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SYSTEMATIC FORMULATION OF HIGH PERFORMANCE CONCRETE PAVEMENT

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ABSTRACT

Following a 2^{5-1} fractional factorial design concept, an experiment was planned ; sixteen experimental mixes were calculated from a basic mix (cement : sand : aggregates : fly ash = 1 : 1.3 : 2.6 : 0.8 and W/C ratio of 0.37) and determined changes (cement = 0.1 ; sand = 0.1 ; aggregates = 0.2 ; fly ash = 0.04 and changing W/C ratio by 0.01) using Taguchi's orthogonal array. Samples were made from each data point. Compressive strength and water absorption were determined after each of two curing conditions (a) 28 days in the water, (b) 28 days in the water and 32 days in the air after that. Mix no 12 [Cement : Sand : Gravel : Fly Ash = 0.9 : 1.2 : 2.8 : 0.76] was found to have highest compressive strength and lowest water absorption.

Keywords: fractional factorial, fly ash, water absorption, compressive.

INTRODUCTION

The Indonesian development in construction during this globalization era is very rapid and as a result, the need of construction materials is increasing rapidly. Since the supply of such materials is not increasing at the same rate, there is increase of price. If the waste materials can be used to make useful construction materials, the price of such materials can be kept down.

Fly ash is a waste material obtained in thermal power plants and other plants during burning of pulverised coal. Fly ash has been studied extensively as a material and from the point of view of its impact on the environment. In this research we have shown a method to make concrete pavement using fly ash as one component.

Most of the paving bricks normally used here do not meet the international standard. It has been shown in this research that by systematic formulation paving bricks of very high quality can be made using fly ash. People generating fly ash and those utilizing it for product development will find this research beneficial. Those who use products made with fly ash will also benefit in terms of lower buying cost. In recent years, there has been a growing interest to develop cementitious products using fly ash.

Note: Discussion is expected before November, 1st 2005. The proper discussion will be published in "Dimensi Teknik Sipil" volume 8, number 1, March 2006.

Roller Compacted Concrete with improved properties has been made using fly ash and water reducing admixture in the formulation and utilizing the vibrating roll compaction technology [1].

Considerable saving of cost can be achieved in making ready mix concrete by using up to 30% of standard quality fly ash [2]. High Performance concrete has been made incorporating fly ash in the formulation [3].

Asphalt concrete made by replacing 10% fine aggregate by ash can be successfully used in road construction. This replacement could fulfill all standard requirements except the air void. To improve the air void, an additive (chemcrete) can be added. The use of chemcrete can increase the stability and improves the air void of asphalt concrete [4].

Fly ash has also been used in formulation of crack free mortar [5]. The preliminary study on paving bricks from five randomly selected sources gave the following compressive strength and cost values (Table 1).

Table 1. Mean Compressive Strength and Cost of Five Locally Available Paving Bricks

Source Number	Strength ,MPa	Price/m² (Rp)
1	42.4	25,500
2	24.0	22,600
3	33.1	24,000
4	27.3	23,800
5	20.4	24,000

However the BS 6717: Part 1 requires the paving bricks to have a minimum strength of 49 MPa. The weakness of the bricks can't be understood from the appearance but this weakness is responsible for premature failure of many road pavement requiring early repair and replacement [6]. Fly ash is rich in silica and alumina. The chemical composition of a typical fly ash is given in Table 2.

Table 2. Typical Analysis of a Fly Ash

Oxide Constituent	Weight (%)
SiO_2	60.0
$Al2O_3$	24.0
Fe_2O_3	5.0
TiO_2	1.0
CaO	4.0
MgO	1.0
Na_2O	0.2
K_2O	1.8
L.O.I	3.0
Total	**100.0**

Al_2O_3 forms mullite (M) with SiO_2 and the remaining SiO_2 is present as Quartz (Q) in fly ash. Typical X-ray diffraction pattern of fly ash is shown in figure 1; the figure indicates the presence of quartz and mullite as the two major phases.

