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DEVELOPMENT OF FLY ASH USAGE IN THAILAND

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ABSTRACT: This paper describes the situation of fly ash usage in Thailand. Firstly, the general information including typical characteristics of fly ash in Thailand is given. Properties of fly ash in Thailand were compared with those of the fly ash in Japan in terms of chemical composition and physical properties. It was found that generally fly ash in Thailand has higher CaO content, higher alkali content but lower silica content and LOI while fineness of the Thai fly ash was generally lower. It was also found that water requirement of both countries fly ashes was about the same. Regarding strength, the Thai fly ash was slightly better. The consumption of fly ash in Thailand increases significantly after the economic crisis in 1997 and at present almost all fly ash produced in Thailand is used as cement replacing material in concrete industry. The paper also describes problem at the early stage of introducing fly ash into the construction industry together with the strategies to promote its use. Finally, examples of application of fly ash in various types of concrete and cementitious products in Thailand are given.

KEYWORDS: Fly ash, cement replacement, pozzolan, concrete

1. INTRODUCTION

Fly ash is one of the by-products produced from the process of coal burning. Electricity generating using coal as the energy source is the main industry which produces fly ash as its major solid waste. There are still other types of solid wastes produced from the coal generating plants like bottom ash and gypsum but their volumes are generally far less than that of the fly ash. There are difficulties around the world to achieve effective utilization of fly ash or even to get rid of it. Majority of the fly ash is dumped or used in low-valued methods such as using as a land-fill material, soil improvement, road base, land reclamation, raw material for producing cement. Some high-valued methods of using are available such as used as fertilizer, as filler in plastics and resins, as metal matrix composite (ceramic additives) [1], etc., but only a little amount of fly ash can be consumed in such utilization. The most effective use of fly ash at present, by considering both volume and value, is still in the area of concrete. The use of fly ash as a cement substituting material is believed to be beneficial by various reasons. In regard of environment, the cement substitution reduces the depletion of natural resources used for cement production. It also reduces the energy used for clinkerization, then reduces the gases emitted to the environment especially CO_2. It is estimated that abut 1 ton of CO_2 is released per a ton of clinker produced [2]. Although some properties of fly ash concrete, such as initial strength, carbonation and freezing and thawing resistance, have been found to be inferior than the concrete without fly ash, the use of fly ash to partially replace cement improves many properties of concrete especially durability properties such as increasing workability and pumpability, improving long-term strength, reducing temperature, reducing shrinkage, improving resistance against chloride-induced steel corrosion, increasing sulfate resistance, reducing risk due to alkali-aggregate reaction, etc [3,4,5,6,7,8,9]. A proper use of fly ash based on the type of construction work and the service environment that the constructed structure is located is considered to be most rational.

Though there have been worldwide studies, indicating the benefit of using fly ash in concrete, fly ash has still not been effectively utilized in most countries until now due to many reasons. In Thailand, fly ash has been domestically available since the end of the 1970's. However, the use in concrete was just started in early 1990's and the effective use of fly ash was just materialized in 1997. At present (2005), almost all fly ash produced in Thailand is used as a partial cement substitution material for both quality improvement and cost reduction of concrete. The author believed that Thailand is one of the most successful countries in regard of the effective use of fly ash in concrete industry. This paper states the efforts of the author and his colleagues in Thailand in paving ways for the construction societies in Thailand to the effective use of fly ash.

2. GENERAL INFORMATION ON FLY ASH IN THAILAND

The amount of fly ash produced annually is approximately 3 million tons during the past 10 years. About 95% of the total production is produced from the Mae Moh generating plant of the Electricity Generating Authority of Thailand in Lampang province, in the north of Thailand. The rest of fly ashes are produced near Bangkok. In this section, some comparative studies are conducted to compare the general trend of characteristics of fly ash produced in Thailand and Japan.

2.1 Typical characteristics of fly ash in Thailand

2.1.1 Chemical Composition

Table 1 compares the ranges of chemical composition of fly ash in Japan and Thailand. The data of Thai fly ashes are those observed continuously for more than 10 years. The data of Japanese fly ashes, though were obtained from a single study, covered large enough sample types and sources i.e. 40 types of fly ash from 24 generating plants in Japan [10]. It can be seen that the chemical composition of fly ash in Thailand covers a wider range than that of Japan. This is mainly because, in addition of the differences of the types of the plants and processes, Thailand uses many sources of coal both local and imported ones. The biggest local source is in Mae Moh, Lampang province, which is located in the north of Thailand. The coal used in Mae Moh is lignite while most of the imported coals are anthracite or bituminous coals. It is noted that for the Mae Moh fly ash, which comprises of 95% of the total fly ash produced in Thailand, the scattering of the chemical composition is not much.

