- Technical Paper -

EXPERIMENTAL STUDY ON THE STRENGTH PROPERTIES OF CEMENT TYPE MATERIALS IN UTILIZING PAPER SLUDGE ASH

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ABSTRACT

As a substitute material for concrete, not utilizing fine and coarse aggregates, a material (paper sludge ash lump) made with a mixture of paper sludge ash and cement is presented and the compressive strength and the bending strength are examined. As a result, there appeared a possibility to utilize the material as a substitute for concrete.

Keywords: industrial waste, paper sludge ash, materials for construction, slab, mechanical properties

1. INTRODUCTION

Recycling industrial wastes to conserve natural resource, and their efficient uses have become a significant theme in the construction industry. There is concrete as an example of them.

The production of concrete consumes vast amounts of natural resources such as coarse aggregate like gravel and fine aggregate like sea sand or crushed sand as well as cement. Especially, the use of vast amounts of sea sand causes the deterioration of the environment of the sea coast and the ecology. Therefore, it is necessary to reduce its use as much as possible. However, it is rare for recycling products to be used as substitutes for this kind of fine and coarse aggregates at present.

On the other hand, lightening weight of buildings is one of safety measures which protect buildings from earthquakes. In order to lighten the weight of buildings, it is necessary to lighten the weight of materials from which they are constructed. For the reinforced concrete buildings, because slab accounts for a remarkable rate to the weight of buildings, the materials used for the floor parts are often lightly weighted in the construction of high-story buildings.

As one of industrial wastes, there is paper sludge ash produced by incinerating of the paper sludge (PS), which is discharged from paper mills, to stabilize the material property and to reduce the quantity of the PS. Paper sludge ash is reused with other industrial wastes as one of the materials mixed with cement in the field of construction. It is also sometimes used as the substitutes for aggregates, soil improvement materials for soft ground, fill materials and roadbed materials, and so on.

However, there are few researches into a large-scale application of paper sludge ash in building structure member. Besides, the compressive strength of aggregates with paper sludge ash is under 30N/mm^2. There are few studies which shows high strength over 60 N/mm^2.

From the perspective of the creation of the recycling-oriented society mentioned above, the final goal of this study is to develop structural materials which can be used to the structural member which includes reinforcing bars, by mixing large volumes of the paper sludge ash with cement in substitution for coarse and fine aggregates, and to urge to manufacture the slab with this material more.

Aims of this paper to reach the final goal is to clarify the mechanical properties such as the compressive strength and the bending strength of the hard paper sludge ash lump, which is mixed with cement in large quantities.

Still, while the bending strength of concrete can be small, this is also the case for hard paper sludge ash lump. Therefore the increase in the bending strength of the paper sludge ash lump was examined by using various kinds of additive agents of acrylic resin type to increase the bending strength.

2. PAPER SLUDGE ASH (PS ASH)

PS ash is the industrial waste produced by incinerating the paper sludge, which is discharged by paper mills.

PS ash takes powder form (see Photo 1). The maximum particle diameter is distributed over the range

Photo 1 Paper sludge ash

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Table 1 Chemical compositions and physical properties of paper sludge ash used

Density g/cm^3	Chemical composition mass%													Organic impurities
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	MnO	P_2O_5	CO_2	CL^{-1}	Others	
2.993	29.0	22.0	1.2	31.0	3.3	3.3	0.5	0.2	0.1	0.6	0.4	0.14	8.5	Light color

Table 2 Constitution materials used for hard PS ash lump

Classification	Materials	Purpose of use
Main materials	Portland blast furnace slag cement(type B)	To mix with PS ash
	PS ash lump	To attempt lightweighting
	Water	
Admixture which improves flowability	High-range water-reducing admixture/superplasticizer (polycarboxylate compound)	To spend PS ash in large quantities
	Air-entraining admixture/agent (Natural resin vinegar and Alkyl ether anion surfactants/surface-active agent)	To take air by minute bubbles
Additive which improves bending strength (compound of Inorganic type)	Styrene modified acrylic resin	Increase of bending strength
	Acrylic ester copolymer	
	Acrylic copolymer	

