RESEARCH ARTICLE
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Effect of Finenesses of Fly Ash on Expansion of Mortars in Magnesium Sulfate

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ABSTRACT: This paper presents the effect of fineness of fly ash on expansion of fly ash-cement mortar in magnesium sulfate solution. Fly ash from the Mae Moh power plant in Thailand was classified in to three different levels of fineness of Blaine of 3215, 4440 and 5890 cm^2/g with a median particle size of 25.57, 7.69, and 4.81 microns, respectively. Fly ash at each level of fineness was used to replace Portland cement type I and type V at percentages of 0, 20, 30, and 40 by weight of the cementitious material, to cast mortar bars of 2.5x2.5x30 cm^3. Expansion of the fly ash-cement mortar bars, which were immersed in 5% by weight of magnesium sulfate solution, were measured at the age of 1 to 540 days. The results showed that the replacement of Portland cement type I and type V by fly ash reduced expansion of the mortar bars. When the same level of fineness and same percent of replacement of fly ash were used in the mortar bars, the replacement of Portland cement type V by fly ash produced less expansion than that of Portland cement type I. For the same level of fineness of fly ash, the mortar bars made with 40% fly ash replacement had less expansion than those made with 20 and 30% replacement. The mortar bars with 20-25% replacement of fine fly ash (Blaine fineness of 4440 or 5890 cm^2/g) and the mortar bars with 40% replacement of original fly ash (Blain fineness of 3125 cm^2/g) had the same expansion. The smaller particle size of fly ash not only reduced expansion of the fly ash-mortar bars but also produced higher strength activity index of mortar than the bigger particle size of fly ash. Therefore, very fine fly ash could be used effectively for reducing the expansion and improving sulfate resistance of mortar.

KEYWORDS: Fineness, fly ash, sulfate, expansion, mortar bar.

INTRODUCTION

During the last decades, deterioration of concrete by sulfate is frequently observed in concrete structures exposed to high sulfate environment. Sulfate may be found in soils or dissolved in groundwater and is always present in seawater. The concrete structures, especially those constructed underground and under sea water, are at risk of sulfate attack. The majority of the sulfate salts present in ground soil and sea water are sodium sulfate and magnesium sulfate. Sulfate attack of concrete can be classified into two catagories, namely physical and chemical attacks [1]. For the physical attack, the sulfate ions enter the concrete by diffusion, and subsequently react with cement in the concrete, leading to disintegration. For the chemical attack, the sulfate ions react with calcium hydroxide and calcium aluminate hydrate which are components of cement paste, producing solid products with larger volume. Sulfate attack usually exhibits concrete expansion and strength reduction, leading to cracking and spalling.

Many researchers reported the recommendation for improving sulfate resistant in mortar and concrete. Djuric et al[2], Irassar et al[3] and Kurtis et al[4] suggested that low water-cement ratio, low C_3A content in cement, and Portland cement type V could improve the resistance of concrete to sulfate attack. Khatri and Sirivivatnanon[1] concluded that the permeability of concrete and the type of binder played an important role in governing the sulfate resistance. Torii and Kawamura[5] studied sulfuric acid and sulfate resistance of mortar with fly ash and silica fume and found that the replacement of Portland cement by fly ash and silica fume effectively improved the resistance of mortar to sulfuric acid and sulfate attack. Torri et al[6] studied the sulfate resistance of concrete with high fly ash composition and showed that concrete containing fly ash at 50% replacement could improve the resistance against sulfate attack.

In Thailand, it is estimated that fly ash has been produced at the rate of more than 3.5 million tons per year since 2001. However, the utilization of fly ash is still limited due to lack of understanding on the characteristics of fly ash itself and the properties of concrete using fly ash. Jaturapitakkul et al[7] separated fly ash into various levels of fineness by using an air classifier machine and showed that the mortar containing finest fraction of fly ash had the highest compressive strength and fastest rate of strength gain. Kiattikomol et al[8] studied the property of mortar containing coarse fly ash with different levels of fineness and concluded that the finer the coarse fly ash is, the

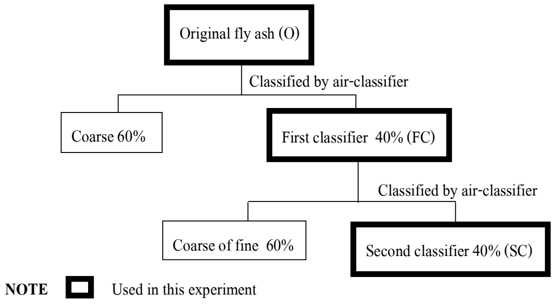


Fig 1. Schematic Presentation of the Process of Fly Ash.