From Table 1, most of the Thai fly ashes have lower SiO_2 content, larger CaO and alkali content than the Japanese fly ash. Though the data on SO_3content of the Japaneses fly ash does not appear in the Table, it is realized that most of the Thai fly ashes have rather high SO_3 content. It must be noted here that the high CaO and high SO_3 fly ash mostly belongs to the Mae Moh power plant where lignite coal is used.

Table 1 Comparison of Chemical Compostion between Fly Ashes in Japan and Thailand

Composition	Japan* (%)	Thailand** (%)
SiO_2	47-70	20-55
CaO	0.49-7.55	1-35 (majority 7-20)
Al_2O_3	15.64-32.03	5-40
Fe_2O_3	2.54-15.68 (majority<5.0)	1-15
SO_3	-	0^+-10 (majority between 1.5-4.0)
MgO	0.22-2.81	0^+-5
(Na_2O+0.658K_2O)	0.22-3.27 (majority <1.5)	0.5-2.5 (majority >1.5)

* from reference [10]

** from reference [11] and the Electricity Generating Authority of Thailand.

2.1.2 Physical Properties and Loss on Ignition

Table 2 compares some physical properties and loss on ignition between the Japanese and Thai fly ashes. It can be observed from the Table that the majority of the Thai fly ashes have lower specific gravity, Blaine fineness and loss on ignition than the Japanese fly ashes. From the data of Blaine fineness and the amount retained on sieve#325, the Thai fly ashes are thought to be coarser. However lower specific gravity of the Thai fly ashes denotes that the Thai fly ashes have more cenospheres and plerosheres. The lower loss on ignition of the Thai fly ashes is considered to be due to higher allowable burning temperature of the coal powder in Thailand than that allowed in Japan due to the limitation of the emission.

Table 2 Comparison of Physical Properties between Fly Ashes in Japan and Thailand

Properties	Japan* (%)	Thailand** (%)
Specific gravity (g/cm^3)	1.98-2.43	1.7 - 2.4 (almost half <2.0)
Blaine fineness (cm^2/g)	2350-6580	1800 – 4000 (about 80% <2500)
% Retained on sieve #325	4.8-53.9	20 - 65
Loss on ignition (%)	0.4-13.9	0.1 – 5 (about 80%<1.0)

* from reference [10]

** from reference [11] and the Concrete Products and Aggregates Co.ltd

2.2 Properties of Paste, Mortars and Concrete using Fly Ash

2.2.1 Water Requirement

Table 3 shows the comparison of water requirement between the Thai fly ashes and the Japanese fly ashes. It should be noted here that the test methods of both countries are not the same (JIS A6201-1991 was used to test the Japanese fly ashes and ASTM C311 was used to test the Thai fly ash). Mix proportion of the test samples, apparatus and the test procedure are all different. Especially for the mix proportion, in JIS A6201-1991, the water to binder ratio of the control sample (cement only mortar) is set at 0.65 and the sand to binder ratio is 2.0 while ASTM C311 specifies water to binder ratio of 0.484 and sand to binder ratio of 2.75. However, though both countries' fly ashes were tested based on different standards but they have the same concept to evaluate the test results. If the two set of data are compared by discarding the difference of the test methods, then both countries' fly ashes have similar water requirement as can be seen from Table 3. The lower loss on ignition makes the Thai fly ashes have similar level of water requirement to the Japanese fly ashes though they are coarser.

Table 3 Comparison of Water Requirement between Fly Ashes in Japan and Thailand

Properties	Japan* (%)	Thailand** (%)
Water requirement (%of the control)	91-105 (majority <100%)	93-103(majority <100%)

