Journal of Marine Science and Technology

Volume 3 | Issue 1 Article 7

Engineering Properties and Application of Cement-Based Fly Ash Blocks

R. Huang
Department of Harbor & River Engineering National Taiwan Ocean University Keelung, Taiwan, R. O. C.

J.J. Chang
Department of Harbor & River Engineering National Taiwan Ocean University Keelung, Taiwan, R. O. C.

W. Yeih
Department of Harbor & River Engineering National Taiwan Ocean University Keelung, Taiwan, R. O. C.

Recommended Citation
Huang, R.; Chang, J.J.; and Yeih, W. (1995) "Engineering Properties and Application of Cement-Based Fly Ash Blocks," *Journal of Marine Science and Technology*: Vol. 3: Iss. 1, Article 7.
DOI: 10.51400/2709-6998.2505
Available at: https://jmstt.ntou.edu.tw/journal/vol3/iss1/7

ENGINEERING PROPERTIES AND APPLICATION OF CEMENT-BASED FLY ASH BLOCKS

R. Huang, J.J. Chang, and W. Yeih

Department of Harbor & River Engineering
National Taiwan Ocean University
Keelung, Taiwan, R. O. C.

Key words: fly ash, environmental protection, properties, strength.

ABSTRACT

Under the consideration of environmental protection, direct disposal of coal ash is not acceptable. It is required to solidify fly ash before ocean disposal or land disposal. The objective of this study is to investigate the properties and the possible applications of the solid blocks produced from fly ash. Thirty-six mixes have been proportioned using different cementing materials such as portland cement, lime, sludge treatment compound, and industrial silica slag. Extensive laboratory studies have been conducted to evaluate the block properties such as compressive strength, tensile strength, abrasion resistance, and soundness. In addition, the possible engineering application is also evaluated.

Test results show that (1) portland cement is the most possible cementing material for solidifying fly ash, and the use of lime, silica fume and sludge treatment Compound as partial replacement for cement may improve the properties of the solid blocks; (2) natural sand used as part of mixes may improve the strength and durability of the solid blocks; (3) the leaching rate of metals is low so that the solid blocks can be environmentally acceptable in the seawater; (4) based on the laboratory observations, the fly ash blocks of this study are potential construction materials for marine engineering.

INTRODUCTION

In last two decades, the coal combustion in Taiwan has been dramatically increased because of the increasing demand of electricity [1]. Due to the shortage of crude oil and the fear of nuclear disaster, coal-fired electric power plants are expected to cons ume large amount of coal to meet the demand of electric utilities in the future. Coal ashes are the coal combustion by-products. Most of coal ashes are fly ash. In Taiwan, nearly 1.3 million metric tons of ash were produced in 1989. Less than forty percent of fly ash production was utilized. The potential problem of coal ash disposal becomes more serious. In the past, direct ocean disposal or land-based disposal could be effective to solve the ash problem. Recently, due to the possible detrimental impact on the environment, direct disposal of coal ashes is restricted by the Environmental Protection Authorities [2]. It is required to solidify fly ash before ocean or land disposal. However, better solution for ash problem is to raise the percentage of engineering application, especially in the road construction and the building trade. The technology development of civil engineering will determine the consumption of the increasing amount of fly ash [2].

Nowadays the application of fly ash is mainly on cement, concrete, and road construction [3, 4]. However, the amount of fly ash consumption is still not enough to solve the problem of treatment of fly ash. A large-scale alternative application is to solidify great amount of fly ash with other industrial waste materials [5]. Any shape can be cast for various types of application such as artificial reefs and building blocks. This possible method may satisfy the environmental restrictions on ocean disposal imposed by the authorities (the compressive strength of solid block for ocean or land disposal should be at least 100 kgf/cm^2) and solve the disposal problem of fly ash. In addition, utilization of other industrial waste materials may save lots of energy and further reduce the environmental impact [6]. The solidification of fly ash can be achieved by use of pozzolanic properties [7]. The solidified fly ash blocks may be used as artificial reef or other building materials. The cementing materials and manufacturing procedures were investigated. The overall objective of this study is to explore the properties and possible applications of the solid blocks produced from fly ash.

