Mechanical Properties of Concrete Containing Construction Sludge

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ABSTRACT :

We proposed to use the solidified construction sludge as coarse aggregate for structural concrete. Three series of the experimental works were performed to obtain the fundamental mechanical properties of the concrete including solidified construction sludge. In the mechanical test, the compressive strength of the concrete which the mixing rate was 100% was approximately 70% of that of the normal concrete. In the structural member test, the shear cracking strength and the maximum strength could be estimated by the present equations for the normal concrete. It is anticipated that there is possibility of utilizing concrete containing the aggregate made from construction sludge for structural.

KEYWORDS: Construction sludge, Mechanical property, Confinement, Seismic performance

1. INTRODUCTION

In Japan, construction sludge as by-product of construction is approximately 10% of all by-products of construction and is increasing up to eight million ton. Currently, the recycling rate of construction sludge is not so high in comparison with those of other by-product of construction. If construction sludge is used as concrete material the recycling rate of construction sludge rapidly increase and the amount of the consuming natural resources decrease. We proposed to use the solidified construction sludge as concrete material. Three series of the experimental works were performed to obtain the fundamental mechanical properties of the concrete including solidified construction sludge in comparison with the normal concrete. The main parameter in this paper was the mixing rate of the replaced natural aggregate with solidified construction sludge.

2. MATERIAL PROPERTY OF SOLIDIFIED CONSTRUCTION SLUDGE

2.1. Strength of the Solidified Construction Sludge

The solidified construction sludge made from the construction sludge including the coal ash, the cement, the reproduction crushed rock, and the coal by each 51.7%, 31.1%, 15.6%, 1.6%. The solid state properties of the construction sludge were shown in Table 2.1. And the strength of solidified construction sludge is shown in Fig. 2.1.

Table 2.1 Solid state properties of the construction sludge

Density of surface-dry (g/cm^3)	Density of absolute dry (g/cm^3)	Water-absorbing ratio (%)	Abraded quantity (%)	Micro-particle quantity (%)	Weight of unit quantity (kg/ℓ)	Loss ratio (%)
2.04	1.72	18.6	2.6	2.2	1.07	62.1

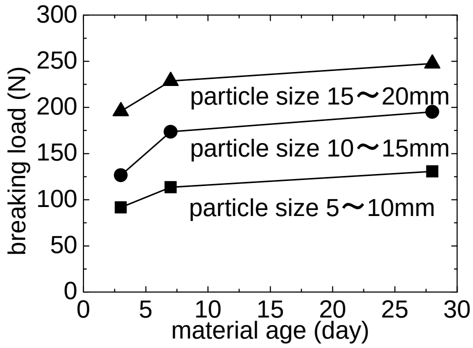

Figure 2.1 Breaking load - Material age

2.2. Mix properties of Concrete

The considered mix rate was shown in Table 2.2. The concrete based on the concrete mixture design indicator of Architectural Institute of Japan(1). Solidified construction sludge was made from the classified construction sludge, cement and the recycled concrete. The specified concrete strength was 30MPa. And coarse aggregate was replaced to the solidified construction sludge in the rate of absolute volume 0, 25, 50, 75 and 100%.

Table 2.2 Mix properties of concrete with solidified construction sludge

Specimen	W/C	Absolute volume (ℓ/m^3)			
		Cement	a	g	Solidified construction sludge
NC000	51.6	114	288	368	0
EB025				277	92
EB050				184	183
EB075				92	277
EB100				0	369

2.3. Mechanical Property of Concrete Including Solidified Construction Sludge

The compression and splitting tests of the concrete using Φ100×h200mm test cylinders including the solidified construction sludge as coarse aggregate were performed to obtain the mechanical characteristics of the hardened concrete.

2.3.1 Compressive Strength

The compressive strength decreased as the mix rate increased as shown in Fig. 2.2. When the mix rate of the solidified construction sludge increased, the more compressive strength decreased. The compressive strength of the concrete of mixing rate 100% was approximately 70% of that of the normal concrete. The relations between the compressive strength and the material age were shown in Fig.2.3.