* from reference [10], tested by JIS A6201-1991

** data from the Concrete Products and Aggregates Co.ltd., tested by ASTM C311

2.2.2 Strength

The strength properties of fly ashes were compared by using the strength index which is the ratio of compressive strength between the fly ash mixed mortar and the cement only mortar (control mixture) at the age of 28 days. As in the case of flow, the different test methods between the JIS A6201-91 and the ASTM C311 must be noted fro preparing the test specimens in both countries. The most important difference is the w/b of the control mortar samples which is 0.65 for JIS A6201-91 and 0.5 for ASTM C311. This makes the two set of data not directly comparable. The JIS A6201-91 is supposed to give wider differences between the control and different fly ash samples due to lower strength of the control sample. However, the evaluation concept of the test results is the same. Then if ignoring the difference of the mix proportion, it may be able to state that the Thai fly ashes are about the same as the Japanese fly ashes in terms of strength development up to 28 days even though they are coarser. It should be noted here that another test condition that is not similar is the curing temperature which is 20°C in Japan but is 23°C for the Thai data used in this report. However, this 3°C difference in the curing temperature can be considered to have negligible effect. The not lower strength of the Thai fly ashes is possibly due to the higher CaO content, as the major reason, and lower loss on ignition, as the minor reason, in most of the Thai fly ashes than the Japanese ones

.Table 4 Comparison of Strength Index between Fly Ashes in Japan and Thailand

Properties	Japan* (%)	Thailand** (%)
Strength index at 28 days (% of control)	57.8-97.8 (about 90% between 65-85)	65-100

* from reference [10], tested by JIS A6201-1991

** data from the Concrete Products and Aggregates Co.ltd., tested by ASTM C311

2.3 Fly Ash Consumption in Thailand

Fig.1 shows the fly ash consumption in concrete in Thailand. The consumption shown in the figure is only for those used as a cement replacing material in concrete. In Thailand, up to the time this report is being written, almost 100% of the fly ash consumption is for this purpose. It is expected that the consumption of fly ash in cement and concrete will still increase in the future.

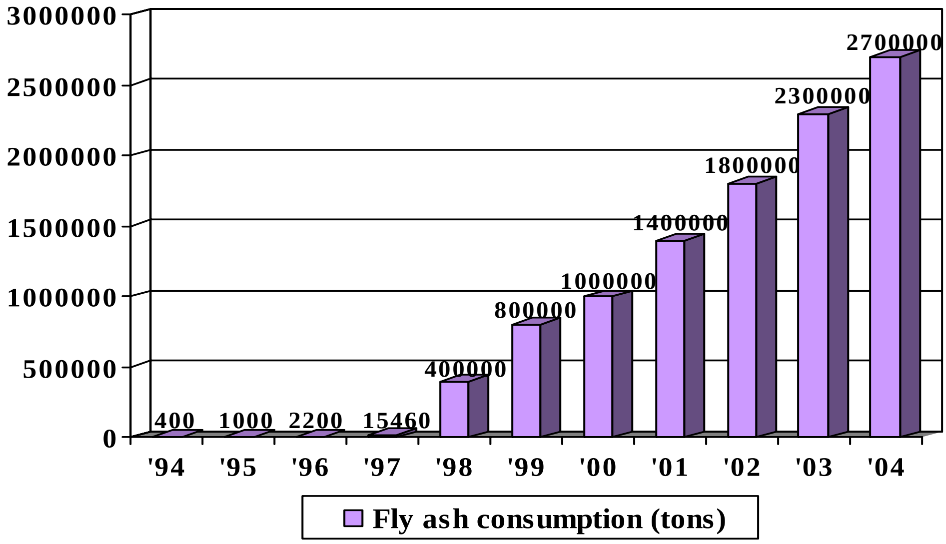

Fig.1 Fly ash consumption in concrete in Thailand
(The value of year 2000 is the forecasted one)

Fig.2 and Fig.3 show the statistics of fly ash used in various types of concrete. It can be seen from Fig.2 that up to 1997, fly ash was used mostly to produce special concrete like self- compacting concrete, sulfate resisting concrete and low heat concrete for mass concreting. However, the situation changes in 1999 when fly ash was used mostly in normal concrete. This expressed that fly ash had become more and more popular and engineers were more and more confident with the fly ash application in concrete at that time. At present, fly ash has already become a conventional cement replacing material in Thailand so that majority of the ready-mixed concrete plants, including those in precast concrete and on-site ready mixed plants, are using it as a major cementitious material and fly ash concrete has now become a conventional concrete in Thailand.