Table 3 Chemical compositions and physical properties of Portland blast furnace slag cement (type B) used

Density g/cm^3	Specific surface area cm^2/g	Setting			Stability	Compressive strength(N/mm^2)			Chemical composition mass%			
		Water mass%	Initial setting time	Final setting time		3d	7d	28d	MgO	SO_3	Ig-loss	CL^{-1}
3.02	3720	28.9	2h-44min	4h-05min	good	21.5	34.1	60.2	3.22	2.03	1.62	0.013

Table 4 Physical properties of additive used in order to examine increase of bending strength

Sign	R61	R62	R63
Appearance	White aqueous emulsion	Milk-white aqueous emulsion	Milk-white aqueous emulsion
Main ingredient	Styrene denaturation acrylic acid resin	Acrylate ester copolymerization resin	Acrylic copolymerization resin
Solid content (%)	55.0	43.0	55.0
Viscosity(mPa・s)	500	500	200
pH	9.0	8.0	5.0
Minimum film forming temperature (Cels.)	0	2 below	0
Thermogravimetry(Cels.)	-10	0	-20

between 0.02 to 0.12mm.

Table 1 shows chemical compositions and physical properties of the PS ash used. The main components of the PS ash were silicon dioxide, aluminum oxide and calcium oxide and the weight ratio of those components was 29.0, 22.0 and 31.0% each. The other components were magnesium oxide, sulfur trioxide and ferric, etc. The weight ratio of three above components was different each, but the component constitution of the PS ash is similar in the case of normal cement.

Since PS ash is in accordance with the environmental standards [1] mostly, PS ash itself is fundamentally applicable as a material in the construction field. For example, the use as finish materials or the member built with a single material is possible by following to The Japan Industrial Standard correspondingly. However, in the case of applying PS ash to the members which have reinforcing bars built–in, it must be satisfied for the guarantee of durability that rusts would not be generated to a reinforcing bar.

3. MATERIAL USED FOR HARD PS ASH LUMP

3.1 Materials

Table 2 shows materials which compose the hard PS ash lump. These materials were divided into three groups; main material, admixture which improves flowability, and additive to increase the bending strength.

Main materials are Portland blast furnace slag cement (type B), PS ash and water. Table 3 shows chemical compositions and physical properties of the Portland blast furnace slag cement (type B) used. The high-range water-reducing admixture (super-plasticizer) was used to mix a volume of PS ash in large quantities. The air-entraining admixture which adjusts the amount

Table 5 Mixing proportion for specimens (weight ratio：%)

Name of specimen	Cement	PS ash	Water	High-range water-reducing admixture	Additive which improves bending strength	dispersant	Kind of additive which improves bending strength	Air-entraining admixture
SR101 SQ101 SN101	63.8	16.0	19.1	1.1	—	—	—	0
SR102 SQ102 SN102	63.8	16.0	19.1	1.1	—	—	—	0.003*
PA30-M1 SR103	52.3	22.0	15.7	1.0	9.0	0	R61	0
PA30-M2 SR104	52.7	21.4	15.7	1.0	9.1	0.1	R62	0
PA60-M1	35.1	34.7	21.0	1.0	8.1	0.1	R63	0

(Note) ＊：Ratio for cement

of air was also used to increase formation of air bubbles.

Furthermore, the increase of bending strength for the hard PS ash lump was examined by using three kinds of acrylic resin.

3.2 Additive Used to Examine Increase of Bending Strength

As it is shown in Table 2, three kinds of acrylic resins of inorganic type are used which would be expected to increase the bending strength. These three additives are specially manufactured to connect Portland blast furnace slag cement (type B) and PS ash chemically. Its physical properties are shown in Table 4.