Table 1. Proportions of mortar bars.

Symbol	Fly Ash Replacement (%)	Mixture Proportion by Weight								
		Cement Type		Fly Ash			Sand	W/(C+F)	Flow	Water Requirement
		I	V	O	FC	SC				
T1	-	1	-	-	-	-	2.75	0.64	106	100
T1O20	20	0.80	-	0.20	-	-	2.75	0.63	108	98
T1O30	30	0.70	-	-	0.30	-	2.75	0.63	112	98
T1O40	40	0.60	-	-	-	0.40	2.75	0.63	106	98
T1FC20	20	0.80	-	0.20	-	-	2.75	0.61	113	95
T1FC30	30	0.70	-	-	0.30	-	2.75	0.58	111	91
T1FC40	40	0.60	-	-	-	0.40	2.75	0.59	106	92
T1SC20	20	0.80	-	0.20	-	-	2.75	0.65	110	102
T1SC30	30	0.70	-	-	0.30	-	2.75	0.62	111	97
T1SC40	40	0.60	-	-	-	0.40	2.75	0.60	109	94
T5	-	-	1	-	-	-	2.75	0.65	109	102
T5O20	20	-	0.80	0.20	-	-	2.75	0.65	105	102
T5O30	30	-	0.70	-	0.30	-	2.75	0.64	114	100
T5O40	40	-	0.60	-	-	0.40	2.75	0.64	106	100
T5FC20	20	-	0.80	0.20	-	-	2.75	0.63	113	98
T5FC30	30	-	0.70	-	0.30	-	2.75	0.63	115	98
T5FC40	40	-	0.60	-	-	0.40	2.75	0.61	115	95
T5SC20	20	-	0.80	0.20	-	-	2.75	0.63	111	98
T5SC30	30	-	0.70	-	0.30	-	2.75	0.65	112	102
T5SC40	40	-	0.60	-	-	0.40	2.75	0.59	110	92

T1 : Portland cement type I
T5 : Portland cement type V
O : Original fly ash
FC : First classifier of fly ash-fine fly ash
SC : Second classifier of fly ash-very fine fly ash
20, 30, 40 : replacement of fly ash 20, 30, 40% by weight of total binder, respectively.

better compressive strength the mortar had. The previous studies have indicated that concrete or mortar containing very fine fly ash has high compressive strength. Therefore, the main objective of this study is to evaluate and compare the effect of different levels of fineness and replacement of cement with fly ash on the expansion of mortar immersing in magnesium sulfate solution. The sulfate resistance of mortar made from Portland cement type I with partial replacement with fly ash was as high as that of mortar made from Portland cement type V.

MATERIALS AND METHODS

Materials

The materials used in this investigation consisted of Portland cement type I, Portland cement type V, river sand, and fly ash. Fly ash from the Mae Moh power plant, in Thailand was classified using an air-classifier machine, into 3 different particle sizes. The abbreviations O, FC, and SC indicated the fineness of fly ash as original fly ash, fine fly ash, and very fine fly ash, respectively. The refinement and separation process are shown schematically in Fig.1.

Material Properties

Physical and chemical properties of fly ash as well as Portland cement type I and type V were investigated. Fly ash particle morphologies were recorded using a scanning electron microscope (SEM). Specific gravity, the particle retained on sieve No.325, and the Blaine fineness of the cementitious materials were tested in accordance with ASTM C 188, C 430, and C 204, respectively. Chemical composition was determined by using X-ray fluorescence spectrometer (XRF).

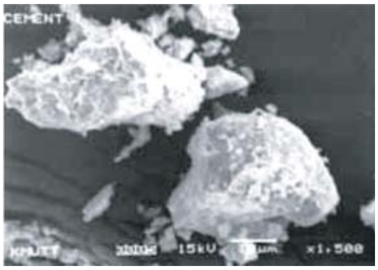
Methods

Mixture Proportion of Mortar Bars

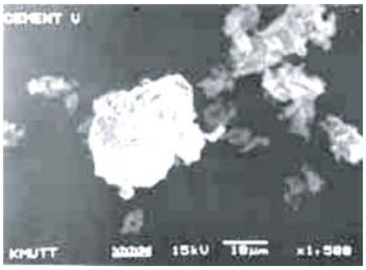
A ratio of cementitious material (Portland cement type I or type V plus fly ash) to sand was set as a constant ratio of 1 to 2.75, and the consistency of mortar was controlled by using the flow tests (ASTM C 109). The percentage flow of mortar was adjusted to 105±5 % by mixing with water. Portland cement type I or type V was replaced by fly ash O, FC, and SC at percentages of 0, 20, 30, and 40 by weight of cementitious materials, and all mixture proportions of mortar are shown in Table 1.