EXPERIMENTAL DESIGN

The experiments were designed to determine the strengths of fly ash blocks and the environmental acceptability. Thirty-six mixes have been proportioned to determine the influence of cementing materials and fly ash replacement percentage on mortar strengths. Ordinary portland cement, silica fume, sludge treatment compound, and industrial silica slag were used as part of cementing materials. For improving the workability, type F superplasticizers was applied to the mixes. The mix design was based on ASTM standard C109. The water/cementitious material ratio was kept at a constant of 0.58 and fine aggregate/cementitious materials ratio was 2.75. Details of mix proportions are presented in Table 1. Based on the strength results and economical consideration, nine mixes as shown in Table 2 were selected to investigate the possible engineering application of fly ash.

MATERIALS

Fly ash produced from bituminous coal which conformed to the specifications of class F according to ASTM standards C618 was utilized in this study. The characteristics of fly ash is presented in Table 3. The properties of cementing materials which includes sludge treatment compound, industrial silica slag, silica fume are tabulated in Table 4 through Table 6. The specific gravity of lime was 2.41.

TESTING METHODS AND RESULTS

Compressive Strength

Two types of specimens were used: 5-cm cube for group A through I and 10 × 20cm cylinders for group AC. Specimens were cast and cured according to ASTM standard method (ASTM C109, C39). A 100-metric ton universal testing machine was used. Compressive strengths were determined at ages 3, 7, 14, 28, and 90 days respectively. Testing results are presented in Table 7. Fig. 1 through Fig. 9 illustrate the influence of cementing materials and the amount of fly ash replacement on the compressive strength. It appears that the use of lime, silica fume and sludge treatment agent compound partial cementing materials may improve the strength of solid block of proper fly ash replacement for natural sand.

Flexural Strength

Mortar flexural strength were determined according to ASTM standard method for group A through I. Testing results are illustrated in Fig.10. The ratio of flexural strength to compressive strength was between 0.25 and 0.32. For group AC, ASTM standard test method for concrete was applied to determine the flexural strength of the specimens. In addition, splitting tensile strength was measured for this group according to ASTM standard C496. Table 7 shows that the ratio of flexural strength to compressive strength is between 0.16 and 0.19 and the ratio of splitting tensile strength to compressive strength is between 0.1 and 0.13.

Drying Shrinkage

Prismatic specimens with a dimension of 2.5cm × 2.5cm × 28.5cm were used to determine the drying shrinkage according to the ASTM standard C157-80. The specimens were kept in an environmental-controlled chamber with a constant te mperature of 23 ± 1°C and a relative humidity of 50%. The shrinkage deformations at various time are plotted in Fig.11.

Leaching of the Block's Soluble Components

After 28-day moist curing, specimens were immersed into seawater which had a double volume of the specimens for five months. The seawater of different specimen immersion was sampled and analyz ed for Fe, Mn, Zn, Ca, Cr using the atomic absorption spectrophotometry with an accuracy of 0.1 ppm. No significant difference was found in comparison with the control sample. However, the pH value appeared higher in the water in which fly ash specimens were immersed.

Abrasion Resistance

The abrasion resistance of the testing materials was determined using sandblasting method (ASTM C418-81). The abrasion coefficients were calculated and plotted as bar charts in Fig. 12. It appears that the slag replacement for natural sand in the mix has better abrasion resistance.

CONCLUSIONS

Based on the laboratory testing results, the following conclusions may by drawn.

1. Portland cement is the most possible cementing material for fly ash block. Proper use of lime, silica fume and sludge treatment agent may improve the strength of fly ash blocks.