4. MACHINE TO MANUFACTURE HARD PS ASH LUMP

In this experiment, the highfrequency vibration table which is vibrating up and down over 150Hz and the churning machine which engine speed is over 1000rpm are used to mix a volume of paper sludge ash with cement and then knead super hard to increase the mixture's compressive strength. Fig. 1 shows the highfrequency vibration table. The size of the vibration table is 2000×3000.

5. TYPES OF SPECIMENS AND METHOD OF MANUFACTURING

5.1 Types of Specimens

There were two kinds of specimens. One was for the experiment of compressive strength and another was for the experiment of bending strength.

Table 5 shows a list of mixing proportions of each specimen. Table 6 shows configurations and dimensions of each specimen.

5.2 Method of Manufacturing

PS ash lump is manufactured through the following order.

(1) Mixing the additive A to be able to expect the increase of bending strength, the admixture B which improves flowability, and water, we made the mixed liquid. Here, there are 3 types of R61, R62, and R63 in the additive A, as shown in Table 4. When the increase of bend strength is not especially needed, this is not mixed. The admixture B is made by mixing the air-entraining admixture with the high-range water-reducing admixture.

(2) Cement and PS ash are added to the mixture liquid. This mixture becomes like the powder and was dry. Moreover, there was no consistency at all. That is, the slump and the flow value could not be measured.

(3) (2) was agitated at high speed by using a churning machine until it causes flowability partially.

(4) As showed in Fig. 1, (3) was put into the mold attached on the highfrequency oscillating table. Since the table is vibrating up and down by 147-153Hz, the characteristic of material in it changes into the state of flowability completely. It takes about 10 minutes to complete a condition of flowability by the vibration.

(5) The product was removed from the mold two days later.

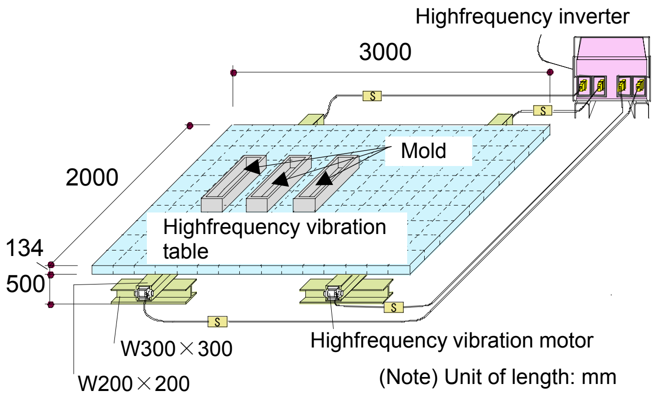


Fig.1 Highfrequency vibration table

6. OUTLINE OF EXPERIMENT

6.1 Specimens

While the water-cement ratio of the specimen only PA60-M1 is 0.6, that of other specimens are all 0.3. The size of specimens and the weight which were measured in the day before the experiment' day, were shown in Table 6.

The weight per unit volume of specimens SR 103 and PA30-M1, which the additive R61 to increase the bending strength was added, were about 14kN/m^3. The weight per unit volume of specimen PA60-M1, which R63 was added, was about 12kN/m^3. Comparing the weight per unit volume of specimens SR104 and PA30-M2, which R62 was added, with that of the specimen mentioned above, each specimen had 80% and 70% value, respectively. Therefore, the effect to minimize the weight per unit volume of specimens appears in the order of acrylic copolymer resin, styrene modified acrylic resin and acrylic ester copolymer resin.