Expansion of Mortar Bars in Sulfate Solution

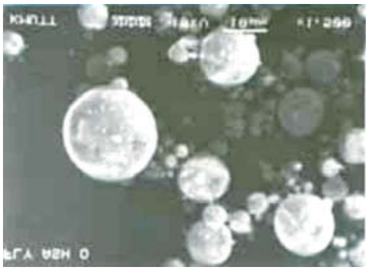
Mortar bars of 2.5x2.5x30 cm^3. were cast and removed from the mold after 24 hours. They were immersed in magnesium sulfate solution to investigate the expansion of mortar bars. Magnesium sulfate solution with a concentration of 5% by weight was prepared by dissolving 50 grams of magnesium sulfate



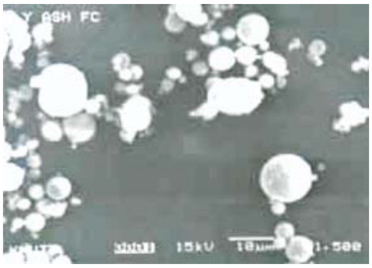
(a) Portland Cement Type I



(b) Portland Cement Type V



(c) Original Fly Ash-O



(d) Fine Fly Ash-FC

(e) Very Fine Fly Ash-SC

Fig 2. Scanning Electron Microscope of Portland cements and Fly Ashes.

salt in 950 milliliters of deionized water. Length change of mortar bar was measured at 1, 3, 7, 21 days and after that was measured every 14 days until 540 days. The initial length of mortar bar was measured prior to be immersed in the magnesium solution. Expansion of mortar bars were measured by using a length comparator as specified by ASTM C 490.

Results and Discussion

Particle Shape

Particle shapes of Portland cement type I, type V, and fly ash were visualised by SEM as shown in Fig. 2. The particle shapes of Portland cement type I and type V (Figs. 2a and 2b) are solid and irregular, whereas those of fly ash are solid and spherical (Figs. 2c, 2d, and 2e). Fly ash SC (Fig. 2e) is clearly the finest one, followed by fly ash FC and fly ash original O. Normally, fly ash was collected in a form of solid and spherically shaped particles at high temperature combustion of some 1500-1700°c[9].

Specific Gravity and Fineness

The specific gravity and fineness of Portland cement type I, type V, and fly ash are shown in Table 2. Fig. 3 shows the particle size distribution of the materials. Portland cement type V is finer than Portland cement type I. The median particle sizes of fly ash SC, FC, and O were 4.81, 7.69, and 25.57 micron, respectively. Blaine fineness as well as the percentage of materials retained on sieve No. 325 (45 micron) are tabulated in Table 2. The percentage of fly ash O retained on sieve No.325 was 20.1% which was less than 34% prescribed by ASTM C 618, whereas all particles of fly ash FC and SC passed through the sieve No. 325. The level of fineness by Blaine air permeability method showed that fly ash SC was the finest with the surface area of 5,899 cm^2/g as compared with 4,440, and 3,215 cm^2/g for fly ash FC, and O, respectively. The median particle size of fly ash SC, FC, and O were in the ratio of 1 : 1.6 : 5.3, while the Blaine fineness gave the ratio of 1.8 : 1.4 : 1, respectively.

The specific gravity of fly ashes increased with the fineness, being 2.23, 2.38, and 2.57 for fly ash O, FC, and SC, respectively, but was still lower than that of Portland cement type I and type V, which was 3.13 and 3.15, respectively. The specific gravity of classified fly ash depended on its particle size, because many coarse particles of fly ash are porous, thus, occupying large volume but little weight.