Table 1a. Mix Proportions

Mix No.	$\frac{SF}{C+SF}$ (%)	$\frac{FA}{S+FA}$ (%)	Mix Proportions (kg/m³) Water (W)	Cement (C)	Silica Fume (S)	Fly Ash (FA)	Natural Sand (S)	Supeplasticizer (SP)
A1	0	0	296	510	0	0	1403	5.1
A2	0	40	353	434	0	478	717	6.5
A3	0	70	385	391	0	752	322	6.6
A4	0	100	412	355	0	976	0	7.1
B1	5	0	296	485	25.5	0	1405	5.1
B2	5	40	351	411	21.6	479	714	6.5
B3	5	70	384	370	19.5	750	21	6.6
B4	5	100	411	336	17.7	974	0	7.1
C1	10	0	294	456	50.7	0	1394	5.1
C2	10	40	350	388	43.1	474	712	6.5
C3	10	70	383	349	38.8	747	320	6.6
C4	10	100	409	318	35.3	970	0	7.1

Table 1b. Mix Proportions

Mix No.	$\frac{ISS}{C+ISS}$ (%)	$\frac{FA}{S+FA}$ (%)	Mix Proportions (kg/m³) Water (W)	Cement (C)	Silica Fume (S)	Fly Ash (FA)	Natural Sand (S)	Supeplasticizer (SP)
D1	5	0	296	485	25.5	0	1404	5.1
D2	5	40	352	412	21.6	477	716	6.5
D3	5	70	385	371	19.5	752	322	6.6
D4	5	100	412	337	17.7	975	0	7.1
E1	10	0	296	459	51	0	1403	5.1
E2	10	40	352	390	43.4	477	716	6.5
E3	10	70	385	351	39	751	322	6.6
E4	10	100	411	319	35.5	975	0	7.1

Table 1c. Mix Proportions

Mix No.	$\frac{L}{C+L}$ (%)	$\frac{FA}{S+FA}$ (%)	Mix Proportions (kg/m³) Water (W)	Cement (C)	Silica Fume (S)	Fly Ash (FA)	Natural Sand (S)	Supeplasticizer (SP)
F1	5	0	296	484	25.5	0	1402	5.1
F2	5	40	353	412	21.6	477	715	6.5
F3	5	70	385	371	19.5	752	322	6.6
F4	5	100	412	337	17.7	975	0	7.1
G1	10	0	296	457	51	0	1389	5.1
G2	10	40	351	389	43.4	476	714	6.5
G3	10	70	384	350	38.9	749	321	6.6
G4	10	100	410	318	35.4	973	0	7.1

Table 1d. Mix Proportions

Mix No.	$\frac{STA}{C+STA}$ (%)	$\frac{FA}{S+FA}$ (%)	Mix Proportions (kg/m³) Water (W)	Cement (C)	Silica Fume (S)	Fly Ash (FA)	Natural Sand (S)	Supeplasticizer (SP)
H1	5	0	296	485	25.6	0	1405	5.1
H2	5	40	353	410	21.7	478	717	6.5
H3	5	70	385	371	19.5	752	32	6.6
H4	5	100	412	337	17.8	976	0	7.1
I1	10	0	296	460	51	0	1705	5.1
I2	10	40	353	391	43.4	479	717	6.5
I3	10	70	385	352	39.1	750	322	6.6
I4	10	100	412	320	35.5	974	0	7.1

Table 2. Mix Proportions per Cubic Meter

	Mix No.								
	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8	AC9
Tap Water, Kg									
Cement, Kg									
Fly Ash (Class F), Kg	486	446	494	481	462	439	466	511	429
Lime, Kg	173	320	177	172	247	235	271	244	248
Copper Slag, Kg	694	765	706	687	741	704	876	790	739
Bottem Ash, Kg	116	–	125	115	–	–	–	–	–
Sludge Treatment Agent, Kg	–	–	187	–	329	–	–	–	–
Silica Fume, Kg	–	–	–	172	–	313	–	–	–
Sludge Treatment Agent, Kg	–	–	–	–	–	–	48	–	–
Silica Fume, Kg	–	–	–	–	–	–	–	43	–
Nature Sand, Kg	173	193	–	–	–	–	–	–	–
Crush Stone, Kg	–	–	–	–	–	–	–	–	328
Slump, Cm	12.4	7.8	8.9	8	12.1	5.8	4.3	8.3	6.3

