タイトル	THE COMPRESSIVE STRENGTH OF CONCRETE CONTAINING TILE CHIPS, CRUSHED SCALLOP SHELLS, OR CRUSHED ROOFING TILES
著者	SUGIYAMA, Masashi
引用	北海学園大学学園論集，124: 61-69
発行日	2005-06-25

THE COMPRESSIVE STRENGTH OF CONCRETE CONTAINING TILE CHIPS, CRUSHED SCALLOP SHELLS, OR CRUSHED ROOFING TILES

Masashi SUGIYAMA*

Abstract

This paper addresses waste disposal through recycling; tile chips, crushed scallop shells, or crushed roofing tiles were mixed into concrete, and compressive strength was tested. The experiment was carried out in three parts.

Series 1 measured the compressive strength and the static elastic modulus of concrete containing tile chips. That replaced 30% to 100% of the volume of the coarse and fine aggregate. The results showed that compressive strength increased as the proportion of tile chips was increased.

Series 2 measured the compressive strength of porous concrete containing crushed scallop shells that replaced 50% to 100% of the volume of the coarse aggregate. The results showed that compressive strength decreased as the percentage of crushed scallop shells was increased.

Series 3 measured the compressive strength and the static elastic modulus of concrete containing crushed roofing tile material that replaced 20% to 100% of the volume of the coarse aggregate. The results showed that compressive strength was increased when the percentage of roofing tile material was 20% to 60% of the volume of the coarse aggregate.

Key words: Compressive strength, Crushed roofing tile, Crushed scallop shell, Static elastic modulus, Tile chips.

*) Hokkai Gakuen University, Faculty of Engineering, Professor.

1. INTRODUCTION

The annual investment in construction in Japan amounts to about 70 billion yen, corresponding to about 14% of the gross domestic product. This activity produces about one hundred million tons of waste from construction sites, about 25% of the total amount of industrial waste in Japan [1, 2]. It is important to promote the recycling of construction materials as well as other commercial by-product in order to suppress the generation of waste.

In this paper, tile chips, crushed roofing tiles, or crushed scallop shells were mixed into concrete, and compressive strength and static elastic modulus were tested.

2. SERIES 1: TILE CHIPS

2.1 Design of experiments

Series 1 measured the compressive strength and the static elastic modulus of concrete containing tile chips.

The mixing ratio of the tile chip was varied in the following manner.

(1) A test series in which the tile chips replaced 30% to 100% of the volume of coarse aggregate.

(2) A test series in which the tile chips replaced a fixed 30% of the coarse aggregate and 30% to 100% of the fine aggregate.

(3) A test in which the tile chips replaced 100% of both the coarse and fine aggregate.

2.2 Mix proportions

Mix proportions are shown at Table 1.

Table 1: Mix proportions

Specimen	Tile Chip Aggregate		W/C	River Gravel	Tile Coarse	River Sand	Tile Fine	Sl.	Air
	Coarse	Fine	(%)	(L/m3)	Agg.	(L/m3)	Agg	(cm)	(%)
G0 S0	0%	0%	50	394	0	274	0	19.5	0.8
G30 S0	30%	0%	50	276	118	274	0	19.0	0.9
G60 S0	60%	0%	50	158	236	274	0	18.5	1.0
G100 S0	100%	0%	50	0	394	274	0	18.0	1.0
G30 S30	30%	30%	50	276	118	191	83	18.5	0.9
G30 S60	30%	60%	50	276	118	110	164	18.0	0.9
G30 S100	30%	100%	50	276	118	0	274	19.0	1.0
G100 S100	100%	100%	50	0	394	0	274	18.5	0.9

The mix proportions all contain a 50% water cement ratio. Plain concrete was selected in order to minimize the effect of variations in entrained air quantity on compression strength. The coarse aggregate river gravel (2.75 density, 1.08% water absorption rate) was from Shizunai town, Hokkaido. The fine aggregate river sand (2.69 density, 1.42% water absorption rate) was from Mukawa town, Hokkaido. The tile was originally used as decorative for reinforced concrete external wall. By crushing, the tile was divided in coarse and fine aggregates: the coarse tile aggregate sized between 20mm and 5mm (6.52 fineness modulus, 2.30 density, 0.11% water absorption rate) and fine tile aggregate sized 5mm or less (3.83 fineness modulus, 2.30 density, 0.11% water absorption rate). The target slump was 18cm. The curing of the concrete was carried out in water at 20 degrees centigrade.

