APPLICATION OF FLY ASH TO CONCRETE PAVING BLOCK

Karasawa, A.[1], Suda, S.[2], Naito, H.[3] and Fujiwara, H.[4]

[1]Research and Development Centre, Taiheiyo Cement Corporation, Japan.
[2]Technical Support Department, Kansai Branch, Taiheiyo Cement Corporation, Japan.
[3]Office of Civil Engineering and Architecture, The Kansai Electric Power Co., Inc., Japan.
[4]Research and Development Department, The Kanden Kakou Corporation, Japan.

ABSTRACT

The amount of coal combustion by-products in Japan has been increasing recently due to the increased number of coal-fired power plants. The demand for more effective applications for recycling coal ash than the conventional use as a substitute for clay in cement has become intense.

This study investigated the applicability of fly ash as a substitute for fine aggregate in concrete paving blocks, which is regarded as inferior in quality to concrete of the Japanese Industrial Standard specifications, by testing the fresh properties and strength characteristics.

The results show that if fly ash accounts for 25% of the mixture of fly ash and cement by weight, the plastic deformation during demoulding and curing and the flexural strength satisfy the target values of 1 mm and 6 MPa. The authors conclude that fly ash can be used as a substitute for fine aggregate in the production of concrete blocks for pavement.

1. INTRODUCTION

In recent years in Japan, the amount of coal ash produced by coal-fired power plants has been increasing as the number of new and expanded coal-fired power plants has risen, and is expected to reach around 10 million tons per year by 2005. Figure 1 shows the transition of coal ash generation in Japan. Disposal of coal ash is broadly classified into two categories: recycling and landfills. In recycling, coal ash is mainly used as a substitute for the clay in cement, where approximately 0.1 ton of coal ash is used to produce 1 ton of cement. Other uses include, though not in large quantity, as an admixture for cement and concrete and as a material for a variety of agricultural, civil engineering and construction works. Regarding landfills, the potential landfill capacity is estimated to be no more than 1.5 million tons a year, because domestic landfills are becoming scarce. In addition, the cement industry has been pressed by local governments to accept domestic wastes such as household rubbishes and sludge incineration ash. In view of these circumstances and the fact that the demand for cement is unlikely to accelerate over the coming years, the capacity for disposing of coal ash will soon be exceeded, and so effective new applications will need to be developed.

The authors therefore investigated the applicability of raw fly ash for concrete paving blocks. Raw fly ash, which has not been classified by grading, is commonly regarded to be inferior in quality to fly ash products that comply with JIS specifications. In this study, tests were conducted on the fresh properties and the strength characteristics of concrete paving blocks in which a large amount of raw fly ash was used in place of fine aggregate.

Proceedings of the 7th International Conference on Concrete Block Paving (PAVE AFRICA 2003) 12th – 15th October 2003
ISBN Number: 0-958-46091-4 Sun City, South Africa
Proceedings produced by: Document Transformation Technologies Conference Organised by: Conference Planners

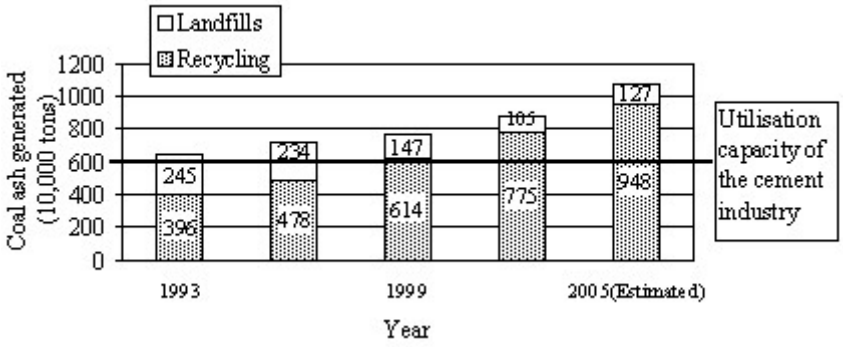

Figure 1. Transition of coal ash generated in Japan.

