce risks of injury from tripping over). However, they appeared to have lower strength and lower resistance to abrasion (as compared to conventional concrete block). In addition to the laboratory test, the field test was also carried out for a 30-day period. The field performances in terms of skid and abrasion resistance were found to be slightly poorer than those obtained from the lab.

Keywords: Pedestrian Block, Rubber Crumb, Concrete, Skid Resistance, Abrasion Resistance

1. Introduction

Every year, large numbers of vehicle tires are used worldwide. In the year 2000 alone, approximately 250,000 metric-tons of rubber products were consumed in Thailand and about 38% of that (94,000 metric-tons) was vehicle tires [1]. Wasted or abandoned tires are not easy to decompose. The simplest way to get rid of them is by burning, but this method generates many problems and pollution (due to smoke). Therefore, the burning method is unacceptable and in some countries it is prohibited by law. An easier solution is to leave them piling up on empty lands (Fig. 1a), which indirectly generates several other problems because they simply turn into fire sources or insect and animal habits (Fig. 1b). Some were purged away by illegally shipping them aboard to other countries (as found in Thailand about two years ago, Fig. 1c).

Nowadays, several countries are able to come up with several new methods to recycle wasted tires. One method is to grind them into small particles called crumb rubber. Crumb rubber has been used in several applications such as: asphalt rubber, water sealer, rubber sheets [2-5] or in cementitious material like concrete [6-7].

In this study, we are attempting to use crumb rubber to replace parts of the aggregate to produce concrete pedestrian block. By using cement as a binder and the conventional way of producing cement block as a manufacturing process, the crumb rubber concrete block is expected to be more durable, less expensive (low material cost and easy to manufacture) and absorb higher energies. The experiments were carried out both in and outside the laboratory. In the laboratory, the investigation was mainly on the mechanical and physical properties of the block. In the field, the focus was on the durability properties.

(a) (b) (c)

Fig. 1 (a) Abandoned Tires Left Piling Up in Thailand, (b) Fire Accident at a 25-Million Tire Dump in Central Ohio's Wyandot County and (c) Wasted Tires Illegally Shipped to Thailand

2. Experimental Procedure

2.1 Manufacturing Crumb Rubber

The crumb rubber used in this study came in 2 particle sizes: No. 6 (passing sieve no. 6) and No. 20 (passing sieve no. 20). It is produced by grinding vehicle tires. The grinding process is carried out at one of the rubber reclaiming plants in Thailand. According to the manufacturer, there is a limitation on the grinding method in that it can only grind rubber. Therefore, for the whole tire, only the rubber parts are grindable, and parts of the tire consisting of steel radial are discarded. The first process is to cut and sort out the grindable parts. In the grinding process, rubber pieces are fed into the cutting wheel several times until the desired size is achieved. Finally, the crumb rubbers are sorted out and grouped together according to their particle size. The production process (Fig. 2) includes: 1) sorting the recyclable parts, 2) grinding process, and 3) sieving and grouping process.

2.2 Material Properties

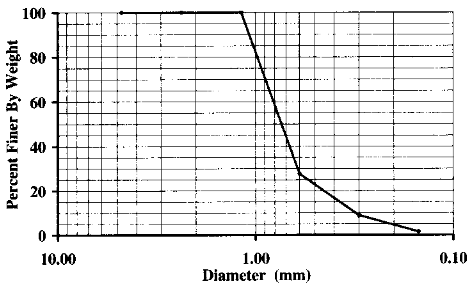
Materials used in this study were: 1) cement type I, 2) 3/8" coarse aggregate, 2) river sand, 3) crumb rubber and 4) water. As mentioned before, two particle sizes of crumb rubber were used (No. 6 and No. 20). Basic properties required for the mix design such as specific gravity, gradation and finess modulus of both crumb rubbers are shown in Table 1 and Fig.3.