2.3 Compressive Strength Results (Figure 1)

The concrete containing no tile chips is designated G0S0, the control samples.

G30S0, the concrete with tile chip coarse aggregate replacing 30% of the river gravel, exhibited a compressive strength larger than that of G0S0. This result was also found for the G60S0 (tile chip coarse aggregate replacing 60% of the river gravel) and G100S0 (tile chip coarse aggregate replacing 100% of the river gravel). In fact, the compressive strength increased as the proportion of the tile chips replacing the river gravel was increased.

G30S30, tile chip coarse aggregate replacing 30% of the river gravel and tile chip fine

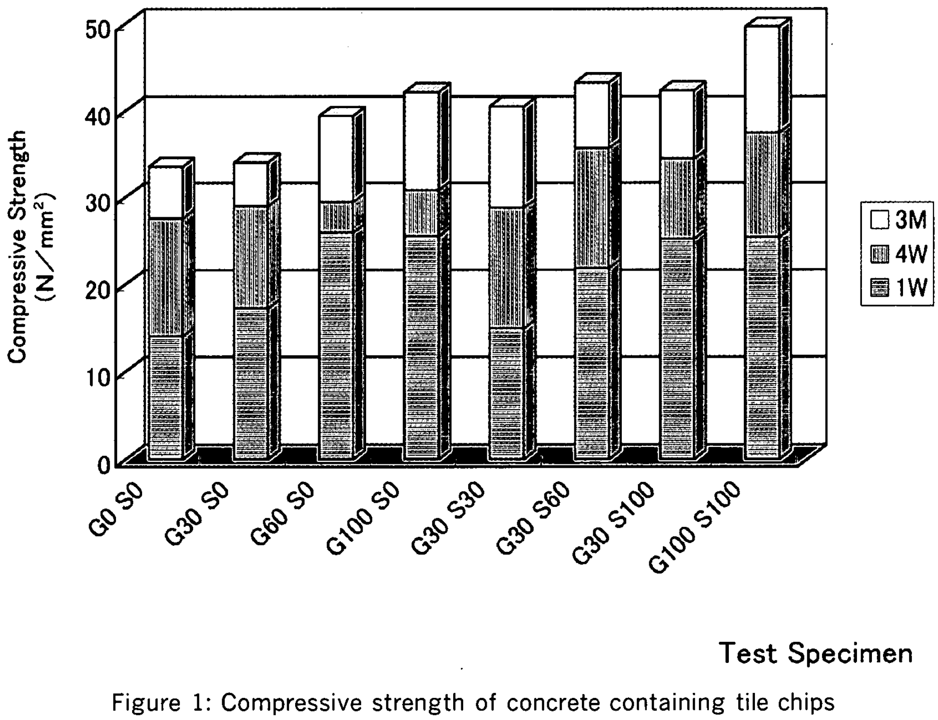

Figure 1: Compressive strength of concrete containing tile chips

aggregate replacing 30% of the river sand, also exhibited a compressive strength larger than G0S0. As the proportion of tile fine chip aggregate replacing river sand was increased from 30 to 100% with the proportion of crushed tile coarse aggregate fixed at 30% (G30S30, G30S60 and G30S100, respectively) the compressive strength increased. The concrete containing coarse and fine aggregates composed only of tile chips, G100S100, exhibited the largest compressive strength of all the concrete specimens in Series 1.

2.4 Static Elastic Modulus Result (Figure 2)

Static elastic modulus was calculated from the 1/3 stress-strain relationship of the maximum load. The static elastic modulus of concrete containing any level of tile chip aggregate is larger than that of the control concrete, G0S0.