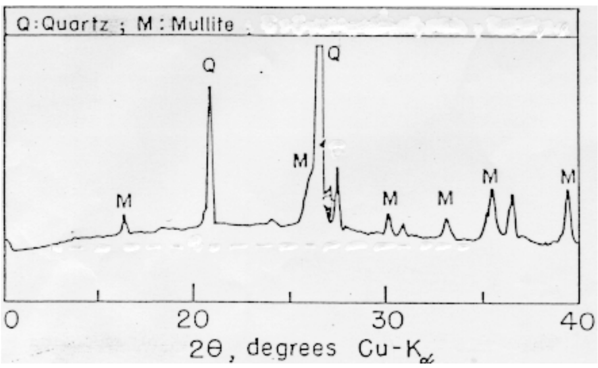

Figure 1. Typical X-ray Diffraction Pattern of Fly Ash

In this research sixteen experimental formulations based on a 2^{5-1} fractional factorial design were studied for compressive strength and water absorption. The size fractions and the fineness modulus of the sand and the coarse aggregate used were also measured. A further study of the effect of replacement of sand by fly ash was done.

EXPERIMENTAL

Sieve numbers 10mm to 0.063mm were used for the sieve analysis of the sand and the gravel used in this experiment [7]. The sieve analysis of the sand and the gravel used are given in Table 3.

Table 3. Sieve Analysis of Sand and Aggregate

Sieveness Number	Gravel		Sand	
	% Weight Retained	Σ % Weight Retained	% Weight Retained	Σ % Weight Retained
10.000*	0.202	0.202		
5.000*	12.340	12.542	0.000	0.000
2.360*	72.730	85.272	0.510	0.000
1.180*	5.481	90.753	0.204	0.510
0.600*	2.354	93.107	0.204	0.714
0.300*	1.311	94.418	25.400	0.918
0.150*	1.614	96.032	69.450	26.318
0.063	2.656	98.688	4.182	95.768
Bottom	1.312	100.000	0.050	100.000
Total	100.000		100.000	

* = standard of sieve to calculate the fineness odulus

From the sieve analyses the calculated fineness modulus of the sand and of the gravel were 1.24 and 4.72 respectively. Standard Portland cement of Gresik Cement Type I and municipal water were used. Fly ash used was obtained from Tjiwi Kimia. Madiun sand and coarse aggregate were used. Compressive Strength was measured using Compression Machine in Cement Gresik as per BS 6717; Part 1 1986. Water absorption of each sample was also measured from the dry weight and the wet weight of the samples [6].

Using a basic formula (cement : sand : aggregates : fly ash = 1:1.3:2.6:0.8 and W/C ratio of 0.37) and fixed change in each constituent (cement = 0.1 ; sand = 0.1 ; aggregates = 0.2 ; fly ash = 0.04 and changing W/C ratio by 0.01) 16 experimental mixes were determined following Taguchi's orthogonal array. Each factor was studied at two levels [8]. The sixteen mixes thus obtained are given in Table 4.

Table 4. Sixteen Experimental Mixes

No Treatment	Cement (A)	Sand (B)	Gravel (C)	Fly Ash (D)	W/C (E)
1	1.1	1.4	2.8	0.84	0.38
2	1.1	1.4	2.8	0.84	0.36
3	1.1	1.4	2.8	0.76	0.38
4	1.1	1.4	2.8	0.76	0.36
5	1.1	1.2	2.4	0.84	0.38
6	1.1	1.2	2.4	0.84	0.36
7	1.1	1.2	2.4	0.76	0.38
8	1.1	1.2	2.4	0.76	0.36
9	0.9	1.2	2.8	0.84	0.38
10	0.9	1.2	2.8	0.84	0.36
11	0.9	1.2	2.8	0.76	0.38
12	0.9	1.2	2.8	0.76	0.36
13	0.9	1.4	2.4	0.84	0.38
14	0.9	1.4	2.4	0.84	0.36
15	0.9	1.4	2.4	0.76	0.38
16	0.9	1.4	2.4	0.76	0.36

Five cubes (20x10x6) cm3 were made from each mixes and compressive strength as well as water absorption was determined on each cube.

RESULTS

The average compressive strength and the average water absorption of the 16 mixes are given in Table 5.