2. OUTLINE OF THE TEST

2.1 Materials used

Fundamental properties of the materials used for the test are listed in Table 1. The physical and chemical properties of fly ash are shown in Table 2. The material symbols shown in Table 1 are used throughout this paper.

The properties of all the fly ash used in the test comply with "Fly Ash Class II" of JIS 6201 "Fly Ash for Concrete Applications" except for the flow ratio which is smaller than the standard value. Generally, the flow ratio is an indicator of the flowability in concrete containing fly ash. For concrete with a high slump, if fly ash with smaller flow ratio is used, a higher unit water content is needed to obtain the required flowability.

Table 1. Fundamental properties of materials used.

Material used	Symbol	Nature	Density (g/cm^3)	Grain size (mm)	Fineness modulus FM
Water	W	Tap water	1.00	-	-
Cement	OPC	General Portland cement	3.14	-	-
Fly ash	FA	Coal ash	2.15	-	-
Coarse aggregate	G1	Crushed stone	2.64(surface dry)	13 - 5 (not inclusive)	6.23
	G2	Crushed stone	2.64(surface dry)	5 - 2.5 (not inclusive)	4.92
Fine aggregate	S	Land sand	2.59(surface dry)	2.5 or more	2.89

Table 2. Physical and chemical properties of fly ash.

Item to be tested		Fly ash	JIS value (Fly ash class II)
Physical properties	Density (g/cm^3)	2.15	1.95 or more
	Specific surface area (cm^2/g)	4520	2500 or more
	Residue on 45 μm sieve (%)	23	40 or less
	Flow ratio (%)	92	95 or more
	Activity index (%) 28-day	82	80 or more
Chemical properties	Ignition loss (%)	3.7	5.0 or less
	Moisture content (%)	0.2	1.0 or less
	Methylene blue adsorption (mg/g)	1.20	Not stipulated

2.2 Specimen production and curing conditions

The specimens were produced by using a compact concrete block making machine which is capable of producing the pieces under the same conditions as the production machine.

The machine was set up as follows: the frequency was 72.5 Hz, the amplitude was 0.7 mm, the applied pressure was 0.123 MPa, and the main vibration time was 7 seconds. The specimens were rectangular type (no wavy shape on the sides) each of dimensions 98 mm wide, 198 mm long and 80 mm deep. The concrete was placed in one-lift. The specimens were cured in a temperature/humidity test chamber at a constant temperature of 20°C and a relative humidity of 70% until they reached the stipulated material ages.

2.3 Mix design conditions

The cement content of each mix was equalised as 330 kg/m^3, the average cement content of concrete blocks in production. Fly ash was used to replace part of the fine aggregate of each mix. The replacement with fly ash was tested at three levels: 0%, 25% (110 kg/m^3) and 40% (220 kg/m^3) of the cement weight (FA replacement ratio).

Dry cast concrete requires a mix proportion that facilitates a high filling capacity, small plastic deformation at both demoulding and curing, and good finished appearance. However, a large amount of fine grains such as fly ash in the mix causes a large plastic deformation at demoulding and curing, deteriorating the dimensional quality of the products. To resolve this contradiction, an optimal blending ratio of fine and coarse aggregates (optimal composite FM) must be found to satisfy those requirements of the dry cast concrete.

In this test, test mixes were made according to each combination of the FA replacement ratio and the composite FM of the aggregate used, and the water content was confirmed when water was completely segregated at the time of moulding or demoulding. The confirmed water content minus 5 kg/m^3 was determined as the unit water content at the moulding limit. Also, three levels of unit water content were set: (1) W1 = unit water content at moulding limit, (2) W2 = W1 minus 10 kg/m^3, and (3) W3 = W1 minus 20 kg/m^3. At the factory, the unit water content is controlled within the range of W1 through W2 with an allowance of up to W3.

