

## Practices for Sustainable Development for Concrete Construction in Thailand

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### ABSTRACT

In this paper, concepts of sustainable development in concrete construction in Thailand are described. Observation on the practices during the past decades showed many inadequate attention on good practices leading to some low quality and short-life structures. Solutions have been proposed for all practicing steps, i.e. 1) analysis and design, 2) materials selection and specification, 3) construction, and 4) maintenance, for achieving sustainable practices. This paper describes some efforts in the aspects of design and materials. For design, the new Thailand Building Codes Project launched by the Department of Public Works and Town & Country Planning is one of the successful efforts. The Codes include durability and service life design which is practiced for the first time in Thailand. For materials, problems on specification and examples of application of cement replacing materials are described. The multi binder concept is introduced as an examples for sustainable practice in this paper.

**Keywords:** Sustainable Development, Durability and Service Life Design, Carbonation, Chloride-Induced Steel Corrosion, Cement Replacing Materials

### INTRODUCTION

It is clear that the construction practice in Thailand still involves problems. Reports showed that many low quality structures caused by inadequate attentions to good practices have been found in many countries including Thailand (Tangtermsirikul, Kaewkhluab and Kaewmanee, 2003), (Tangtermsirikul, 2004). It was also shown that there are still many opportunities to reduce burdens on environment by proper construction practices [3]. Many countries have been spending a huge amount of money for repair and maintenance of structures. Those low quality structures were normally caused during one or more of the following 4 steps of practice ; 1) analysis and design, 2) materials selection and specification, 3) construction and 4) maintenance. Since it is not possible to elaborate all issues in details in this paper, only some examples of efforts to establish good practices in Thailand for issues 1) and 2) will be briefly introduced.

### SUSTAIABILITY PROBLEMS AND SOLUTIONS

Inspection on the deterioration of concrete structures in different areas in Thailand has been performed for years. Various types of damages of concrete structures could be observed. Structural damages caused by loading were found in some special cases where

unexpected load took place. Although these severe load-inducing structural damages call for immediate repairs, they can be found in much smaller number of cases when compared with the damages due to durability problems. This fact highly emphasizes that the current practices are not sufficient to guarantee designed service life of structures and then leads to needs of a great deal of maintenance works for these structures. Therefore, it is obvious that practices which enable us to obtain durable structures should be employed as the standards of practice for construction and the new standards of practice should be applicable to various construction and environmental conditions.

## Proposed Solutions

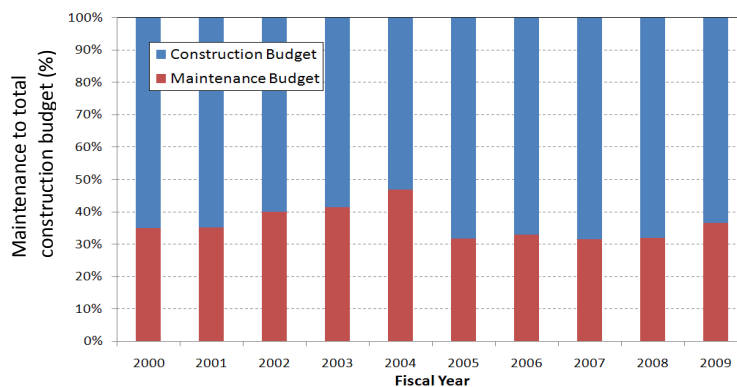
The author has been spending efforts to promote the concept of sustainable practice for concrete construction in Thailand during the last two decades. The following practices are emphasized.

- practicing a design considering durability and service life
- selecting proper materials and mix proportion of concrete
- practicing good construction control and inspection
- practicing good maintenance

It is clear that to have good quality structures with satisfactory service life, all 4 mentioned steps of practice should not be ignored. There are plenty of opportunities to improve the level of sustainability for construction in Thailand through the improvement of these 4 steps of practice. Due to the limitation of the paper length, only some examples of efforts in Thailand in the first 2 steps, steps of design and material selection and specification will be elaborated here. Without good practices in the first 3 steps, good quality structures cannot be obtained right after the construction. In addition, lack of proper maintenance also results in deterioration with the rate faster than expected. In many advanced countries, the budgets used for maintaining structures are more than half of their total construction budgets. In Thailand, the author estimated the overall figure at approximately 30%. Figure 1 shows an example of data from a major public authority in Thailand. It has been realized that the overall maintenance budget did not usually go along with the economic condition while the total construction budget usually did. Higher of this figure means there is less budget for new construction. Such situation is certainly considered not acceptable for all developing economies.