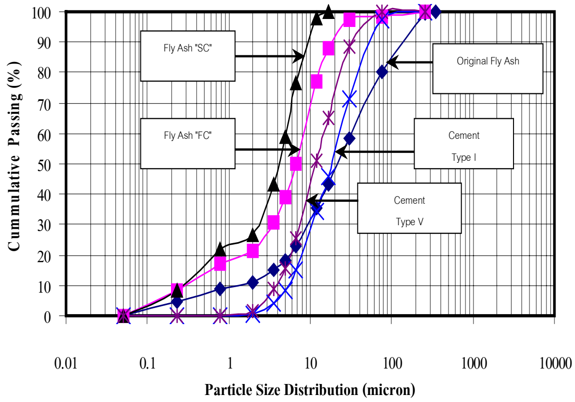


Fig 3. Particle Size Distribution of Portland Cement Type I and V and Fly Ash O, FC and SC.

Chemical Compositions

Table 3 presents the chemical composition of Portland cement type I, type V, and the original and classified fly ash. The amount of C_3A in Portland cement type I, and type V were 9.22% and 1.81%, respectively. The amounts of SiO_2, Al_2O_3, and Fe_2O_3 in the original and classified fly ash were over 70%, and hence they can be classified as class F fly ash in accordance with ASTM C 618. Fly ash O, FC, and SC had a CaO content of 12.15%, 12.67%, and 13.14%, respectively which are fairly high for class F fly ash. In addition, all fly ash had less than 5% SO_3 and loss on ignition (LOI) are only 1.23-1.75% which was not less than 6% as limited by ASTM C 618. The chemical composition of classified fly ashes slightly changed from original fly ash since SO_3 tended to decrease when the level of fineness increased. Recent papers[7, 8, 10] concluded that classifying and grinding of fly ash did not have much effect on chemical composition.

Table 2. Physical of portland cement type I (T1), type V (T5), and fly ashes O, FC and SC.

Sample	Specific Gravity	Retained on Sieve No. 325 (%)	Blaine Fineness (cm^2/g)	Mean Particle Size (Micron)	Strength Activity Index (%) 7-day	28-day
T1	3.13	9.4	3,490	19.00	100	100
T5	3.15	8.1	4,365	15.00	-	-
O	2.23	20.1	3,215	25.57	80.4	87.1
FC	2.38	0.0	4,440	7.69	84.4	102.6
SC	2.57	0.0	5,890	4.81	105.0	111.9

Table 3. Chemical composition of portland cement type I, type V, and fly ash (%).

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	LOI	C_3A
Type I	2.80	5.50	3.16	64.97	1.06	0.55	0.08	2.96	2.89	9.22
Type V	21.52	3.56	4.51	66.70	1.20	0.24	0.10	2.11	1.74	1.81
O	45.69	24.59	11.26	12.15	2.87	2.66	0.07	1.57	1.23	-
FC	44.72	23.69	11.03	12.67	2.63	2.87	0.07	1.28	1.42	-
SC	44.59	23.57	10.78	13.14	2.68	2.96	0.08	1.06	1.75	-

Strength Activity Index of Fly ash

The strength activity indices of fly ash-cement mortar are investigated and shown in Table 2. According to ASTM C 311, the strength activity index is the ratio (in percentage) of the compressive strength of mortar bars containing materials 20% by weight of binder to that of the control cement mortar bar at the specified ages. The strength activity indices of all fly ash-cement mortar with different levels of finenesses were higher than the limit given by ASTM C 618 which was at least 75% at the ages of 7 or 28 days. At the age of 28 days, mortar made with fly ash FC, and SC had strength activity index of 102.6, and 112.9%, respectively which were higher than the standard mortar. The above results indicated that the strength activity index of classified fly ash mortar was much higher than that of the original fly ash mortar and also higher than 100%. The fineness and round shape of the fly ash particle are known to increase workability and thereby reduce the water requirement for a given workability. Therefore, reduced water content in the mortar brings about the increased compressive strength. Similar investigations of fly ashes with different levels of fineness were carried out by Erdogdu and Turker [10], and Slanicka[11] and Paya et al[12]. They separated fly ash into various levels of fineness and found that the mortar and concrete made with finer fly ash gained higher compressive strengths than those made with coarser fly ash. From these results, it can be concluded that very fine fly ash can be used as a good pozzolana in cement based material.