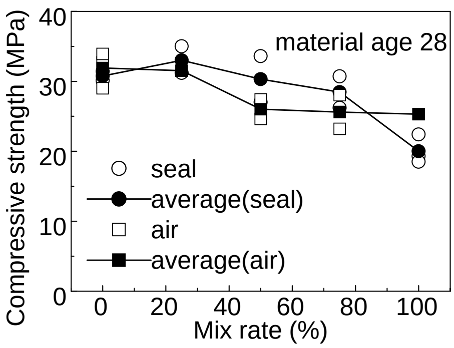

Figure 2.2 Compressive strength – mix rate

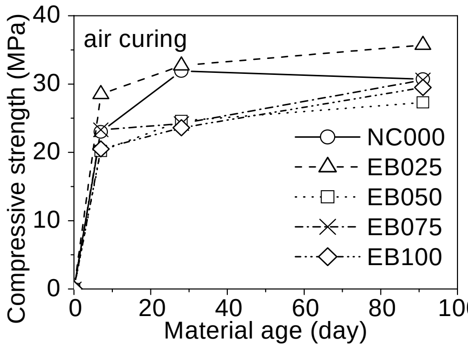

Figure 2.3 Compressive strength – material age

2.3.2 Splitting Strength

The relations between the tensile strength and the compressive strength were shown in Fig. 2.4. The curve in the figure is the equation (1) from the previous study for the compressive strength class of 15-140MPa(2). The results approximately agreed with the curve of eq.(1).

$$\sigma_t = 4 \cdot \left(\frac{\sigma_B}{60} \right)^{2/3} \tag{1}$$

where, σ_t: Tensile strength（MPa）
σ_B: Compressive strength（MPa）

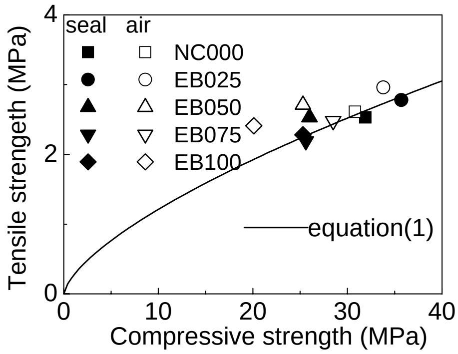

Figure 2.4 Tensile strength - compressive strength

2.3.3 Drying Shrinkage

The drying shrinkage tests of the concrete using 100×100×400 mm rectangular specimens including the solidified construction sludge as coarse aggregate. The length changes of the specimen and material age were shown in Fig. 2.5. The more the mix rate of the solidified construction sludge, the more the mount of the drying shrinkage increases.

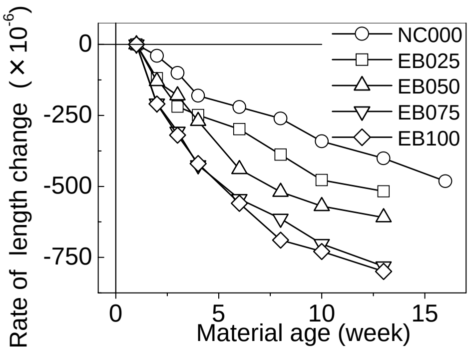

Figure 2.5 Length change of specimen and material age

3. COMPRESSIVE PROPERTIES OF CONFINED COLUMNS

3.1 Specimen

Compressive properties of reinforced column members are significantly affected by the lateral reinforcement. Especially, it is necessary to investigate the behavior of the columns subjected to high axial load. In this paper the monotonic compressive loading tests with the columns of which section were 150×150mm were performed to obtain the effects of the confinement on the compressive properties. Number of the specimen was eight as shown in Table 3.1. The bar arrangement of the test specimen was illustrated in Fig 3.1. The test area was 200mm in the center of the column. Considered mixing rates in this series were two types, 50% and 100%. The lateral reinforcement ratios were 0%, 0.3%, 0.6% and 0.9%. Mechanical properties of reinforcing bars and concrete were shown in Table 3.2 and Table 3.3. Four longitudinal aluminum of □5 were arranged in each test columns to support the lateral reinforcement. Effects of the aluminum bars on the compressive strength of the columns were ignored in this study.

Table 3.1 List of test columns

Name	Solidified construction sludge mixing rate (%)	Lateral reinforcement	
		Bar arrangement	p_w (%)
EB050-00	50	—	0.0
EB050-03		ϕ4@56	0.3
EB050-06		ϕ5@44	0.6
EB050-09		ϕ5@29	0.9
EB100-00	100	—	0.0
EB100-03		ϕ4@56	0.3
EB100-06		ϕ5@44	0.6
EB100-09		ϕ5@29	0.9