Table 5. Compressive Strength and Water Absorption Data

	Curing 28 days in water		Curing 28 days in water + 32 days in air after that	
Sample number	Water Abs (%)	Strength (MPa)	Water Abs (%)	Strength (MPa)
1	6.4	44.00	6.2	58.70
2	3.4	50.03	3.1	67.02
3	8.6	37.27	8.4	49.18
4	2.6	51.04	2.4	68.06
5	7.4	41.82	7.2	56.20
6	2.8	51.66	2.5	70.14
7	4.6	52.08	4.3	66.64
8	1.4	58.72	1.1	78.42
9	6.2	48.62	6.0	62.96
10	4.7	49.36	4.5	66.48
11	8.5	42.58	8.3	56.27
12	1.3	61.74	1.2	79.78
13	2.4	51.19	2.2	68.98
14	5.6	49.74	5.4	66.51
15	6.4	48.34	6.3	64.34
16	1.7	57.74	1.5	75.01

The highest strength was obtained in sample number 12 and this sample also had the lowest water absorption after 28 days of curing in water. The effect of keeping the blocks in the room air for additional 32 days caused an average increase of compressive strength of 32.6%. This can be seen in Table 6. This shows the need to keep the blocks in moist storage for a period before actual paving is done.

Table 6. Effect of Extra Curing for 32 Days in Air

Compo-sition	CompressiveStrength (MPa) Curing 28 days in water	Curing 28 days in water + 32 days in the air after that	Strength difference(%)
1	44.00	58.70	3.34
2	50.03	67.02	3.39
3	37.27	49.18	3.19
4	51.04	68.06	3.33
5	41.82	56.20	3.43
6	51.66	70.14	3.57
7	52.08	66.64	2.79
8	58.72	78.42	3.35
9	48.62	62.96	2.94
10	49.36	66.48	3.46
11	42.58	56.27	3.21
12	61.74	79.78	2.92
13	51.19	68.98	3.47
14	49.74	66.51	3.37
15	48.34	64.34	3.30
16	57.74	75.01	2.99
		Mean :	3.25

The measured compressive strength and the water absorption data are found to be related as in figures 2 and 3.

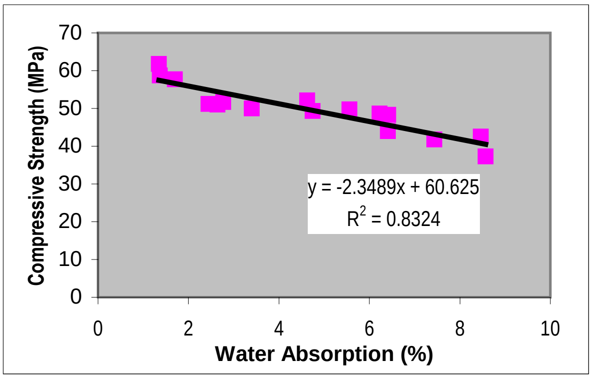

Figure 2. Strength vs Water absorption (Curing 28 days in water)

From the linear regression equation in Figure 2. shows that every 1% water absorption increase will cause 2.3489 MPa strength decrease [9].

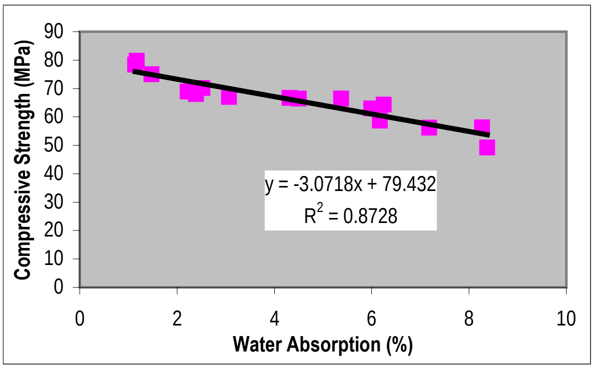

Figure 3. Strength – Water absorption (Curing 28 days in water + 32 days in the air after that)

CONCLUSION

a. Fractional factorial design technique is found useful to develop paving bricks.
b. Composition no.12: Cement : Sand : Gravel : Fly Ash = 0.9 : 1.2 : 2.8 : 0.76 is found, in this study, the best for making paving blocks.
c. Composition no.12 has a compressive strength of 61.7 MPa after curing 28 days in the water.
d. Air curing for 32 days after water curing for 28 days can give 32.58% higher strength.
e. The research shows that economic paving blocks with quality better than BS 6717: Part 1 1986 can be made with local resources.

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