The composite fineness modulus (FM) is represented by Equation 1:

$$\text{Composite FM} = \Sigma \left(\frac{\text{Percentages of the weights of remains on the sieves of 80, 40, 20, 10, 5, 2.5, 1.2, 0.6, 0.3 and 1.5 mm against the total aggregate weight}}{100} \right) \quad (1)$$

2.4 Product standard values and target values in production

The product standard values of dry cast concrete blocks for pavement in Japan and the target values in production used in this test are shown in Table 3. If the plastic deformation of dry cast concrete blocks for pavement becomes larger than the standard value, cracks may appear on the surface mortar or the product may be deformed. Based on the experience, the production target value of deformation was set to at most 1 mm. The production target value of the flexural strength was set to the value used by most factories, that is, 1.2 times that of JIPEA[1)]/JASS[2)] standards.

Table 3. Product standard values of concrete paving blocks in Japan and production target values used in this test.

Item	Description	
Filling capability	No standard value or no target value in production:	The higher, the better
Plastic deformation	Production target value	At most 1 mm each in width and length
Product dimensions	Standard value	At most ±2.5 mm each in width and length At most ±2.5 mm in thickness
Flexural strength	Standard value	At least 5.00 MPa
	Production target value:	At least 6.00 MPa

2.5 Test procedures

To evaluate fresh properties, the filling rates of the concrete paving block specimens were obtained by Equation 2 based on the dimensions and weights measured immediately after moulding. The plastic deformation was then calculated as the difference between the dimensions of the specimens immediately after moulding and those after hardening, using Equations 3 and 4.

To evaluate hardening properties, flexural strength tests were performed on the 7-day and 28-day specimens. Figure 2 shows the test configuration. The test method complies with the method[1)] stipulated by the Japan Interlocking Block Pavement Engineering Association, with the span set to 150 mm and the loading point at its centre. The hardened specimens were visually inspected for honeycombs, cracks, deformation or discoloration.

$$\text{Filling rate (\%)} = \frac{\text{Weight of concrete paving block specimens immediately after moulding (kg)}}{\text{Weight of concrete paving bock with the air void of 0\% (kg)}} \times 100$$

$$= \frac{\text{Weight of concrete paving block specimens immediately after moulding (kg)}}{\Sigma \left(\begin{array}{l}\text{Unit quantity of the materials used (kg/m}^3\text{) x Volume of concrete paving block} \\ \text{specimens immediately after moulding (m}^3\text{)}\end{array} \right)} \times 100 \quad (2)$$

Plastic deformation in the directions of width and length (mm) = $W_2 - W_1$ (3)

Plastic deformation in the direction of thickness (mm) = $H_2 - H_1$ (4)

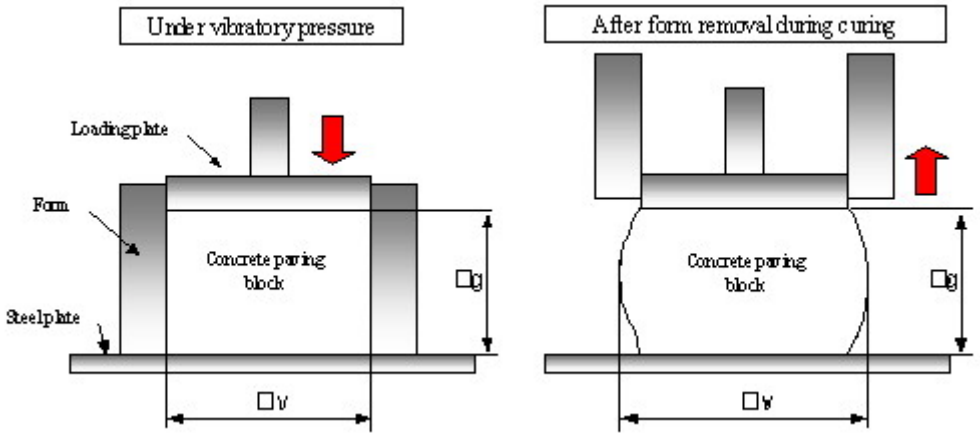

Figure 2. Plastic deformation.

3. TRIAL MIXING TO SELECT APPROPRIATE MIXES

The relationship between the composite FM and the filling rate is shown in Figure 3. The relationship between the composite FM and the plastic deformation is shown in Figure 4. From these figures, it was confirmed that for each FA replacement ratio there was a composite FM that provides a maximum filling rate. Such composite FM was 3.96 for the FA replacement ratio of 0%, 4.23 for 25%, or 4.77 for 40%.