(a) (b) (c) (d)

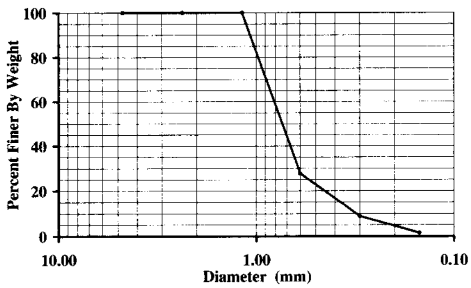
Fig. 2 Manufacturing Crumb Rubber a) Sorting, b) Grinding, c) Sieving and d) Final Product

Table. 1 Properties of Crumb Rubber

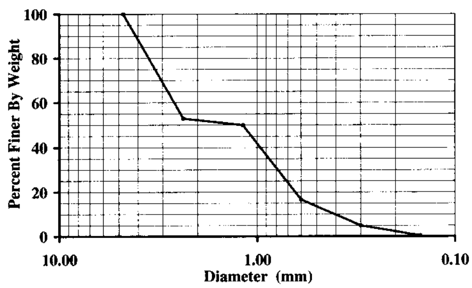
Categories	No.6	No.20	No. 6+20
Average Bulk Specific Gravity	0.97	0.88	-
Average Bulk Specific Gravity (SSD)	0.98	0.89	-
Average Apparent Specific Gravity	0.98	0.89	-
Average Absorption (%)	1.01	1.70	-
Finess Modulus	4.98	2.62	3.77



(a) No. 6



(b) No. 20



(c) No. 6+20

Fig. 3 Gradation of Crumb Rubber

Crumb rubbers are used to replace aggregate in two systems: single and combined type (i.e., No.6, No.20 and No.6+20, respectively) at 10% and 20% by weight. Details and assigned designations of each mix are given in Table 2.

The mix proportion for the control mix was set at 1:0.33:1.5:1.5 (Cement : Water : Coarse Agg. : Fine Agg.). In the case of crumb rubber concrete, the water requirement for each concrete-crumb rubber mix was varied to maintain the same consistency as shown in Table. 3.

Table. 2 Details and Assigned Designations of Crumb Rubber Mix

Designation	Rubber No. and Percentage	
	6	20
Control	0	0
610	10	-
620	20	-
2010	-	10
2020	-	20
62010	5	5
62020	10	10

Table. 3 Water Requirement for Rubber Crumb Concrete Block

Mix	% Rubber	Vebe Time (Second)	Required w/c Ratio
Control	0%	26	0.33
610	10%	28	0.35
620	20%	28	0.39
2010	10%	25	0.45
2020	20%	26	0.47
62010	10%	27	0.40
62020	20%	26	0.43

2.3 Manufacturing Concrete Block

In this study, the conventional block making practice was selected as a manufacturing process. The process was quick and simple. It started with placing the concrete into the mold (Fig. 4a), then compacting it with pressure (Fig. 4b), and finally removing the block for air curing (Fig. 4c and d). All blocks were air-dry cured for 28 days prior to the tests.

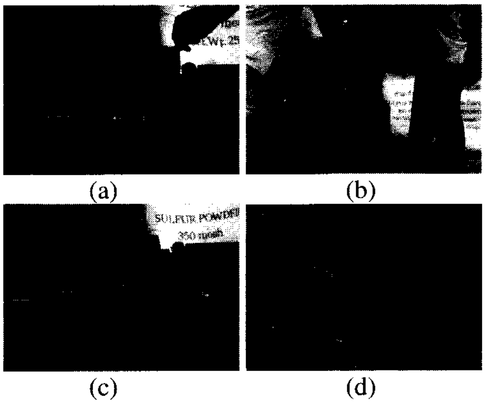


Fig. 4 Block Making Process

3. Testing Programs

3.1 Laboratory Tests

All four tests were carried out in the laboratory: 1) Compression Test (ASTM C39), 2) Flexural Test (ASTM C78), 3) Skid Resistance (ASTM E303) and 4) Abrasion Test (ASTM C944). The first three tests were done at the Department of Civil Engineering, King Mongkut Institute of Technology-North Bangkok and the last one at the School of Civil Engineering, Asian Institute of Technology, Thailand.

3.2 Field Tests

After finishing the laboratory tests, the blocks were subjected to a field test at the King Mongkut Institute of Technology-North Bangkok. The blocks were laid outside for about 3 months. Then, the abrasion (%weight loss) and skid resistance were measured.

4 Experimental Results

4.1 Mechanical Properties

The compression test revealed the effect of rubber type and content on both compressive strength and behavior at different rubber content. The strength and stiffness were found to decrease with an increase of crumb rubber content (Table 4 and Fig. 5). However in the case of energy absorption (area under load-deformation curve), the concrete blocks with crumb rubber exhibited better energy absorption capacity than those without rubber as seen by the larger specific energy density (Table 4) and the longer post-peak response (Fig. 5).