Table 3. Chemical and Physical Properties of Fly Ash

Chemical Properties			Physical Properties	
SiO_2+Al_2O3+Fe_2O_3	(%)	86.94	Specific Gravity	2.06
CaO	(%)	0.45	Moisture Content(%)	0.53
MgO	(%)	0.40	Fineness: No. 325(%)	13.80
K_2O	(%)	1.07	L.O.I.	7.50
Na_2O	(%)	0.27		

Table 4. Chemical and Physical Properties of Sludge treatment Agent

Chemical Properties			Physical Properties	
SiO_2	(%)	25.08	Air Content of Motar (%)	4.0
$A1_2O_3$	(%)	11.36	Fineness (Blaine), cm^2/g	4220
Fe_2O_3	(%)	2.14	Compr. Strength, kgf/cm^2	
CaO	(%)	51.34	3-day	181
MgO	(%)	4.07	7-day	300
SO_3	(%)	3.33	28-day	446
L.O.O.	(%)	1.79	Time of Setting (Vicat test)	
			Inital Set (hr:min)	2:00
			Final Set (hr:min)	3:30

Table 5. Chemical Properties of Industrial Slica Fume

Chemical Properties					
SiO_2	(%)	55.94	K_2O	(%)	2.47
$A1_2O_3$	(%)	16.30	Na_2O	(%)	0.63
Fe_2O_3	(%)	10.76	SiO_2	(%)	0.33
CaO	(%)	6.10	Moisture Content	(%)	5.50
MgO	(%)	1.25	L.O.I.	(%)	

Table 6. Chemical and Physical Properties of Slica Fume

Chemical Properties			Physical Properties	
SiO_2	(%)	94.0	Specific Gravity	2.09
C	(%)	1.5	Fineness (Blaine), m^2/g	20
Fe_2O_3	(%)	0.4	Fineness: No. 325 (%)	0.10
$A1_2O_3$	(%)	0.6	pH Value	7
CaO	(%)	0.3	Density, Kg/m^3	250
MgO	(%)	0.8		
S_2O	(%)	1.0		
L.O.O.(950°C)	(%)	1.5		