It was also confirmed that increasing the composite FM minimized the plastic deformation. The plastic deformation for the FA replacement ratio of 25% and that for the FA replacement ratio of 0% may be considered to be almost the same level.

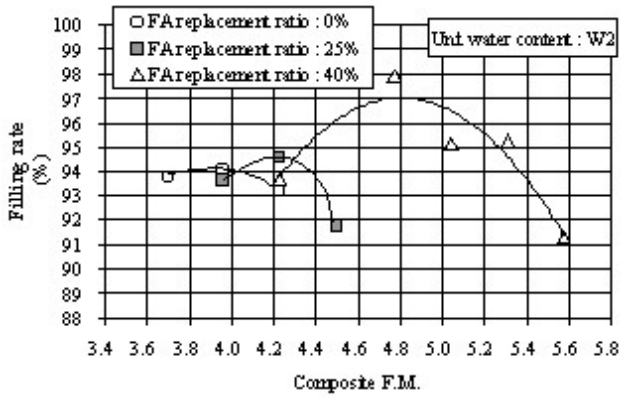

Figure 3. Relationship between composite FM and filling rate (mean values).

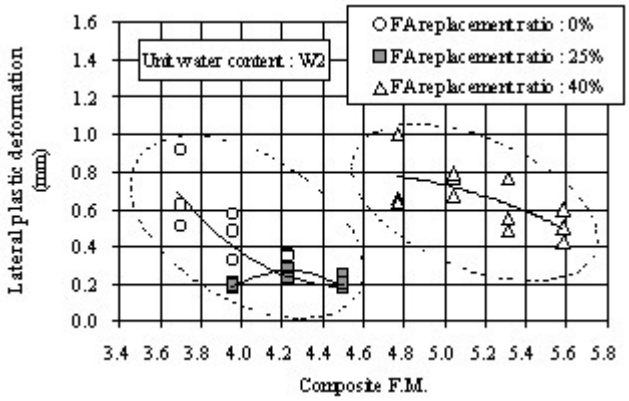

Figure 4. Relationship between composite FM and plastic deformation (individual values).

4. MIXES SELECTED

The dry cast concrete mixes selected based on the results of the trial mixing are shown in Table 4. For the FA replacement ratio of 0%, a mix with FM of 4.23 was selected because the plastic deformation was approximately halved compared to FM of 3.96 despite the fact that the latter provided 1% less filling rate than the former. For the FA replacement ratio of 25%, a mix with FM of 4.23 which achieved a high filling rate and small plastic deformation was selected. For the FA replacement ratio of 40%, a mix with FM of 4.77 which provided a high filling rate and satisfied the production target value (at most 1 mm) was selected, even though it gave somewhat larger plastic deformation.

Table 4. Dry cast concrete mixes selected.

Composite FM	FA replacement ratio*1 (weight %)	Unit water content set *2	Unit content (kg/m^3)					
			W	OPC	G1	G2	S	FA
4.23	0	W1	125	330	503	503	1007	0
		W2	115		510	510	1020	
		W3	105		516	516	1033	
	25	W1	150		453	453	906	110
		W2	140		460	460	920	
		W3	130		466	466	932	
4.77	40	W1	180		563	563	482	220
		W2	170		572	572	490	
		W3	160		581	581	498	

*1) FA replacement ratio = FA / (OPC + FA)
*2) W1 = Unit water content at moulding limit, W2 = W1-10 kg/m^3, W3 = W1-20 kg/m^3

5. RELATIONSHIPS BETWEEN FA REPLACEMENT RATIO AND OTHER FACTORS TO BE CONSIDERED IN CONCRETE MIX DESIGN

As the result of the trial mixing, the following findings on relationships between the FA replacement ratio and other factors in concrete mix design were obtained.

5.1 FA replacement ratio and unit water content

The relationship between the FA replacement ratio and the unit water content is shown in Figure 5. It was apparent that the unit water content increased as the FA replacement ratio was increased, and this tendency was much stronger where the substitution ratio was larger.