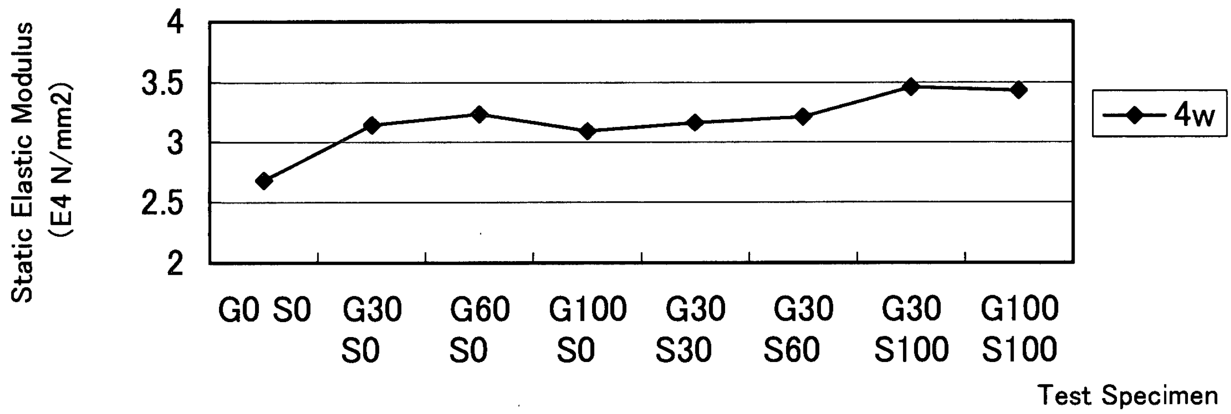

Figure 2: Static elastic modulus of concrete containing tile chips

3. SERIES 2: CRUSHED SCALLOP SHELLS

3.1 Design of Experiments

It has been shown that crushed scallop shell material can filter muddy water, effectively cleaning it [3]. If this beneficial effect can be obtained from porous concrete containing this crushed shell material, the environment will be improved with the ability to recycle both the shells as well as the resulting concrete when it becomes waste.

In this test series, crushed scallop shell material was mixed into porous concrete, and the compressive strength was tested.

3.2 Mix Proportions

The mix proportions are shown in Table 2. The water-cement ratio and the target air void for all test specimens were 22% and 30%, respectively. As mentioned above, the crushed shell material was used to replace the aggregate at volumetric mixing ratios of 0%, 50%, and 100%. The materials used in the concrete are as follows: ordinary cement (density 3.16), aggregate (crushed stone, sieve size 5-15 mm, density 2.84), crushed shell material (sieve size 5-25 mm, density 2.50), and high-range water reducing admixture (1.68%). The porous concrete was cured in water at 20°C for four weeks. The concrete was manually placed into forms using table and hand vibrators. The concrete specimens were removed from the forms the next day and then cured in water for four weeks at 20°C. The compressive strength tests were conducted after 28 days of curing. The dimensions of the specimens were 10ϕx20cm.

Table 2: Mix proportions

Crushed Shell (%)	W/C (%)	Water (Kg)	Cement (Kg)	Aggregate (Kg)	Crushed Shell (Kg)	Admixture
0	22	53	240	1622	0	High-range
50	22	53	240	811	714	Water Reducing
100	22	53	240	0	1428	Admixture

3.3 Air Void Percentage Measurement Method for Porous Concrete

The air void percentage was measured using Japan Concrete Institute Methods: volumetric and weight [6]. The dimensions of the specimens were 10ϕx20cm.

1. Volumetric method

$$A = (1-(W_2-W_1)/V)\times 100 \quad (1)$$

Where A = Air void percentage of porous concrete (%)

W_2 = Weight in air

W_1 = Weight in water

V = Volume.