Table 7. Strengths of Fly Ash Blocks

Mix No.	Compressive Strength (Kgf/cm^2)					Flexural Strength (28-day)	Splitting Tensile Strength (28-day)
	3-day	7-day	14-day	28-day	90-day		
A1	193.9	203.7	233.5	248.0	266.7	64.2	--
A2	137.9	177.6	242.1	273.2	324.3	68.2	--
A3	106.7	126.4	161.7	197.5	222.2	58.3	--
A4	42.4	80.1	108.8	158.2	181.1	48.2	--
B1	180.1	230.8	251.3	260.8	296.1	--	--
B2	146.0	187.6	237.6	261.1	290.7	--	--
B3	97.6	127.4	158.1	209.2	221.3	--	--
B4	53.9	78.3	135.3	169.9	192.0	--	--
C1	178.4	219.9	248.2	265.9	348.5	--	--
C2	123.3	151.2	211.4	250.2	342.2	--	--
C3	85.1	122.2	186.4	247.3	278.8	68.7	--
C4	62.5	92.8	136.1	187.7	202.5	51.1	--
D1	188.0	225.1	247.5	255.6	281.7	--	--
D2	141.6	178.4	243.2	252.4	346.6	--	--
D3	82.8	109.6	153.6	203.2	232.4	--	--
D4	43.1	77.6	111.8	181.6	197.1	43.9	--
E1	183.9	197.9	240.1	249.8	273.3	--	--
E2	136.9	155.6	224.1	252.7	298.7	--	--
E3	79.0	99.4	144.1	195.1	251.9	--	--
E4	26.8	67.6	99.7	153.1	181.9	--	--
F1	157.5	186.3	203.4	275.5	327.8	88.6	--
F2	149.6	177.4	235.2	277.7	362.1	69.1	--
F3	92.4	135.8	160.8	222.7	269.7	60.2	--
F4	60.7	89.6	113.2	162.1	190.1	--	--
G1	164.8	189.9	229.4	245.6	268.4	--	--
G2	143.9	155.2	235.2	267.3	323.5	--	--
G3	84.0	117.7	180.9	219.9	259.2	--	--
G4	45.8	86.4	98.1	161.9	214.2	--	--
H1	178.2	203.8	234.0	272.3	313.2	--	--
H2	141.9	191.4	245.2	300.1	367.9	84.3	--
H3	72.8	130.7	173.7	197.6	259.6	--	--
H4	37.5	87.5	122.8	153.1	177.7	--	--
I1	181.5	232.7	280.5	312.6	357.9	97.1	--
I2	135.5	182.1	241.4	271.9	386.4	--	--
I3	75.2	126.9	175.9	215.3	236.8	--	--
I4	34.1	80.1	99.9	169.2	182.7	--	--
AC1	19.4	36.6	--	79.6	176.2	13.7	9.9
AC2	53.4	65.8	--	20.6	203.5	20.4	12.8
AC3	20.4	30.2	--	90.0	180.5	15.7	10.8
AC4	24.4	43.6	--	78.9	178.0	14.6	10.1
AC5	26.0	47.8	--	08.0	193.1	19.8	12.2
AC6	36.6	60.3	--	98.5	200.3	16.7	11.2
AC7	23.4	52.4	--	81.7	183.2	12.7	10.3
AC8	16.6	38.0	--	85.2	196.9	13.6	10.5
AC9	36.4	50.8	--	13.4	198.2	19.2	12.5

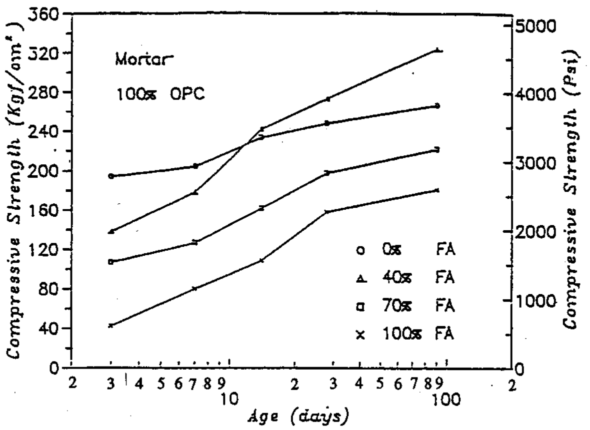

Fig. 1. Compressive Strengths of Motars with Different Percentage of Fly Ash Replacement.

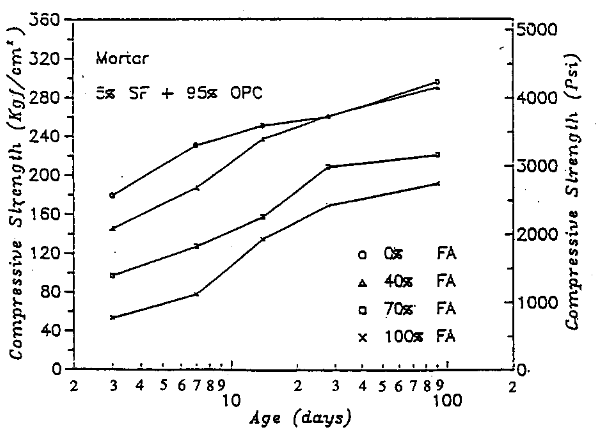

Fig. 2. Compressive Strengths of motars with Different Percentage of Fly Ash Replacement.