5.2 FA replacement ratio and composite FM

The relationship between the FA replacement ratio and the composite FM is shown in Figure 6.

The composite FM of the mix with the FA replacement ratio of 25% was the same as that of 0%. For the mix with the FA replacement ratio of 40%, however, the composite FM showed a tendency to increase.

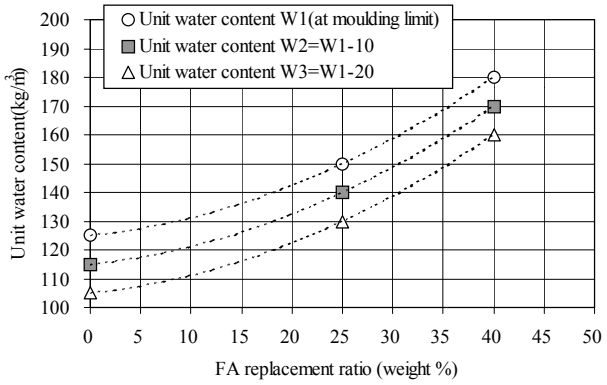

Figure 5. Relationship between FM replacement ratio and unit water content

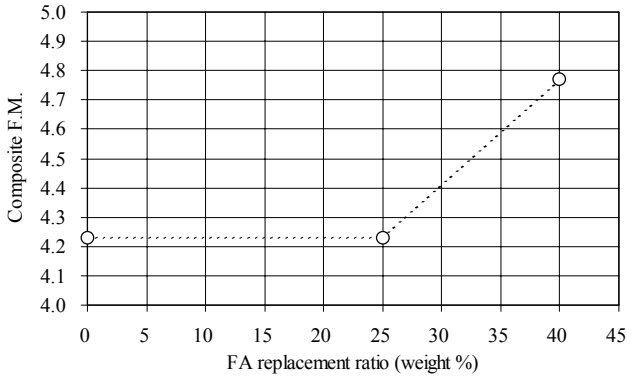

Figure 6. Relationship between FM replacement ratio and composite FM

6. TEST RESULT OF SELECTED MIXES AND FINDINGS

6.1 Fresh properties

6.1.1 FA replacement ratio, unit water content, and filling rate

The relationships among the FA replacement ratio, the unit water content, and the filling rate are shown in Figure 7. When identical unit water contents (W1, W2, and W3) were set for each of the FA replacement ratios, it was observed that the filling rate increased in accordance with the increase of the FA replacement ratio. For each FA replacement ratio, it was observed that the filling rate increased almost in proportion to the increase of the unit water content.

6.1.2 FA replacement ratio, unit water content, and plastic deformation

The relationships among the FA replacement ratio, the unit water content, and the plastic deformation are shown in Figure 8. When an identical unit water content was set for each of the FA replacement ratios, it was observed that the plastic deformation increased as the FA replacement ratio was increased. For the mix with the FA replacement ratio of 0%, the production target value (at most 1 mm) was satisfied for all the unit water content levels. For the mix with the FA replacement ratio of 25%, the production target value was almost satisfied for all the unit water content levels. For the mix with the FA replacement ratio of 40%, however, the plastic deformation was found to largely exceed the production target value for the unit water content at the moulding limit.

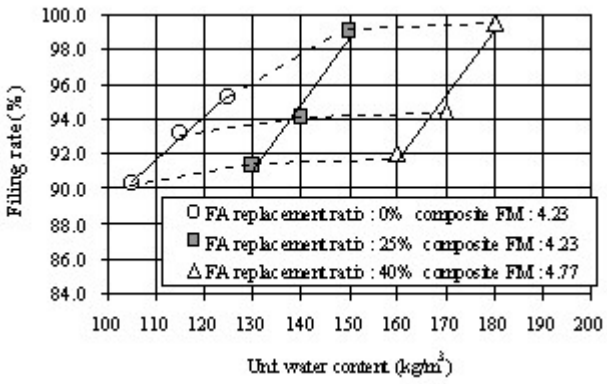

Figure 7. Relationships among FM replacement ratio, unit water content and filing rate (mean values)