2. Weight method

$$A = (T-W)/T\times 100 \quad (2)$$

Where A = Air void percentage of porous concrete (%)

T = Weight, per unit volume, of concrete from which air was removed

W = Weight, per unit volume, of the concrete specimen

3.4 Compressive Strength and Air Void Percentage Results

The results of compressive strength and air void percentage tests are shown in Table 3. The compressive strength measured after four weeks of curing ranged from 10.6 to 0.3N/mm². The compressive strength at 0% crushed shell, i.e., no shell material added, is sufficient for porous concrete. It should be noted that the compressive strength decreased as the percentage of crushed shell material was increased. The target void percentage was 30%. The actual air void percentage determined by the volumetric method ranged from 28.1 to 55.7%; the weight method showed this parameter ranging from 28.3 to 51.1%. Thus, both test methods produced similar results. The air void percentage at 0% crushed shell content is close to the target value. However, the air void percentage increased significantly as the percentage of crushed shell material was increased.

Table 3: Compressive strength and air void percentage

Crushed Shell (%)	Air Void Percentage (%)			Compressive Strength, After 4 Weeks of Curing (N/mm²)
	Target of Air Void	Volumetric Method	Weight Method	
0	30	28.1	28.3	10.6
50		43.1	40.0	1.9
100		55.7	51.1	0.3

4. SERIES 3: CRUSHED ROOFING TILE MATERIAL

4.1 Design of Experiments

Series 3 measured the compressive strength and the static elastic modulus of high volume fly ash concrete containing crushed roofing tile material.

4.2 Mix Proportions

The mix proportions are shown in Table 4. The water-cement ratio for all test specimens was 40%. The crushed roofing tile material was added as 0%, 20%, 40%, 60%, 80%, and 100% of the volume of the coarse aggregate. The materials used in the concrete are as follows: ordinary cement (density 3.16), fly ash (density 2.16, loss on ignition 1.7%, specific surface area 3780cm²/g, methylene blue absorption 0.55mg/g), fine aggregate (river sand, density 2.69), coarse aggregate (river gravel, density 2.80), and crushed roofing tile material (density 1.30). The concrete was cured in water at 20°C. The Slump was from 15 to 19cm.

The compressive strength tests were conducted after 7, 28, and 91 days of curing. The dimensions of the specimens were 10ϕx20cm.

Table 4: Mix proportions

Roofing tile (%)	W/C+F (%)	Water (Kg)	Cement (Kg)	Fly Ash (Kg)	Fine agg. (Kg)	Coarse agg. (Kg)	Roofing tile (Kg)
0	40	158	197	197	764	1112	0
20	40	158	197	197	764	890	103
40	40	158	197	197	764	666	207
60	40	158	197	197	764	445	309
80	40	158	197	197	764	221	413
100	40	158	197	197	764	0	516

4.3 Compressive Strength Results

The results of compressive strength tests are shown in Figure 3. The results show that compressive strength was increased when approximately 20% to 60% of the volume of the coarse aggregate was replaced by roofing tile material.