## DESIGN SOLUTION: DURABILITY AND SERVICE LIFE DESIGN

Most concrete structures improperly designed without considering conditions of construction and surrounding environmental as well as possible durability problems show shorter life than they should. In this section, a concept for design considering durability,



**Figure 1. Ratio between Maintenance and Total Construction Budgets of a Major Public Authority in Thailand**

adopted by the Department of Public Works and Town and Country Planning as the Thailand design standard, is briefly introduced. Most of the design equations, charts and tables were established based on the works done by the research group of the authors (Khunthongkeaw and Tangtermsirikul, 2005), (Samranwanich and Tangtermsirikul, 2004), (Krammart, P. and Tangtermsirikul, 2004) together with those modified from some foreign standards. Only three major deterioration types i.e. chloride-induced corrosion, carbonation and sulfate attack are briefly introduced as examples in this paper.

## Design for Durability and Service Life

The items concerned in durable concrete design are based on selection of type of binders, and concrete mix proportion in addition to the cover thickness. The details of concrete design depend on the involved durability problems. As examples, brief explanations of design or specification for 3 durability problems i.e. chloride-induced steel corrosion, carbonation and sulfate attack are described in this paper.

### Steel corrosion due to Chloride

In the design, the chloride content at the surface of reinforcing bars must be controlled to prevent initiation of steel corrosion as shown in Equation 1.

$$C_d \leq C_{lim} \quad (1)$$

where,

$C_{lim}$  : Critical chloride content that causes steel corrosion (see Table 1)

$C_d$  : Chloride content at the surface of steel bars in concrete (%wt. of binder) coming from external environment and can be estimated from

$$C_d = (C_s - C_0) \left[ 1 - \operatorname{erf} \left( \frac{c}{2\sqrt{D_a t_r}} \right) \right] + C_0 \quad (2)$$

where,

$c$  : Thickness of concrete cover (cm)

$D_a$  : Apparent chloride diffusion coefficient (cm<sup>2</sup>/year)

$t_r$  : Repair-free service life of concrete structure (year)

$C_s$  : Chloride content on the surface of concrete structure (% wt. of binder) (see Table 2)

$C_0$  : Initial chloride content at the surface of steel in concrete (%wt. of binder)

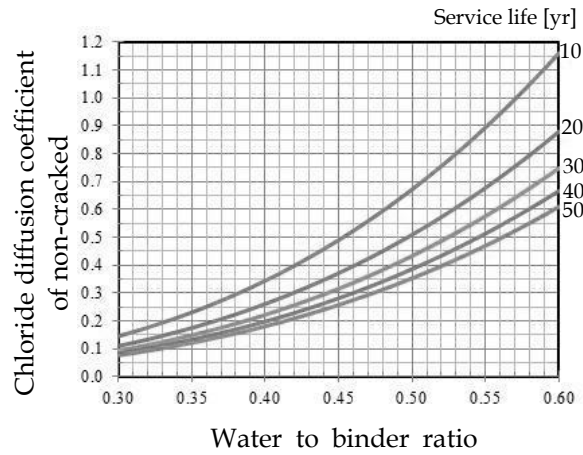
Figure 2 shows an example of the relationship between the apparent chloride diffusion coefficient of a non-cracked cement-only concrete and water to binder ratio.

**Table 1. Critical Chloride Content for Different Type of Binder**

Type of Binder	Critical Chloride Content (% wt. of total binder)
Cement (OPC) only	0.45
Cement (OPC) + Limestone powder (LP) - LP to total binder ratio is not more than 0.15	0.45
Cement (OPC) + Fly ash (FA) - FA to total binder ratio is less than 0.15 - FA to total binder ratio is not less than 0.15 but less than 0.35 - FA to total binder ratio is not less than 0.35 but not more than 0.50	0.45 0.35 0.30
For OPC+LP+FA, if LP to total binder ratio is less than 0.15, the values of OPC+FA shall be used.	