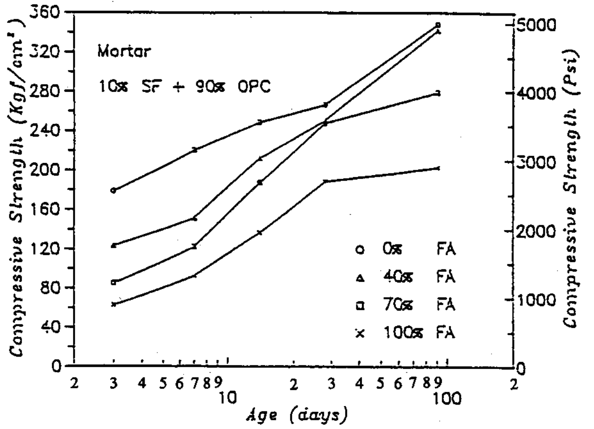

Fig. 3. Compressive Strengths of Motars with Different Percentage of Fly Ash Replacement.

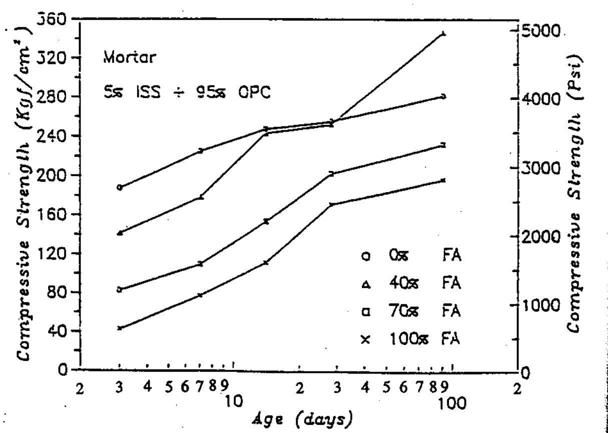

Fig. 4. Compressive Strengths of Motars with Different Percentage of Fly Ash Replacement.

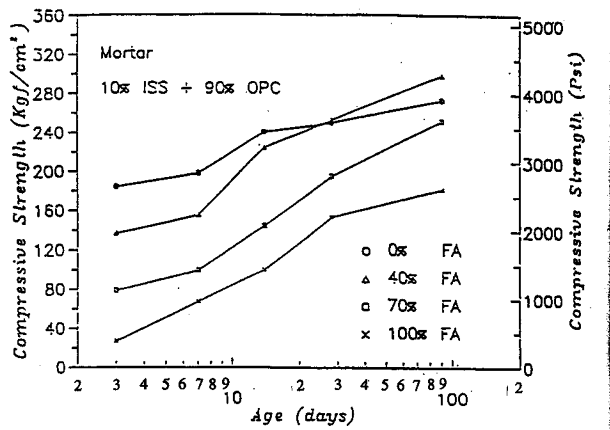

Fig. 5. Compressive Strengths of Motars with Different Percentage of Fly Ash Replacement.

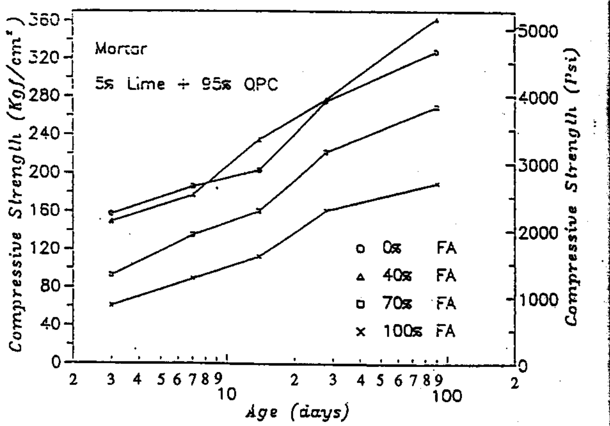

Fig. 6. Compressive Strengths of Motars with Different Percentage of Fly Ash Replacement.