Expansion of Mortar Bars

Expansion of Portland Cement Type I Mortar Bars

Fig. 4 presents the expansion results of mortar bars containing Portland cement type I and fly ash after being immersed in 5% magnesium sulfate solution for up to 540 days. The mortar bars at 540 days containing fly ash up to 30% had significantly improved sulfate resistance as compared with Portland cement type I mortar bars without fly ash. However, the use of 20% of original fly ash in the mortar bar reduced the expansion from 2.3% in the mortar bar T1 to be 1.8% in the mortar bar T1O20, or 1.28-time reduction. When very fine fly ash was introduced in the mortar bars T1FC20 and T1SC20, the expansion of the mortar bars reduced to be 0.4% and 0.9%, respectively or reduced more than 60% of the expansion of the mortar bar T1O20. From the results, the increase of fly ash fineness caused the decrease in the expansion of the mortar bars. This is due to a higher rate of the pozzolanic reaction of fine fly ash than that of the original fly ash, which results in higher strength and lower permeability of mortar. Mortar bars T1SC40 had the best behavior in sulfate resistance due to its high level of fineness and high percent replacement of fly ash, and exhibited less than 0.1% expansion at 540 days. These results were in agreement with Torii and Kawamura[5] who studied the effects of fly ash and silica fume on the resistance of mortar to sulfuric acid and sulfate attack. They concluded that the expansion of mortar was reduced when the percentage of fly ash replacement was higher than 30%. Torri et al[6] also found similar results when using 50% of fly ash as cement replacement to improve of sulfate resistance of concrete. Additional results from Stephens and Carrasquillo[13] confirmed that the mortar containing Class F fly ash showed a significant reduction in sulfate expansion.

Expansion of Portland Cement Type V Mortar bars

Fig. 5 shows the expansion of Portland cement type V mortar bars with and without fly ash, in comparison

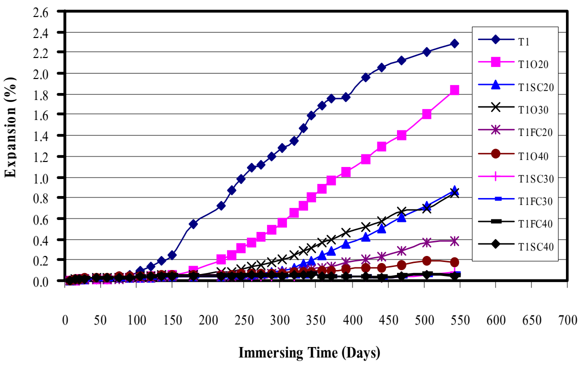


Fig 4. Expansion of portland cement type I mortar bars containing fly ash immersed in 5% magnesium sulfate solution for up to 540 days.

with Portland cement type I mortar bars, after being immersed in 5% magnesium sulfate solution up to 540 days. The mortar bars mixed with Portland cement type V had lower expansion than the mortar bars mixed with Portland cement type I by about 10 times. ASTM C150 limits the maximum percentage of C_3A content, which affects sulfate resistance in concrete, to 5% . In this study, Portland cement type I has a high C_3A content of 9.22% and is thus not suitable for sulfate environments, but Portland cement type V with a low C_3A content of 1.81% improves sulfate resistance. The expansion of mortar bars made with Portland cement type V or Portland cement type V mixed with fly ash were very low and not higher than 0.6%. The expansion reductions in 540 days provided by fly ash were relatively small when fly ashes were mixed in combination with Portland cement type V. Although the expansion of mortar bars at 20% replacement of original fly ash (T5O20) was higher than that of Portland cement type V mortar bars (T5), but the result were significant when compared with those of Portland cement type I. With 40% of fly ash FC replacement, the mortar bars T5FC40 and T5SC40 had expansion of 0.1% at 540 days whereas those of mortar bars T5 and T1were 0.4% and 2.2%, respectively. From the results, Portland cement type V mortars containing fly ash can be used effectively to reduce expansion of mortar in magnesium sulfate solution.

Effect of Fineness of Fly Ash on Expansion of Mortar Bars

Fig.6 shows the relationship between the expansion of Portland cement type I and type V mortar bars containing fly ash O, FC, and SC immersed in 5% of magnesium sulfate solution up to 540 days. It is seen that the expansion of Portland cement type I mortar bars with 40% replacement of original fly ash (T1O40) was of the same magnitude as that of Portland cement type V mortar bar (T5). However, the use of 20 to 25% of fly ashes FC and SC (as shown in Figs. 6b and 6c) in Portland cement type I mortar bars had the same expansion as that of Portland cement type V mortar bar (T5). When 30% of fly ash FC and SC were introduced in the mortar bars T1FC30 and T1SC30, they showed better reduction of expansion than T5 mortar bar. A similar investigation was carried out to study the corrosion resistant property of fly ash mortar with different particle size in sodium sulfate solution by Sheu et al[14], they found that the mortar with a finer particle size of fly ash had a greater resistance to sulfate attack than the mortar with Portland cement type.