Table 6 Type and form of specimens

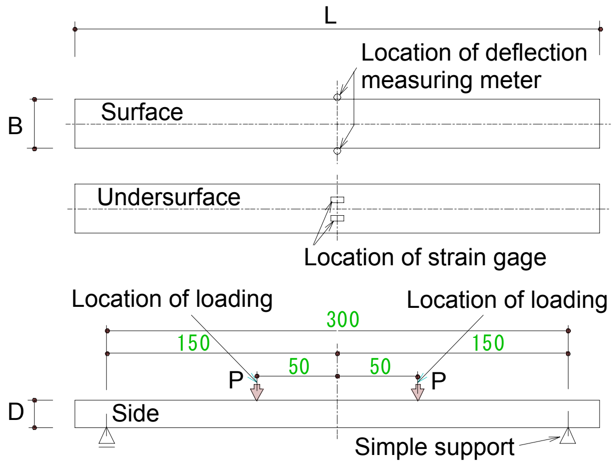
Name of Specimen	Shape of cross-section	Dimensions(mm)			Weight per unit volume(kN/m^3)	Targeted experiment
		Over-all depth D	Width B	Length L		
SR101	Rectangle	100	79	400	19.6	Bending strength
SR102		100	82	400	19.5	
SQ101		50	70	400	19.4	
SQ102		50	82	400	19.4	
SR103		50	58	400	13.5	
SR104		50	45	400	17.2	
PA30-M1	Circle	Diameter φ= 50		100.5	13.9	Compressive strength
PA30-M2				99.7	18.1	
PA60-M1				96.2	11.7	
SN101		Diameter φ=100		196.5	18.8	
SN102				179.5	19.2	

6.2 Method of Loading and Support

In the case of the experiment of the compressive strength, the 1000kN Amsler type testing machine is used.

For the experiment of the bending strength, two point symmetry concentrated loads was applied to the specimens under the simple support. The 200kN hydraulic ram was used for monotonic loading. The distance between support points was 300mm and the distance between forces was 100mm.

Fig.2 shows locations of loading and support points.



L : Length B : Width D : Over-all depth

(Note) Unit of length: mm

Fig. 2 Location of loading and measurement

6.3 Measurement

(1) Experiment of compressive strength

For the cylindrical specimen (diameter φ=100mm ×200mm), in order to obtain the stress-strain curve, two pieces of strain gages for concrete (the inspection length 30mm) were pasted on the center of the both sides of the specimen and then strains were measured. However, for the cylindrical specimen of φ=50mm×200mm, only maximum load was measured.

(2) Experimental investigation of bending strength

The 100kN load cell was used to measure the loads. The deflection in center were measured by using displacement sensors set at the side walls (the inspection length 30mm) and the strain of the bottom surface which was tensile side were measured by using strain gages (the inspection length 2mm) which pasted to the bottom walls.

Table 7 Results about experiments of compressive strength

Name of Specimen	water-cement ratio(%)	Weight per unit volume (kN/m^3)	Compressive strength (N/mm^2) [age(in days)]	Elastic modulus (×10^4 N/mm^2)
SN101	30	1.88	58.29 [62]	2.00
SN102	30	1.92	83.94 [62]	2.65
PA30-M1	30	1.35	29.66 [61]	—
PA30-M2	30	1.76	60.33 [51]	—
PA60-M1	60	1.14	10.19 [51]*	—

(Note) * : This is a value read from the instruction meter of Amusrar examination machine.

7. EXPERMENTAL RESULTS

7.1 Result of Experiment for Compressive Strength

Table 7 shows experimental results of the compressive strength. Fig. 3 shows the compressive stress-strain curves of two specimens of SN101 and SN102. The curves of two specimens were both extended in the straight line until its maximum load. This stress-strain curve illustrated remarkable difference with that

Table 8 Results about experiments of bending strength

Name of specimen	Maximum load P (N)*	Deflection of a center point (mm)	Section modulus (×10^3 mm^3)	Bending strength (N/mm^2)
SR101	1415	0.09	131.67	1.07
SR102	1395	0.08	136.67	1.02
SQ101	465	0.03	29.17	1.59
SQ102	580	0.00	34.17	1.70
SR103	1125	0.19	24.17	4.66
SR104	1615	0.14	18.75	8.61

(Note) * : Maximum load P is a value per one location. See Fig.2.