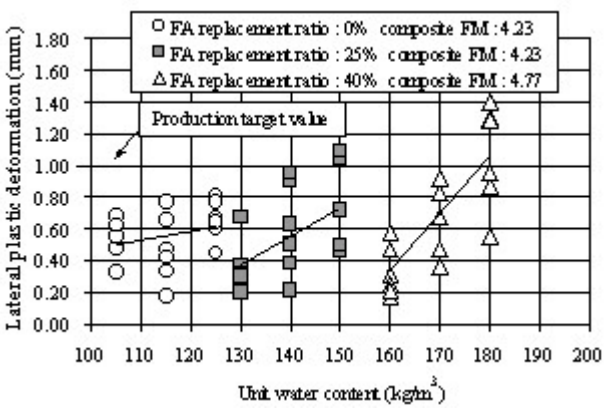

Figure 8. Relationships among FM replacement ratio, unit water content and plastic deformation (individual values)

6.2 Hardening properties

6.2.1 FA replacement ratio, unit water content and flexural strength at the age of 7 days

The relationships among the FA replacement ratio, the unit water content and the flexural strength of the 7-day specimens are shown in Figure 9. When identical unit water content was set, the 7-day flexural strength decreased with increases in FA replacement ratio. This tendency was particularly strong when the FA replacement ratio is 40%.

For the mix with the FA replacement ratio of 0%, the flexural strength satisfied the production target value (at least 6.00 MPa) with the unit water content that is used as the basis of water control at the factory, ranging from W1 (unit water content at moulding limit) through W2 (W1 minus 10 kg/m^3). It also satisfied the standard value (at least 5.00 MPa) with W3 (W1 minus 20 kg/m^3). For the mix with the FA replacement ratio of 25%, the flexural strength almost satisfied the production target value (at least 6.00 MPa) with the unit water content, ranging from W1 through W2. For the mix with the FA replacement ratio of 40%, the flexural strength for W1 through W2 satisfied the standard value but failed to satisfy the production target value. For W3, even the standard value was not satisfied.

With every FA replacement ratio, it was observed that the flexural strength at the age of 7 days increased with increases in unit water content.

6.2.2 FA replacement ratio, unit water content and flexural strength at the age of 28 days

The relationships among the FA replacement ratio, the unit water content and the flexural strength at the age of 28 days are shown in Figure 10. For all the mixes with the FA replacement ratios of 0%, 25% and 40%, the flexural strength satisfied the target value in production (at least 6.00 MPa) for every level of the unit water content. With identical unit water content being set, the differences of the flexural strength for individual FA replacement ratios were smaller than those of the age of 7 days.

With every FA replacement ratio, it was observed that the 28-day flexural strength increased with increases in unit water content.

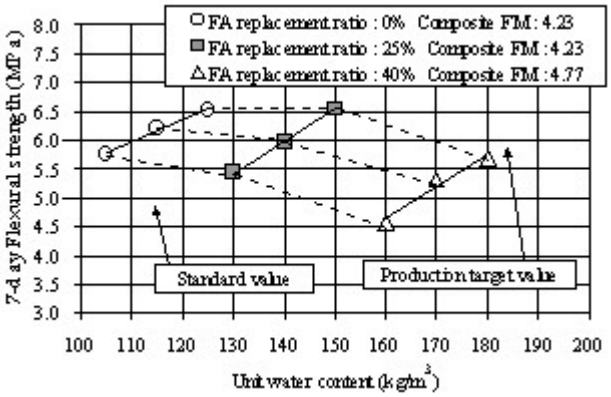

Figure 9. Relationships among FM replacement ratio, unit water content, and 7 day flexural strength (mean values)

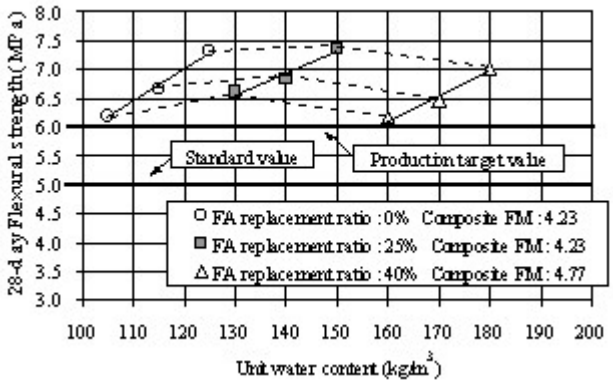

Figure 10. Relationships among FM replacement ratio, unit water content, and 28 day flexural strength (mean values)