Table. 4 Average Compressive Strength and Fracture Energy Density

Mix	No. of Spec.	Strength (MPa)	Fracture Energy Density (MPa)
Control	3	36.00	0.25
610	3	19.96	0.32
620	3	5.58	0.19
2010	3	19.08	0.35
2020	3	5.40	0.21
62010	3	23.44	0.39
62020	3	7.85	0.24

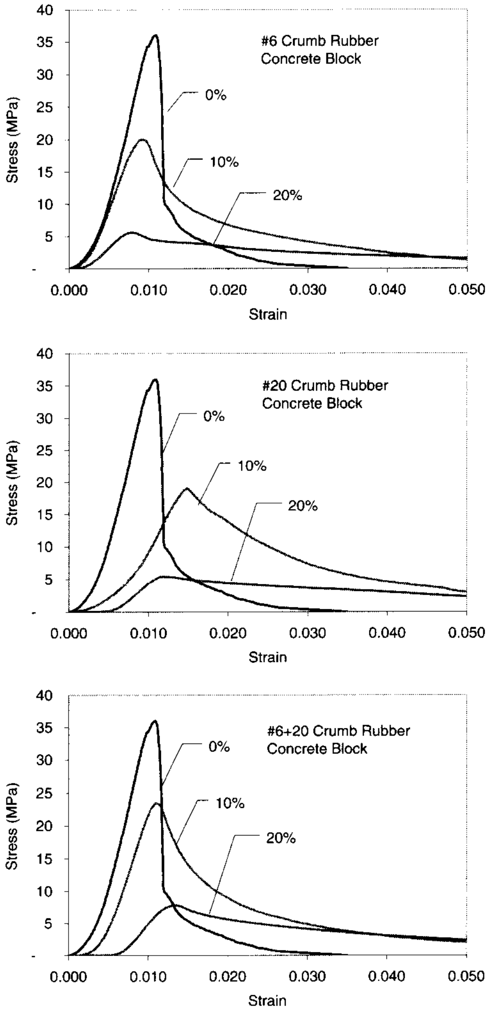


Fig. 5 Compressive Response of Crumb Rubber Concrete Block

The decrease in strength was partly because of the lack of aggregate due to the replacing of high strength and stiffness aggregate with low strength and highly elastic crumb rubber. However, the highly elastic properties of rubber helped increase the energy absorption capacity. Comparing between the three crumb rubber mixes, the block made from mixed rubber (No. 6+20) seemed to perform better than those made from a single rubber, type. This was perhaps due to the better gradation of the combined rubber, which allowed the concrete to have better packing and higher density.

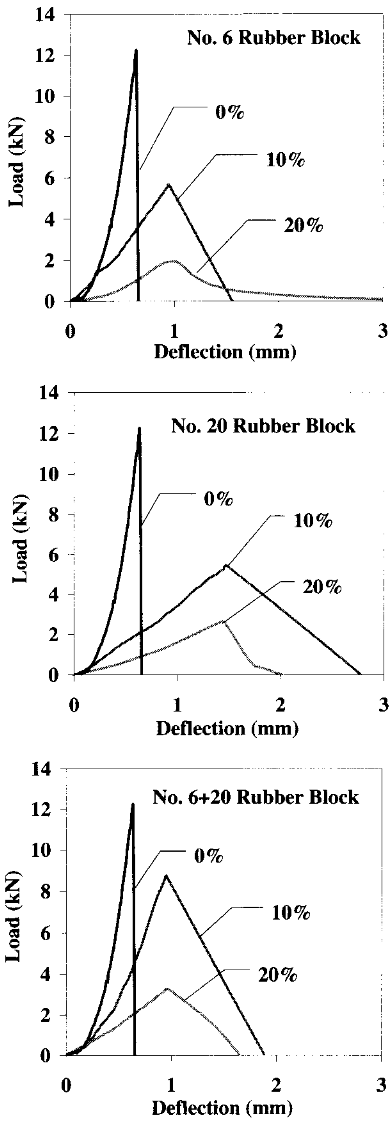


Fig. 6 Flexural Responses of Crumb Rubber Block

The flexural responses of concrete blocks are given in Fig. 6. Similar to the compressive test, the flexural strength of crumb rubber concrete blocks was found to be smaller than that of plain concrete block. However, the responses were found to be more flexible and tougher as seen by a larger deflection at peak load, longer post-peak response and higher fracture energy (area under load-deflection curve).