**Table 2. Chloride Content at the Surface of Concrete Structure ( $C_s$ ) at Different Distance from Seashore**

Service Life(years)	10	20	30	40	50
Distance from Seashore (m)	Chloride content, $C_s$ (% wt. of concrete)				
Splash	0.971	1.233	1.391	1.504	1.592
0 m	0.299	0.389	0.453	0.506	0.551
100 m	0.135	0.176	0.205	0.229	0.249
250 m	0.061	0.079	0.092	0.103	0.112
500 m	0.041	0.054	0.063	0.070	0.076
1000 m	0.040	0.052	0.060	0.067	0.073



**Figure 2. Relationship between Apparent Chloride Diffusion Coefficient of Non-Cracked Cement-Only Concrete and Water to Binder Ratio**

### Carbonation

Spalling of concrete cover due to carbonation can be observed in many transportation infrastructures in Bangkok. Quality and thickness of concrete cover of these structures should be sufficiently provided to ensure that the corrosion of reinforcement due to carbonation does not take place during its designed repair-free service life. The thickness of concrete cover should not be smaller than the depth of carbonation during the designed repair-free service life (see Equation 3).

$$X_c \leq c \quad (3)$$

where,

$c$ : Thickness of concrete cover (mm)

$X_c$ : Depth of carbonation (mm) which can be estimated from

$$X_c = \alpha_1 \alpha_2 k t^{0.5} \quad (4)$$

where,

$\alpha_1$ : Effect of rain subjection (see Table 3)

$\alpha_2$ : Effect of severity of the environment (see Table 4).

**Table 3. Effect of Rain Subjection on Carbonation Depth**

Condition of Rain Subjection	$\alpha_1$
Can be wetted by rain or water	0.95
No possibility of rain/water subjection	1.00

**Table 4. Effect of Severity of Carbonation Environment**

Level of Severity of Carbonation Environment	$\alpha_2$
Typical	0.65
Medium Severity	0.85
High Severity	1.00

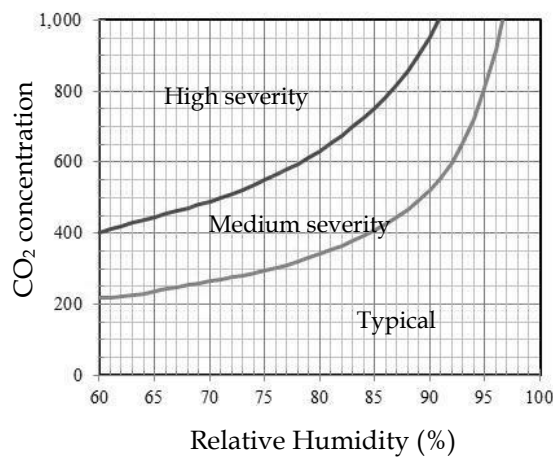
The severity of the carbonation environment is specified from average relative humidity and average CO<sub>2</sub> concentration of the environment as in Figure 3 (Tangtermsirikul, Sumranwanich, Krammart, Khuthongkaew and Sahamitmongkol, 2006).  $t_r$  is the repair-free service life (years).  $k$  is the carbonation coefficient which can be derived from

$$k = 1.5k_r(w/b)^3 \tag{5}$$

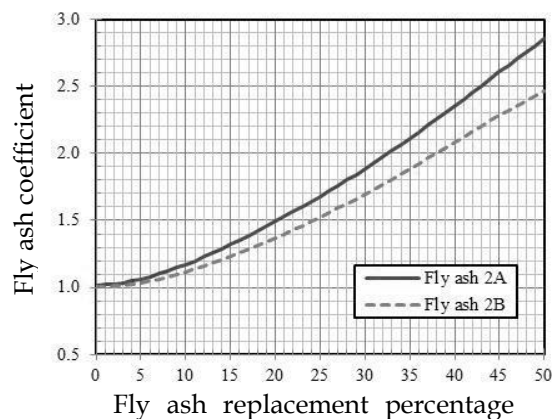
where,

$w/b$  : Water to binder ratio

$k_r$  : Effect of fly ash on carbonation coefficient (see Figure 4).