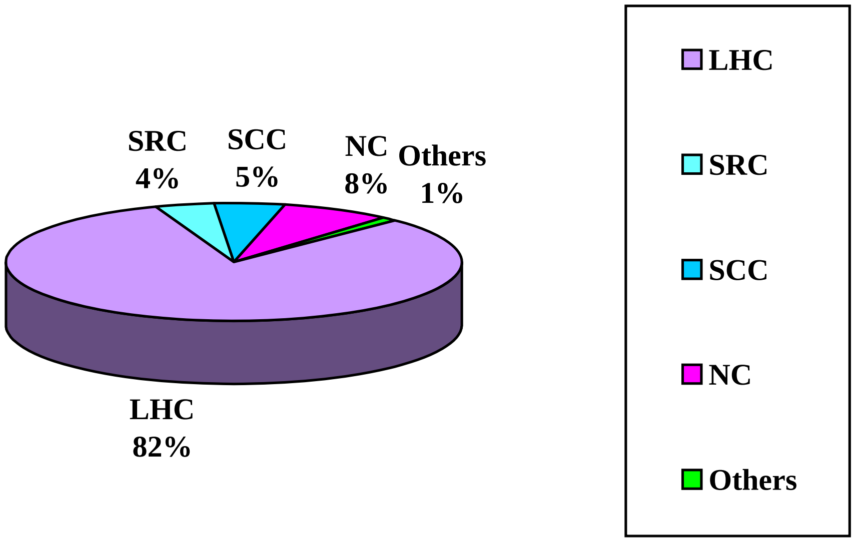

Fig.2 Distribution of fly ash used in various types of concrete from 1994-1997
LHC:Low heat concrete, SRC:Sulfate resisting concrete,
SCC:Self compacting concrete, NC:Normal concrete

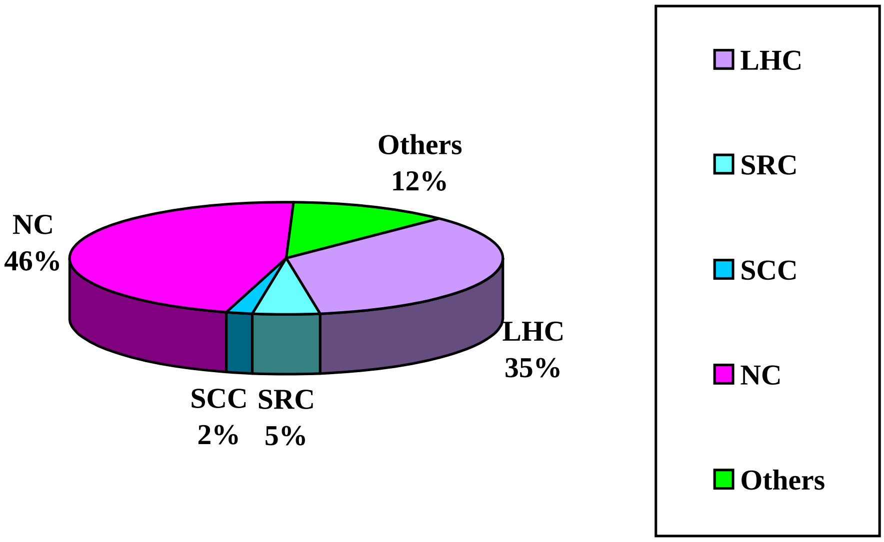

Fig.3 Distribution of fly ash used in various types of concrete in 1999
(forecasted from January to April 1999)
LHC:Low heat concrete, SRC:Sulfate resisting concrete,
SCC:Self-compacting concrete, NC:Normal concrete

3. PROBLEMS AND STRATEGIES TO PROMOTE THE USE OF FLY ASH

3.1 Problems

During 1980's, the image of fly ash produced from Mae Moh was negative due to many researchers' reports which pointed out the volume instability of concrete using fly ash due to high SO_3 content in the fly ash (mostly in the range of higher than 5% by weight of the fly ash) [12, 13]. Therefore the uses of fly ash at that time were in the low-value manners such as used for soil improvement, for embankment slope stability, for sub-base of pavement, for concreting of temporally pavement, etc. It was until the early 1990's that the SO_3 content of fly ash became lower to conservative values of below 5%. From that time, various intensive researches were restarted and many merits were found from using the fly ash in concrete as mentioned earlier in the section of introduction. In spite of the positive study results, fly ash was very little used in concrete production until 1997 (see Fig.1) due to many reasons as follows.

1) Lack of understanding and knowledge on fly ash among the engineers
2) Doubt on fly ash quality and its consistency
3) No systematic supplying system to facilitate the use.

3.2 Strategies

Many efforts were made by the Committee on Concrete and Materials of the Engineering Institute of Thailand to promote the use of fly ash in Thailand.