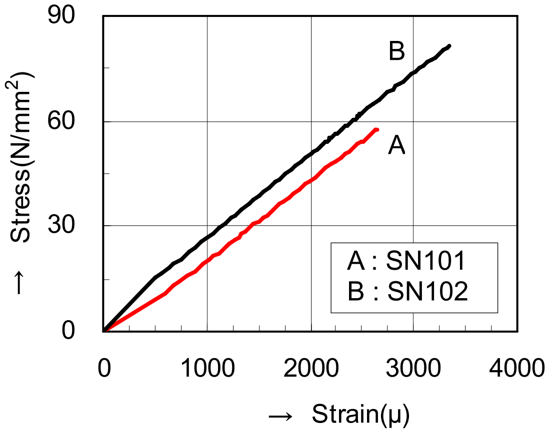


Fig. 3 Compressive stress-strain curve

of the general concrete which was mixed with fine and coarse aggregates. The difference between SN101 and SN102 were whether it had the air-entraining admixture (alkyl ether anion surfactants) or not. The air-entraining admixture of 0.003% concerning the weight of cement was added to the specimen of SN102. As a result, the compressive strength and the elastic modulus were about 1.4 times and 1.3 times higher than those of SN101.

The remarkable difference between PA30-M1 and PA30-M2 were the kinds of additives to increase the bending strength. While styrene modified acrylic resin which expects to increase the bending strength could reduce the weight per unit volume of the hard PS ash lumps, the compressive strength was about 0.5 times lower than that when acrylic ester copolymer resin was used. Furthermore, the compressive strength of PA60-M specimen was low and therefore the acrylic copolymer resin was seen to reduce the compressive strength considerably.

7.2 Result of Experiment for Bending Strength

Table 8 shows the list of experimental results for the bending strength. Fig. 4 shows the load-deflection curve at the central point and Fig. 5 shows the load-strain curves at the bottom of the central position of specimens. There is no remarkable difference between the maximum loads of 4 specimens. This is because the dimensions of sections were different from each other.

Fig. 6 shows the relation between the bending stress and strain at the bottom of the central position of each specimen. The bending stress was calculated by dividing bending moment at the central position by the section modulus.

For the SR101 and SR102 specimens, one vertical crack initiated and grew from the bottom surface to the top surface around the central part at the maximum load and instantaneous fracture occurred toward the top surface. The bending strengths at the maximum load of any specimens were about 1.1N/mm^2. These were only about 0.01-0.02 time of the compressive strength of specimens SN101 and SN102 which had same composing materials. Therefore, comparing to the compressive strength, the bending