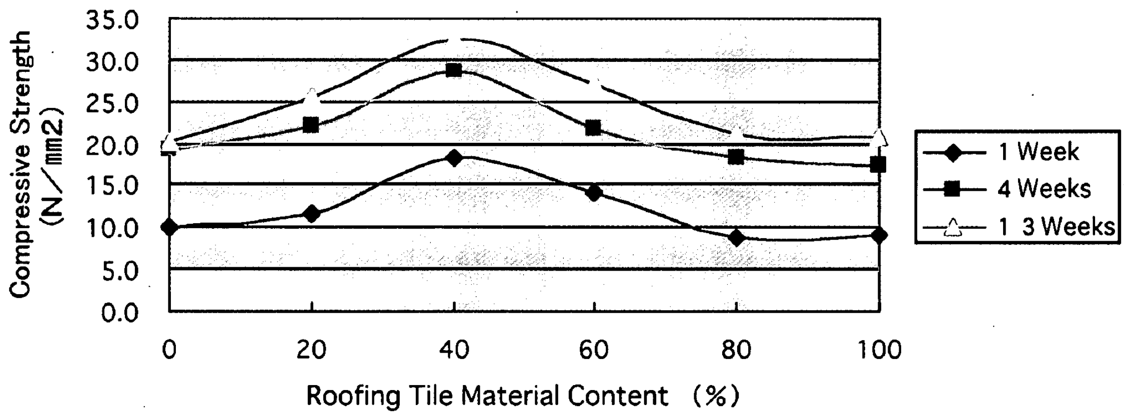

Figure 3: Compressive strength of concrete containing roofing tile material

4.4 Static Elastic Modulus Results

The results of static elastic modulus tests are shown in Figure 4. Even if the mix rate of roofing tile material is increased to 80%, the static elastic modulus does not change significantly. However, when the mix rate of roofing tile material is 100%, the static elastic modulus is somewhat decreased.

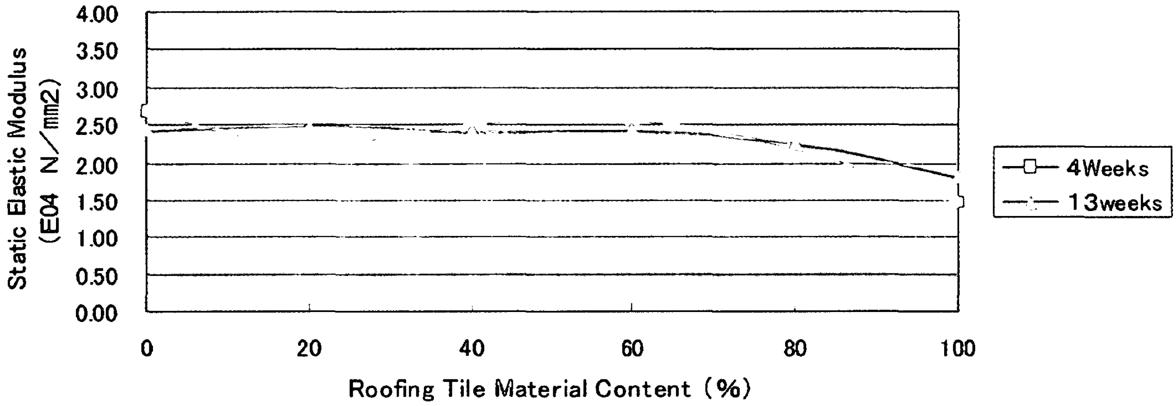

Figure 4: Static elastic modulus of concrete containing roofing tile material

5. CONCLUSION

This study examined the compressive strength and the static elastic modulus of concrete containing tile chips, crushed scallop shells, or crushed roofing tiles substituting for a portion or all of the aggregate.

The conclusions are listed in the following;

1. Both the compressive strength and the static elastic modulus increase as the proportion of tile chips utilized as aggregate is increased.
2. The compressive strength of porous concrete decreases as the percentage of aggregate replaced by crushed scallop shell material is increased. Future studies will center on improving this result.

   The compression strength can be increased by substituting roofing tile material for 20% to 60% of the volume of the coarse aggregate. A mix rate of crushed roofing tile material of up to approximately 80% has little effect on the static elastic modulus; however, when the mix rate is 100%, the static elastic modulus is somewhat decreased.

REFERENCE

[1] Construction Material Subcommittee: Present state and future trends of reuse technology concerning construction by-products, Architectural Inst. of Japan Kanto branch, March 1996.

[2] Construction Material Subcommittee: Present state and future view of zero emission in architectural projects, Architectural Inst. of Japan, Kinki branch, Aug. 1999.

[3] Koyama, N.: Scallop shell: bionic design (in Japanese), (website: Koyama Institute of Technology) http://www.pow.hi-tech.ac.jp/kenkyu/koyama/index.html

[4] Sugiyama M.: The experiment on compressive strength and freeze-thaw resistance of concrete containing tile chip, Recycling and Reuse of Glass Cullet: Proceedings of International Symposium, Dundee, Thomas Telford, March 2001.

[5] Sugiyama M.: The freeze-thaw test results of porous concrete with crushed scallop shell material added, Recycling and Reuse of Waste Materials: Proceedings of International Symposium, Dundee, Thomas Telford, March 2003.