The fracture energy can be calculated from the area under the load-deflection curve up to the point of failure (Fig. 7). At 10%, the fracture energy of crumb rubber concrete was larger than that of plain concrete; this was due to the better and longer post-peak response (even though the strength was smaller). The larger fracture energy of crumb rubber concrete block indicated that the block was able to sustain loads at greater deflection and absorb larger energy after the concrete's first crack (peak load). However, at 20%, the strength of the crumb rubber concrete was quite low. As a result the fracture energy of crumb rubber blocks decreased significantly.

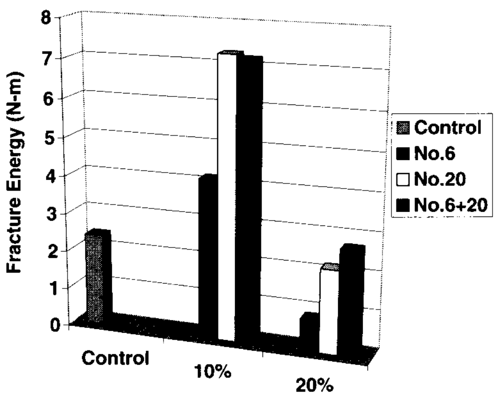


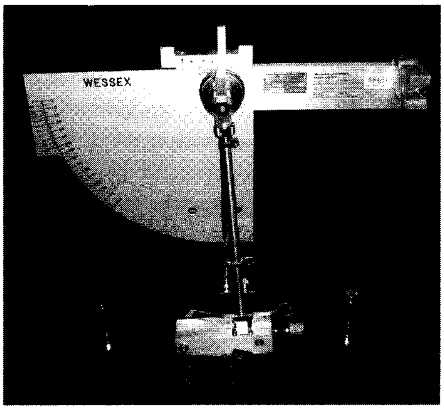
Fig. 7 Fracture Energy of Crumb Rubber Blocks

4.2 Physical Properties

The physical properties of the crumb-rubber concrete block were measured in the laboratory as well as in the field. Two tests were performed: skid and abrasion resistance.

4.2.1 Laboratory results

For the skid resistance, the setup and results are given in Fig. 8. It was found that the crumb rubber concrete blocks exhibited better skid resistance than plain concrete block (except for the blocks made with no. 20 crumb rubber). The highly elastic properties of rubber allowed the block surface to deform more and create more friction as the pendulum passed through it. Mixes with large particle rubbers (both No. 6 and No. 6+20) were able to perform better than those mixed with small particle rubbers.



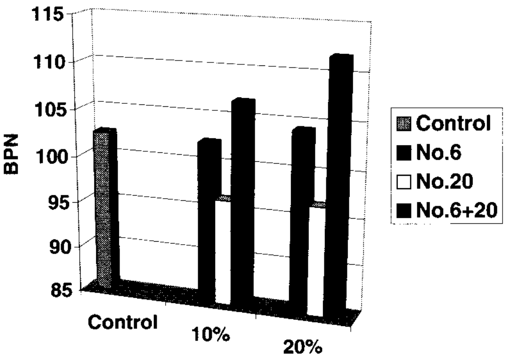


Fig. 8 Skid Resistance Test Setup and Results
(Note: BPN-British Pendulum Number)

For abrasion resistance, the setup is as shown in Fig. 9. Results in terms of percent weight loss are given in Fig. 10. It was found that the crumb rubber concrete block exhibited poorer abrasion resistance than plain concrete block as seen by the higher weight loss. Comparing between the three crumb rubber mixes, the combined mix (No.6+20) seemed to perform better than the single type mix. Even though the percent weight loss of crumb rubber concrete block was higher than that of concrete, the average percent weight loss was still low (between 1% to 3% for 62010 and 62020 respectively).