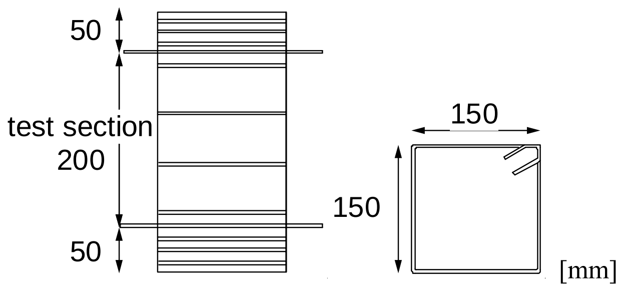

Figure 3.1 Example of bar arrangement : p_w=0.3%

Table 3.2 Mechanical properties of reinforcing bar

Bar	Yield strength (MPa)	Young's Modulus (GPa)	Tension strength (MPa)	Breaking strain (%)
ϕ4	600.2	192.2	791.5	20.4
ϕ5	689.7	180.6	885.4	13.4

Table 3.3 Mechanical properties of concrete

Concrete	Compressive strength (MPa)	Splitting strength (MPa)	Elastic modulus (GPa)
EB050	28.2	2.63	20.4
EB100	23.8	2.32	17.0

3.2. Loading and Measurement

Monotonic axial loading were subjected to the test columns with the 1MN compressive machine. The measurement instruments were mounted on the test columns to measure axial deformation

3.3 Observed Results

The axial stress-strain curves were shown in Fig. 3.2. The maximum increased as the amount of confinement increased with the mixing rate 50% and 100%. After the maximum stress, the stress gradually decreased more slowly as confinement increased. The strength increase ratio of EB050 by the lateral reinforcement was larger than that of EB100.

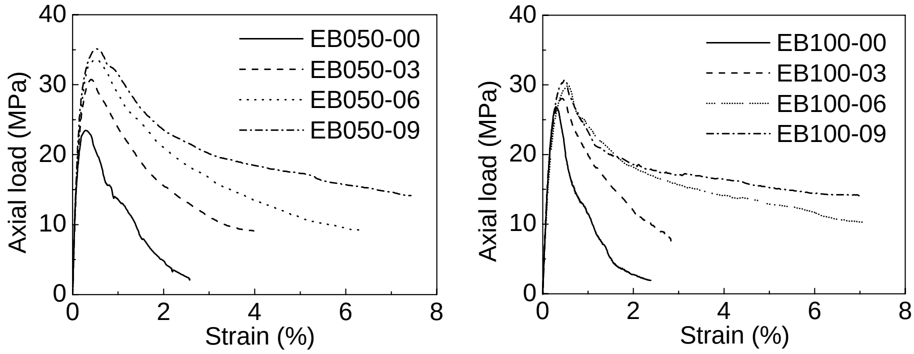

Figure 3.2 Axial stress- strain curves

The maximum stress were normalized with the compressive stress of the test cylinders as shown in Fig.3.3. To investigate the effect of the lateral reinforcement, previously proposed equation (1) and equation(2) of document (3) were inserted in Fig.3.3. The regression estimation with the least-square method were also inserted in Fig.3.3. In addition, equation (1) was proposed to normal concrete and equation (2) was proposed to high-intensity artificial lightweight aggregate concrete. The gradient of EB050 agreed with normal concrete and that of EB100 agreed with that of the high-intensity artificial lightweight aggregate concrete.

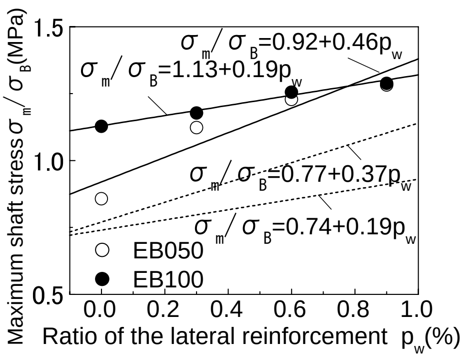

Figure 3.3 Normalized axial stress vs. confinement

$$\sigma_m/\sigma_B = 0.77 + 0.37 \cdot p_w \quad (1)$$

$$\sigma_m/\sigma_B = 0.74 + 0.19 \cdot p_w \quad (2)$$

where， σ_m： Maximum axial strength (MPa)

σ_B： Compressive strength (MPa)

p_w： Lateral reinforcement ratios（%）

4. SEISMIC PERFORMANCE OF RC COLUMN

4.1. Specimen

The reversal loading tests with the reinforced concrete column under the constant axial load were performed to obtain the seismic performance as structural members. The considered mixing rate of the solidified construction sludge was 100% in the member tests. The configuration and the bar arrangement were shown in Fig.4.1. Section of the scaled test column was 300×300mm and shear span was 800mm.