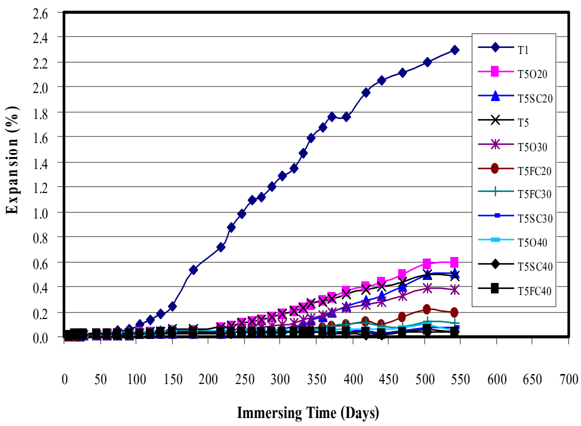


Fig 5. Expansion of Portland Cement Type V Mortar Bars Containing Fly ashes Immersed in 5% Magnesium Sulfate Solution up to 540 Days.

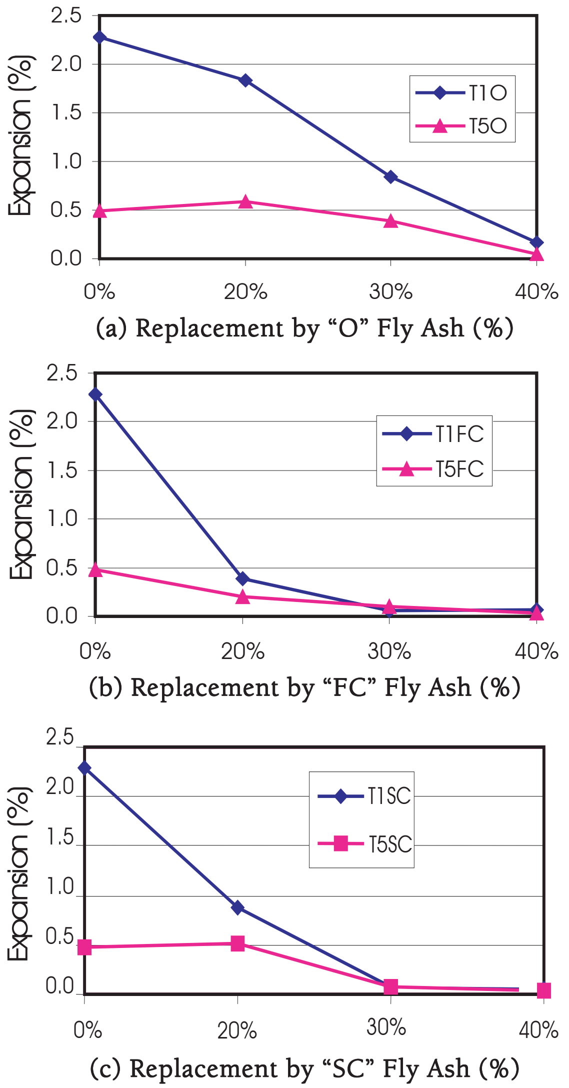


Fig 6. Relationship Between Expansion of Portland Cement Type I and Type V Mortar Bars Containing Fly Ash O, FC and SC immersed in 5% Magnesium Sulfate Solution at 540 days and Percentage of Fly Ash Replacement.

From the results, it is seen that Portland cement type I with fly ash can reduce expansion of mortar bars due to magnesium sulfate solution as effectively as Portland cement type V. The reduction of expansion of mortar bars made with fine fly ash is more effective than that with the coarse one.

Conclusions

Main conclusions which can be drawn from this research are as follow :

1. With the same level of fineness and the same percentage of replacement of fly ash, the expansion of fly ash-cement mortar bars made with Portland cement type I were higher than those of fly ash-cement mortar bars made with Portland cement type V.

2. The fineness of fly ash is a very important factor affecting the strength activity index of mortar and the expansion of mortar bars. The finer the fly ash in the mixture is, the higher strength activity index and the reduction of expansion of mortar bar in magnesium sulfate solution can be obtained.

3. Fly ash from the Mae Moh power plant in Thailand can be used as cementitious material with Portland cement type I for reducing expansion of mortar bars due to magnesium sulfate solution as effectively as Portland cement type V. However, the optimum percentage of replacement and fineness of fly ash should be considered to achieve a good result.

Acknowledgements

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