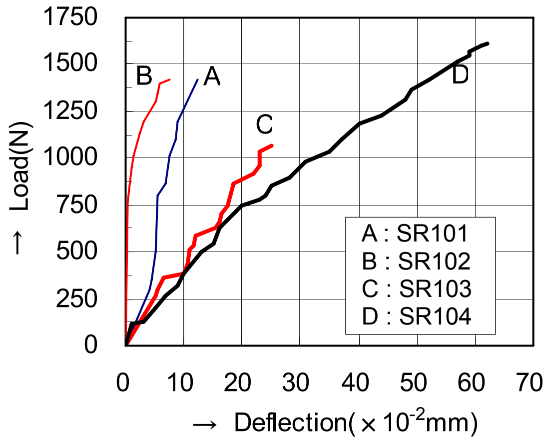


Fig. 4 Load-deflection curve

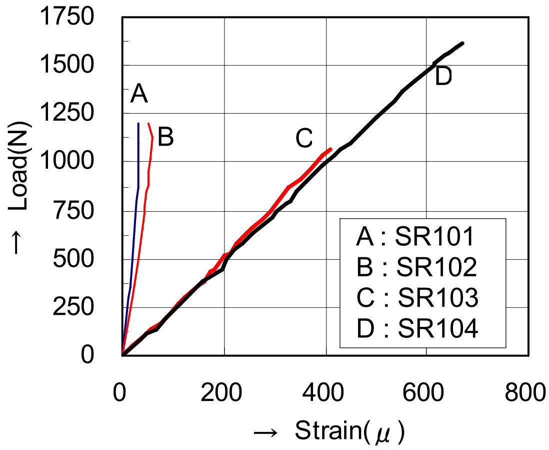


Fig. 5 Load-bending strain curve

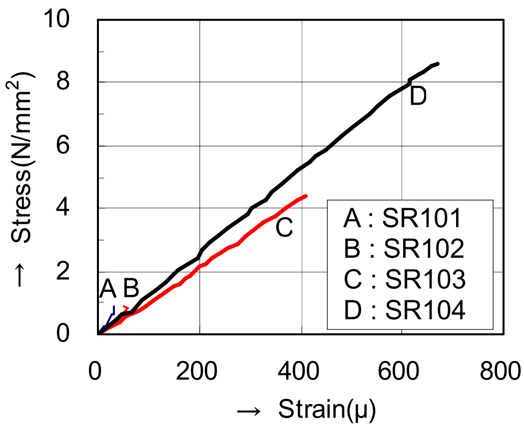


Fig. 6 Bending stress-strain curve

strength was fairly low. Specimens SQ101 and SQ102 had same result.

The difference between specimen SR101 and SR102 depended on the air-entraining admixture. However, the difference in the bending strength of these specimens could not be observed.

The difference between the group of SQ101/ SQ102 specimens and the group of SR101/SR102 specimens were the cross-sectional shape. The bending strength of the latter specimens, which had large width in comparison with height, had 1.7 times as compared with that of the former specimens.

Also, the bending strength of these two specimens had about 0.02-0.03 times as compared with of the compressive strength of the group of SN101/SN102 specimens. It was considerably low, too.

The bending strength of specimen SR104 added acrylic ester copolymer resin was about 8 times as compared with that of SR101 or SR102. Therefore, it was shown that this resin greatly contributes to increasing of the bending strength. When specimen SR103 was compared with SR104, styrene modified acrylic resin contributed to increase of the bending strength, too. But, from comparison with SN101 and SN102, this resin showed a tendency to decrease the compressive strength, as shown in Table 7. Therefore, although it contributed to the increase of the bending strength, it was presumed this resin had the character to decrease the compressive strength.

Furthermore, as shown in Fig. 6, the relation between the bending stress and strain is linear and elastic until stress reached to the bending strength.

8. CONCLUSION

In this paper, the compressive strength and the bending strength of the mixture made from paper sludge ash and cement were examined. The main features found in these results are described as follows:

(1) The PS ash lump kneaded super hardly by use of both the highfrequency vibration table which is vibrating up and down over 150Hz and the churning machine which engine speed is over 1000rpm, could expect to obtain high compressive strength so to be higher than about $60N/mm^2$ after hardening. However, the bending strength was considerably low.

(2) The PS ash lump that added acrylic ester copolymer resin was able to increase the bending strength about 8 times or more, compared with the case not added.

(3) The bending stress of the PS ash lumps reached to the bending strength showing elastic behavior when acrylic ester copolymer resin was added. Also, the compressive stress-strain relation almost behaved elastically.

(4) Even if the same type of acrylic resin was used, the addition of styrene modified acrylic resin or acrylic copolymer resin led to decrease the compressive strength, moreover, did not contribute to increase of the bending strength largely.

(5) Even if it was the same type of acrylic resin, adding a styrene modified acrylic resin or acrylic copolymer resin did not reduce the compressive strength and largely increase of the bending strength.

Consequently, according to experimental results, it seemed possible to adopt PS ash lump as a substitute for the concrete.

REFERENCES

[1] Japanese Basic Environment Law, No.91, February 1993

[2] Japanese Architectural Standard Specification JASS 5 Reinforced Concrete Work, June 1997