**Figure 3. Degree of Severity of Carbonation Environment**



**Figure 4. Coefficient  $k_r$  for Each Type of Fly Ash Indicating Effect of Each Fly Ash on Carbonation Reaction**

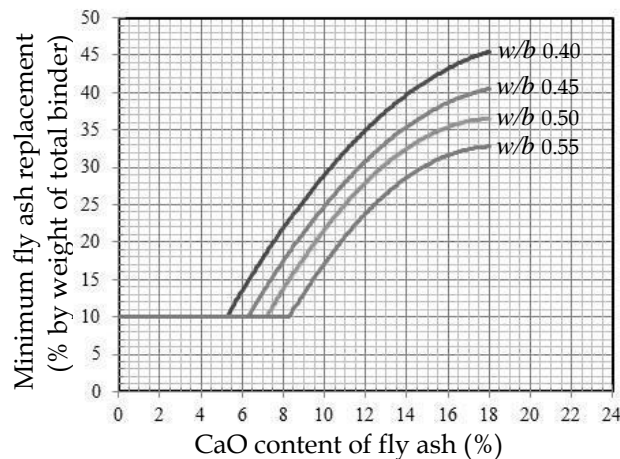
### Sulfate Attack

Different types of sulfate cause different mechanisms of deterioration and the new building code also includes this fact. Sodium sulfate causes expansion whereas

magnesium sulfate mainly causes conversion and dissolution of calcium silicate hydrate with less expansion (Krammart and Tangtermsirikul, 2004). Different recommendations are given for each type of sulfate environment. It is noted that only a few codes have provided separate sulfate resisting specifications for different types of sulfate. Table 5 shows classification of level of severity of sodium sulfate environment and recommended types of cementitious material and conditions of mix proportion for sodium sulfate resisting concrete. In case that fly ash is used to improve sodium sulfate resistance, the minimum amount of fly ash, which gives an equivalent expansion of the fly ash concrete to that of the concrete using Type 5 cement (sulfate-resisting cement), can be estimated from Figure 5. Table 6 shows classification of level of severity of magnesium sulfate environment and recommended types of cementitious material and conditions of mix proportion for magnesium sulfate resisting concrete.

**Table 5. Classification of Level of Severity of Sodium Sulfate Environment and Recommendation for Mixture Condition**

Level of Severity	Concentration of Sulfate ( $\text{SO}_4^{2-}$ )		Recommended Binder Type	Max. w/b
	In Water (ppm)	Soluble Sulfate Content in Soil (% by weight of soil)		
Low	Less than 150	Less than 0.1	-	-
Medium	150-1,500	0.1-0.2	OPC 2 or OPC5 or OPC 1 with pozzolan	0.5
Severe	1,500 –10,000	0.2-2.0	OPC5 or OPC 1 with pozzolan	0.45
Very severe	Higher than 10,000	Higher than 2.0	OPC 1 with pozzolan or OPC 5 with pozzolan	0.40



**Figure 5. Minimum Fly Ash Replacement Percentage to Obtain an Equivalent Sodium Sulfate Resistance of the OPC Type 5**

**Table 6. Classification of Level of Severity of Magnesium Sulfate Environment and Recommendation for Mixture Condition**

Level of Severity	Concentration of Sulfate in Water (ppm)	Recommended Binder Type	Max w/b
Low	Less than 300	-	-
Medium	300 – 1,000	OPC 1 or OPC 2 or OPC 5	0.5
Severe	1,000 – 3,000	OPC5	0.45
Very severe	Higher than 3,000	OPC 5	0.40

## MATERIALS SOLUTION

Major problems regarding practices on materials are summarized as follows.

- Insufficient concerns on environment and energy conservation: Initial cost and familiarity with traditional materials seems to be the priorities.
- Material specification does not consider various necessary properties especially those related to long term durability but mainly only strength is concerned.
- Too prescriptive and rigid specification together with insufficient knowledge of practitioners make it difficult to apply new and more sustainable materials.
- Improper adoption of foreign specifications which do not suit local conditions.

An example is that standard for cement in Thailand does not cover blended cement in a most beneficial way. As of the cement replacing materials (CRM) usage, there are various types of CRMs which are possible concrete including pozzolans like fly ash, slag, silica fume, RHA, bio-fuel ashes, as well as nonpozzolans like limestone powder. Though there are various materials with technically high potential, only fly ash is widely utilized in Thailand due to insufficient studies, standards and specifications for the other materials. Here, only fly ash and limestone powder which now have real application and have great impact on the concrete industry in Thailand will be introduced. The goal of the development is to make success of the application of multi-binder system in Thailand.