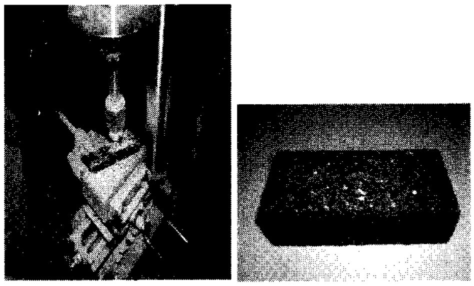


Fig. 9 Abrasion Resistance Test Setup

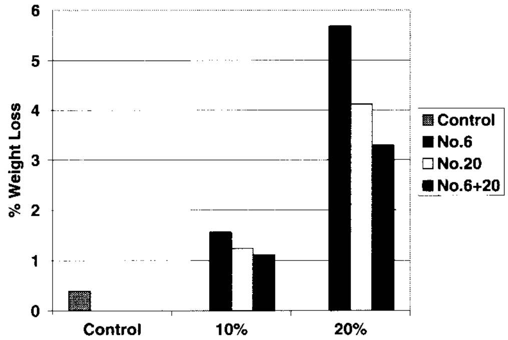


Fig. 10 Percent Weight Loss of Specimens Subjected to Abrasion Test

4.2.2 Field Results

Field testing was carried out at King Mongkut Institute of Technology-North Bangkok. The location of the test was at the narrow walkway from the bridge to the main cafeteria. Each type of block was laid in 1 m^2 as shown in Fig. 11. The number of pedestrian was recorded hourly from 8:30 to 18:00. The average of number of pedestrian passing the test point was approximately 6,000 daily (Table 5).

Results in terms of percent weight loss and skid resistance from the field test are given in Table 6. Both skid and abrasion resistance of the blocks at the field was found to be poorer than those obtained in the lab as seen by the increasing weight loss and reducing skid resisting number (Fig. 12). Poorer performance in the field was suspected to come from several factors and one of them was the weather. Because the test was carried out during the rainy season, the block surface was softened due to the presence of moisture. Another reason could be the age of the block, due to the time constraint, the average age of the blocks was about 3 days (or less). At this age, the strength of a block was not fully developed, which led to a poorer bond between concrete and rubber particles.

Table 5 Average Number of Pedestrian

Period	Avg. Pedestrian
8.30-9.00	338
9.00-9.30	267
9.30-10.00	311
10.00-10.30	312
10.30-11.00	358
11.00-11.30	379
11.30-12.00	562
12.00-12.30	502
12.30-13.00	574
13.00-13.30	466
13.30-14.00	283
14.30-15.00	248
15.00-15.30	212
15.30-16.00	306
16.00-16.30	395
16.30-17.00	338
17.30-18.00	207
Total	**6,058**

Table 6 Results from the Field Test

Block	% Weight Loss	Skid (BPN)
Control	0.55	95
610	2.03	91
620	6.05	102
2010	1.56	86
2020	5.01	88
62010	1.18	106
62020	3.31	105

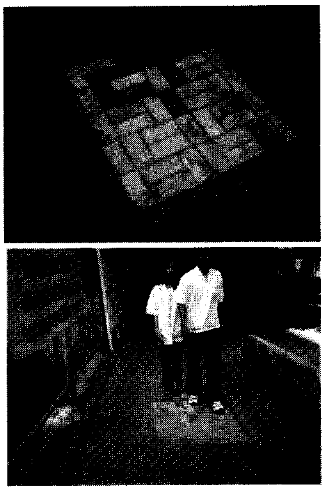


Fig. 11 Field Test

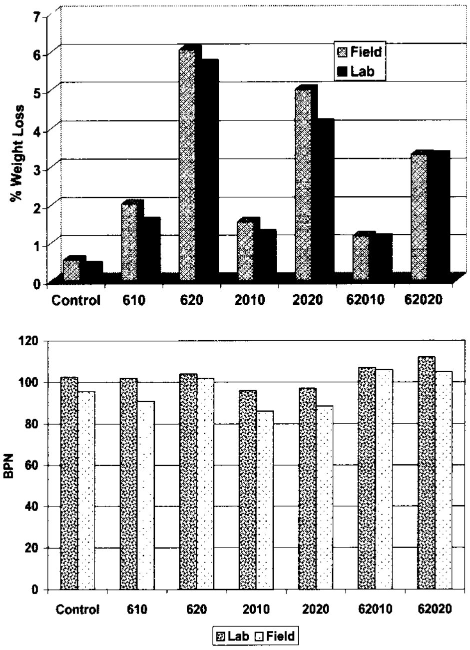


Fig. 12 Comparison between the Laboratory and the Field Test

5. Conclusions

- Concrete block mixed with crumb rubber up to about 20% by weight is possible to make using a conventional plain concrete block manufacturing process.
- The performances of concrete block are affected differently depending on the type and content of the rubber. In the case of mechanical properties, both compressive and flexural strength are found to decrease with rubber content, while the energy absorption is found to increase.
- Other properties such as the skid resistance is found to increase with rubber content. Large particle rubber seemed to provide better skid resistance. However, the crumb rubber concrete block performed poorer that plain concrete block in terms of abrasion resistance.
- Results from the field test in terms of percent weight loss were slightly higher than the results from the laboratory due to factors such as, the weather during the test (rainy season), and the maturity of the blocks.

6. Acknowledgement

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