3.2.1 Research

An original research group consisting of researchers from 7 universities in Thailand was formed to study the properties of fly ash and concrete using fly ash. By this original group, more than 30 research reports and more than 100 technical papers had been already published until 2000. After that many other universities also started to conduct research on fly ash and many more publications have been produced since then.

3.2.2 Education and Training

From 1994 to 2001, eight seminars were arranged, by the committee, in various places around the country to give information and educate engineers on the effective use of fly ash in concrete. A learn-on-line project was created by the cooperation between the National Science and Technology Development Agency, the Electricity Generating Authority of Thailand and the Joint Research Group to provide information in a more effective and broadened way [14]. Many books and documents were also published for the purpose of educating engineers in the country [11,15]

3.2.3 Support for Real Practice

Various efforts were made to provide support for real application as follows

1) Conducting demonstration construction using fly ash concrete. Many demonstration construction projects were conducted during 1992 to 1996 (see Figs. 4, 5 and 6) to provide information.

2) Set up a unit called "By-Product Business Unit" at the Mae Moh generating plant for supplying business and quality control of fly ash. For quality control, the fine coal used for boiler burning is blended from various locations and layers of coal mines in Mae Moh in order to both satisfy the requirement of energy output and obtain fly ash with constant properties. At the moment, the measured properties of fly ash for quality control at Mae Moh are CaO, SiO_2 and SO_3 contents. It is expected that fineness will be another measured value for quality control at Mae Moh in the near future. Since fly ash is not an industrial product but a by-product, the qualities of fly ash is expected to vary and be not constant like cement. The variation in properties is one of the main hurdles for fly ash using in many parts of the world, not excepting Thailand. This system of quality control at the origin together with the coal blending technique will help reducing the uncertainty of fly ash quality and provide confidence to the users.
3) Provision of standard for fly ash. One of the problems at the beginning of fly ash application is the lack of appropriate standard that suited the local fly ash. According to many foreign standards, the properties of Thai fly ash especially the Mae Moh fly ash did not pass the requirement on fineness. However, researches had proved that though the fly ash had low fineness, it provided very satisfactory performance when used in concrete. Many performances are even better than fly ashes from many other countries. The committee on concrete and materials of the Engineering Institute of Thailand then decided to draft a new standard specification for fly ash in Thailand based on properties of Thai fly ashes and was published in 2003 [16]. Tables 5, 6 and 7 summarize the classes of fly ash and the corresponding chemical and physical requirements according to the latest Thai specification.
4) Produced references for practical engineers. Two books were published for being used as references for practical engineers [11,15].
5) A software "FACOMP T1.0" was developed as a tool to facilitate the practical engineers for mix proportioning of fly ash concrete (see Fig.7).
6) Encouraged ready-mixed concrete company to launch special fly ash concrete products such as marine concrete, sulfate-resisting concrete, sulfate-resisting concrete, self-compacting concrete, low-heat concrete, etc.

Table 5 Chemical properties

<table>
<tr><th rowspan="3">Item</th><th rowspan="3">Properties</th><th colspan="4">Requirement</th></tr>
<tr><th rowspan="2">First class</th><th colspan="2">Second class</th><th rowspan="2">Third class</th></tr>
<tr><th>Type a</th><th>Type b</th></tr>
<tr><td>1</td><td>Silicon dioxide (SiO_2), min. %</td><td>30.0</td><td>30.0</td><td>30.0</td><td>30.0</td></tr>
<tr><td>2</td><td>Calcium oxide (CaO), %</td><td>-</td><td>Less than 10.0</td><td>Not less than 10.0</td><td>-</td></tr>
<tr><td>3</td><td>Sulfur trioxide (SO_3), max. %</td><td>5.0</td><td>5.0</td><td>5.0</td><td>5.0</td></tr>
<tr><td>4</td><td>Moisture content, max. %</td><td>3.0</td><td>3.0</td><td>2.0</td><td>3.0</td></tr>
<tr><td>5</td><td>LOI content, max. %</td><td>6.0 [1)]</td><td>6.0 [1)]</td><td>6.0 [1)]</td><td>12.0</td></tr>
</table>

Note: [1)] The use of fly ash with up to 12% LOI may be approved if either acceptable performance records or laboratory test results are made available.

Table 6 Chemical properties (optional)

Item	Properties	Requirement			
		First class	Second class		Third class
			Type a	Type b	
1	Alkali content ($Na_2O + 0.658K_2O$) [1], max. % 1.1 when SO_3 between 3.0 to 5.0 % 1.2 when SO_3 less than 3.0 %	1.5 4.0	1.5 4.0	1.5 4.0	1.5 4.0

Note: [1] Fly ash with alkali content exceeding this limitation may be approved if the test results on control of alkali-silica reaction satisfy the requirement.