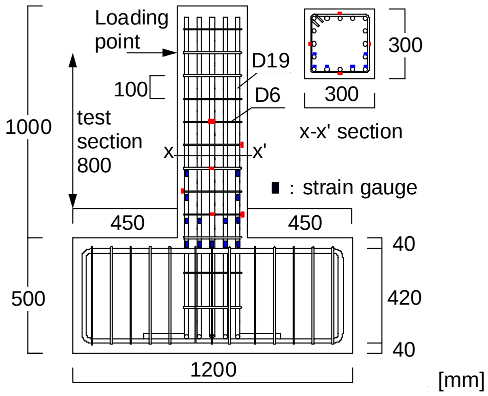

Figure 4.1 Configuration and bar arrangement

Table 4.1 Details of test column

Cross-section b×D(mm)	Concrete strength (MPa)	Bar arrangement		Axial force ratio
		Main reinforcement	Hoop reinforcement	
300×300	30	16-D19	2-D6@100	0.1

Table 4.2 Mechanical properties of reinforced bar

Reinforced bar kind	Yield strength (MPa)	Tension strength (MPa)	Young's modulus (GPa)
D6	328.0	497.7	160.9
D19	414.3	587.9	193.7

4.2. Loading and Measurement Method

The reversal loading tests of test columns under the constant axial load (21.4kN) were performed. The reversal lateral loadings were controlled by the deflection angle of the test columns with two times for each 1/800, 1/400, 1/200, 1/100, and 1/50 rad. reversal. The measurement instruments and the strain gages were set on to the test columns to measure the displacements of the test columns and strains of the re-bars.

4.3 Experimental Result

4.3.1 Destruction Property and Load-transformation Relation

The photographs at maximum shear strength and at the final stage are shown in Fig.4.2 and Fig.4.3, respectively. The load deflection curves is shown in Fig.4.4. The flexural cracks occurred at the drift angle of 1/800 rad. and the flexural shear cracks occurred at 1/400 rad. The shear cracks occurred in the drift angle of 1/200 rad. Then strain of the lateral reinforcement reached the yield strain. After the maximum strength, strength of the test columns gradually decreased.


Figure 4.2 Crack patterns at the maximum strength


Figure 4.3 Crack patterns at the final stage

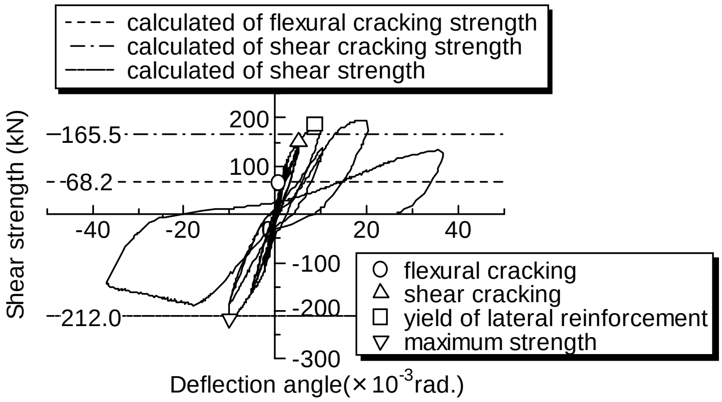

Figure 4.4 Load deflection curves

4.3.2 Cracking and Maximum Strength

Summary of the observed and calculated strength were shown in Table 4.3. Each strength could be estimated by the previously proposed equations for the normal concrete.

Table 4.3 Observed and calculated strength

Observed strength (kN)			Calculated strength (kN)		
Strength of flexural crack(4)	Strength of shear crack(5)	Maximum strength	Strength of flexural crack(4)	Strength of shear crack(5)	Shear strength
66.2	149.5	216.3	68.2	165.5	212

5 . Conclusions

1) Material tests

1-The compressive strength decreased with increase of mixing rate of the solidified construction sludge.

2- The splitting strength could be estimated at each mixing rate.

3-In the drying shrinkage, the length change rate increased as the mixing rate of the solidified construction sludge increased.

2) Compressive tests of columns

1-In the compressive properties of confined column, the maximum load increases as the confinement increased.

2-The increasing strength ratio of EB050 by the lateral reinforcement was larger than that of EB100.

3-The gradient after maximum strength of EB050 was approximately same of normal concrete.

3) Seismic test of column

1-Strengtn of the column could be estimated by the present equation for normal concrete.

From results of the three test series it is anticipated that there is possibility of utilizing concrete containing the aggregate made from construction sludge for structural members of building.

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