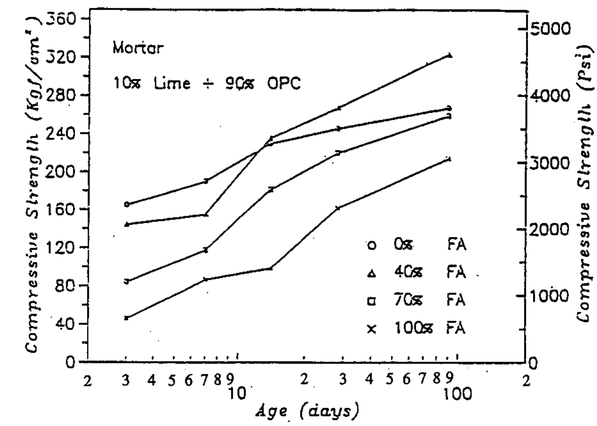

Fig. 7. Compressive Strengths of Motars with Different Percentage of Fly Ash Replacement.

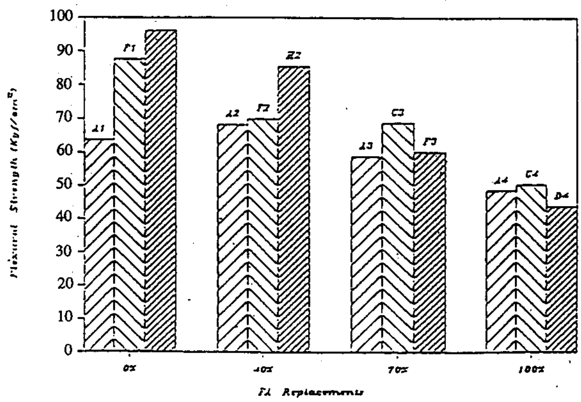

Fig. 10. Comparative Diagram for Flexural Strengths of Motars.

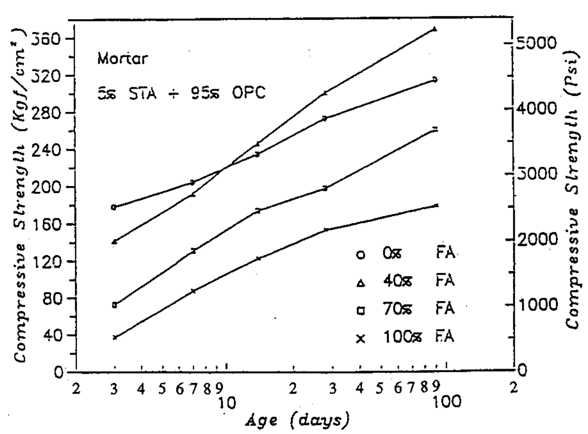

Fig. 8. Compressive Strengths of Motars with Different Percentage of Fly Ash Replacement.

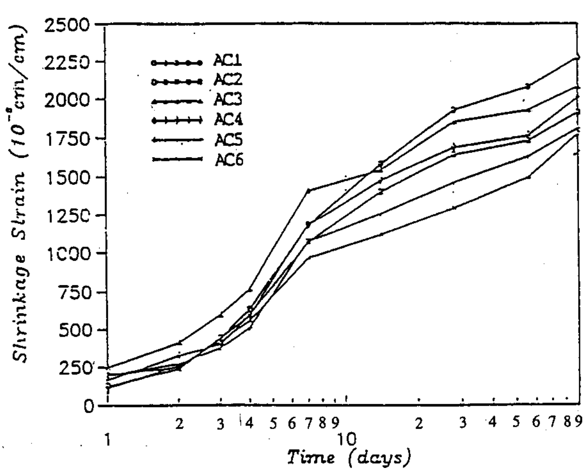

Fig. 11. Diagram of Shrinkage Strains vs Time for Different Fly Ash Mixes.