Table 7 Physical properties

Item	Properties	Requirement			
		First class	Second class		Third class
			Type a	Type b	
1	Fineness (select a method) Amount retained on 45-µm-mesh sieve, max. % Or Blaine fineness, min. cm^2/g	10 6000	50 2300	55 2000	65 1600
2	Strength activity index [1] with OPC type 1 7-day, min. % of the control 28-day, min. % of the control 91-day, min. % of the control [2]	85 95 100	70 75 85	70 75 85	60 70 75
3	Water requirement, max. % of the control	102	105	105	108
4	Autoclave expansion [3], max. %	0.8	0.8	0.8	0.8

Fig.4 Demonstration of mass concreting using fly ash concrete at Mae Moh power generating plant

Fig.5a Concrete wall

Fig.5b Concrete box culvert

Fig.5 Demonstration of Self-Compacting Concrete using fly ash at Mae Moh power generating plant

Fig.6 Demonstration construction of Roller-Compacted Concrete Pavement using fly ash at Mae Moh power generating plant

Fig.7 A computer software for mix proportioning of fly ash concrete

4. APPLICATION OF FLY ASH IN CONCRETE

Fly ash has become a popular cement replacing materials for concrete application since 1997 (see Fig.1) after the country faced economic crisis. One of the main reasons is that the cost of fly ash is much lower than that of the cement. The immediate gain from the low cost of fly ash could overcome the more

4.1 Ready-Mixed Concrete

For ready-mixed concrete, fly ash is normally used to replace cement in the ranges of 20 to 30% by weight of the total cementitious materials. Fly ash concrete has become conventional concrete for ready-mixed concrete industry. As mentioned above, many ready-mixed concrete companies started to launch special concrete products with fly ash such as marine concrete, sulfate-resisting concrete, sulfate-resisting concrete, self-compacting concrete, low-heat concrete, since late 1990's. Some high volume fly ash concrete were also practiced in Thailand with the maximum fly ash content up to 55% of the total binders for self-compacting concrete, 47.5% for low-heat concrete and 68% for roller-compacted concrete (see Fig.8 for Pak Mool dam constructed using roller-compacted concrete). The ready-mixed concrete industry is currently the major consumer of fly ash in Thailand.

Fig.8 Pak Mool dam in Ubol Rachathani constructed using roller-compacted concrete with fly ash content of 68% of the total cementitious materials.

4.2 Precast Concrete, Concrete Products

For precast concrete and concrete product industries, fly ash is normally used in the works that does not require early strength such as non-prestressed concrete works. For prestressed concrete industries, fly ash is also used but with a maximum cement replacement of only up to 10%. The exception may be in the case of self-compacting concrete application in which fly ash may be used up to a range of 30% to 50% even in prestressed concrete work..

4.3 Other Cementitious Products

Some cementitious material products which use fly ash to replace cement in the production are such as cementitious fibered roof tile, cementitious fibered panel, etc. In this category, fly ash is normally used up to a maximum of 30% of the total cementitious materials.

4.4 Blended Cement

Some cement companies have made efforts to introduce ready-blended fly ash cement into the concrete market in Thailand. Most of them are introduced in the form of cement for durability purposes such as cement for marine environment having high resistance against sulfate attack and chloride-induced steel corrosion, sulfate-resisting cement or low-heat cement, etc. However, these cements are still not popular especially for project constructions using ready-mixed concrete. For projects, where ready-mixed concrete is usually applied, it is more popular to mix fly ash at the ready-mixed concrete plants. This is because 1) ready-blended fly ash cement is more expensive than cement with fly ash as a separate binder, 2) the ratio of fly ash is usually adjusted according to the required performances of concrete when it is used as a separate binder.

4.5 Repair Materials

Fly ash is also used in enhancing performances and reducing cost of some repair materials especially for grouting materials. Fly ash has also been studied as a stabilizer and to control expansion of expansive cement [17].

5. CONCLUDING REMARKS

Based on what mentioned in this paper, it can be said that Thailand has become a very successful country in regard of fly ash usage in concrete industry. The success was obtained on great efforts and good strategic planning and patience of a number of academicians and professional engineers. The use of fly ash has also become one of the significant factors to change the concept of concrete practice in Thailand from that considering strength only to considering both strength and durability.

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