6.3 Summary

6.3.1 Strength development of concrete paving blocks with fly ash

The flexural strength tended to be reduced as the FA replacement ratio increased. This tendency was stronger in the 7-day specimen than in the 28-day one.

This reduction in strength may be explained as the result of substantially increased water-cement ratio caused by the largely increased unit water content due to the increase in the FA replacement ratio, while the increase in the filling rate was at a minimal level.

6.3.2 Finished status
As the result of the visual inspection, no honeycombs, cracks or outstanding deformation were found on hardened paving dry cast concrete blocks in every mix tested.

The surface colours of the concrete blocks in the mixes with FA replacement ratios of 25% and 40% were slightly darker than that with the fly ash substitution ratio of 0%. This slight coloration would not cause a significant problem when used as the base layer of concrete placed in two lifts.

7. CONCLUSION ON APPLICABILITY OF FLY ASH TO CONCRETE BLOCKS FOR PAVEMENT

The concrete paving blocks with the FA replacement ratio of 25% satisfied the production target value of the plastic deformation (at most 1 mm), at the unit water content which is used as the basis of water control at the factory, where the unit water content ranges from "the unit water content at the moulding limit" through "the unit water content at the moulding limit minus 10 kg/m^3." Also, this mix satisfied the target production value of the 7-day flexural strength (at least 6.00 MPa).

For the mix with the FA replacement ratio of 25%, the dry cast concrete blocks for pavement satisfied the production target value of the plastic deformation (at most 1 mm) for the unit water content which is used as the basis of water control at the factory. The unit water content ranges from "the unit water content at the moulding limit" through "the unit water content at the moulding limit minus 10 kg/m^3." From this observation, it is considered that fly ash (25% content) can be used as a substitute for fine aggregate in concrete.

For the mix with FA replacement ratio of 40%, the dry cast concrete blocks for pavement exceeded the production target value of the plastic deformation at the unit water content used as a basis of water control at the factory. In addition, this mix did not satisfy the production target value of the 7-day flexural strength. From this finding, fly ash (40% content) is considered inappropriate as a substitute for fine aggregate in concrete.

8. FUTURE PLANS

The authors' future plans include establishing the mix design method and production technology for actual production in the factory, and evaluating the performance of the blocks on site in long-run operation.

9. REFERENCES

Japan Interlocking Block Pavement Engineering Association, 2000, "Interlocking Block Pavement Engineering Design and Build Guidelines, Interlocking Block Pavement Quality Standard", pp.68 - 71

Architectural Institute of Japan, 2000, "Japanese Architectural Standard Specification JASS 7, Masonry Construction M-101, Interlocking Block Pavement Quality Standard", p.p363 - 383

APPLICATION OF FLY ASH TO CONCRETE PAVING BLOCK

Karasawa, A.[1], Suda, S.[2], Naito, H.[3] and Fujiwara, H.[4]

[1]Research and Development Centre, Taiheiyo Cement Corporation, Japan.
[2]Technical Support Department, Kansai Branch, Taiheiyo Cement Corporation, Japan.
[3]Office of Civil Engineering and Architecture, The Kansai Electric Power Co., Inc., Japan.
[4]Research and Development Department, The Kanden Kakou Corporation, Japan.

A BRIEF RESUME OF AKIHIKO KARASAWA

Graduated from Gumma National College of Technology and entered Taiheiyo Cement Corporation in 1984.

Worked at The Central Research Center for the last 19 years and engaged in studying dry-mix concrete products including concrete paver.

Recently engaging in utilizing industrial by-products and wastes to concrete products.

Today's paper covers the results of a co-research with a power company on effective usage of fly-ash produced in the power company to concrete paver.