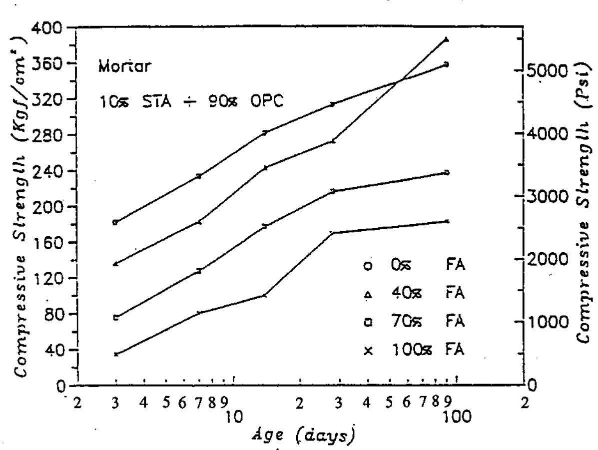

Fig. 9. Compressive Strengths of Motars with Different Percentage of Fly Ash Replacement.

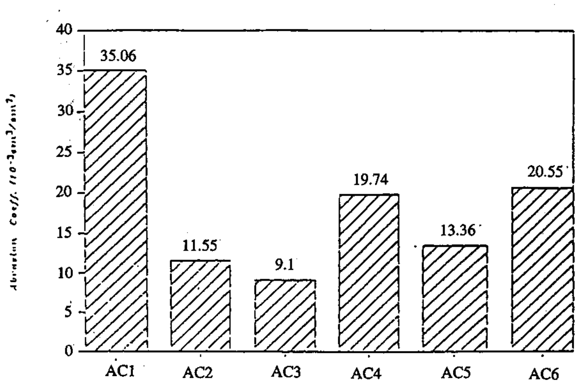

Fig. 12. Abrasion Coefficients for Different Fly Ash Mixes.

2. The drying shrinkage of fly ash blocks are much larger than ordinary fly ash concrete. Bleeding is very prominent in the early age of fly ash blocks.
3. Natural sand used as constituent part of the mixes may improve the strength.
4. The leaching of the block's soluble components is so low within the range of this study that the solid blocks may be environmentally acceptable in the seawater.
5. Based on the 90-day strength, fly ash blocks may be applied to the secondary structure members for marine engineering.
6. From the viewpoint of engineering economy, overall physical performance, and environmental protection, the engineering application of the fly ash blocks should be considered and promoted. However, supplementary field testings are needed to assure the long-term performance for more applications.

REFERENCES

1. "The Study of Ash Utilization", Technical Report, Power Research Institute, Taiwan Power Company, Vol. 2, 1987, pp. 1-87.
2. N. Bolt and A. Snel, "Environmental Aspect of Fly Ash Application in The Netherlands", Kema Scientific & Technical Report, Vol. 4, No. 11, 1986, pp. 125-140.
3. M.N. Aaque, B.W. Langan, and M.A. Ward, "High Fly Ash Concrete", ACI Journal, Title No. 81-84, Jan.-Feb. 1984, pp. 54-60.
4. D. Ravina and P. K. Metha, "Compressive Strength of Low Cement/High Fly Ash Concrete", Cement and Concrete Research, Vol. 18, 1988, pp. 571-583.
5. S.T. Kuo, "Solidification of Fly Ash with Other Industrial Waste Materials", Proceeding of the Seventh International Ash Utilization Symposium and Exposition, Vol. 2, 1985, pp. 402-417.
6. S.B. Lee, "A Study of the Utilization of Industrial Waste Materials", Proceedings of the First National Symposium on the Treatment and Utilization of Industrial Waste Materials, Taiwan, 1985, pp. 1-10.
7. K. Yeh, "Pozzolanic Reaction of Coal Ashes", Tai-Power Engineering Monthly, No. 428, 1984, pp. 20-25.