### Fly ash

There are difficulties around the world to achieve effective utilization of fly ash or even to get rid of it. The most effective use of fly ash at present, by considering both volume and value, seems to be in the area of concrete. The use of fly ash as a cement substituting material is believed to be beneficial in both environmental and quality improvement aspects. Although some properties of fly ash concrete have been found to be inferior than the concrete without fly ash, the use of fly ash to partially replace cement improves many other properties of concrete especially durability (Krammart and Tangtermsirikul, 2004), (Tangtermsirikul, Sudsangium and Nimityongsakul, 1995), (Tangtermsirikul and Chatveera, 1997), (Samranwanich and Tangtermsirikul, 2004). A proper use of fly ash based on type of construction work and the service environment that a 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. Since 2004, approximately more than 80% of fly ash produced in Thailand is used as a partial cement substitution material for both quality improvement and cost reduction of concrete. Table 7 shows the fly ash annual consumption in construction industry in Thailand.

**Table 7. Annual Fly Ash Consumption in Thai Construction Industry**

Year	1998	2000	2002	2004	2006	2008	2009	2010
Fly ash consumption (x1,000 tons)	400	950	1,400	1,850	2,000	1,850	1,750	1,850

- **Typical Characteristics of Fly Ash in Thailand**

From the data of Thai fly ashes observed continuously for more than 10 years together with the report of a study which cover 40 types of fly ash from 24 generating plants in Japan (Yamamoto and Kanazu, 1998), it can be seen that the chemical composition of fly ashes in Thailand covers a wider range than that of Japan and typically have higher CaO but lower SiO<sub>2</sub> and fineness. This is mainly because, in addition to the differences of the

types of the plants and processes, Thailand uses many sources of coal both local and imported ones. The domestic coal is lignite while most of the imported coals are bituminous coals. For physical properties, the majority of the Thai fly ashes have lower specific gravity, Blaine fineness and LOI 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 plerospheres. 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.

- **Properties of Concrete Using Fly Ash**

As generally known, fly ash has advantages over cement-only system in many performances ; improved workability and pumpability, lower heat of hydration, lower autogenous and drying shrinkage (the latter if cured well), higher longterm strength, lower permeability, improved chloride penetration and sodium sulfate resistance, lower alkali aggregate reaction potential, while on the contrary, worsens some properties like delayed setting and early strength, lower carbonation and magnesium sulfate resistance.

- **Application of Fly Ash in Concrete**

**Ready-Mixed Concrete** : Fly ash is normally used to replace cement in the ranges of 20 to 30% by weight of the total binder. Fly ash concrete has become a conventional concrete for ready-mixed concrete industry. Many ready-mixed concrete companies also started to launch special concrete products with fly ash such as marine concrete, sulfate-resisting concrete, self-compacting concrete, low-heat concrete, etc. 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, 50% for low-heat concrete and 68% for roller-compacted concrete for dams. Ready-mixed concrete industry is currently the major consumer of fly ash in Thailand.

**Precast Concrete and Concrete Products** : For precast concrete and concrete products, fly ash is normally used in the works that does not require early strength such as non-prestressed concrete. 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.

**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 binder.

**Blended Cement** : Some cement companies have made efforts to introduce ready-blended fly ash cement into the concrete market in Thailand. Most of the introduced cements are in the form of cement for durability purposes such as marine cement having high resistance against sulfate attack and chloride-induced steel corrosion, sulfate-resisting cement or low-heat cement, etc. However, these cements are not popular. 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.

**Repair Materials** : Fly ash is also used in enhancing performances and reducing cost of some repair materials especially grouting materials. Fly ash has also been studied as a stabilizer and to control expansion of expansive cement (Jakpaisal and Limsuwan, 2003).



## **Limestone Powder (CaCO<sub>3</sub> Powder)**

Fly ash has been successfully utilized in concrete industry for almost two decades in Thailand. It has been proved to enhance many properties of concrete and has become the most popular cement replacing material for concrete industry in Thailand. However, fly ash is also known to reduce some performances of concrete such as slow setting, low early strength, low magnesium sulfate resistance, and high sensitivity to curing, etc. These make fly ash not appropriate for some applications. There are several more types of cement replacing materials available in Thailand. Some are in the stage of R&D but some have already been utilized and have high potential.

Limestone powder, LP, is one of the CRMs which has high potential to be used in concrete in Thailand. It should be noted that the application of LP as an addition powder to the binder is not popular in Thailand. Limestone powder usually contains calcium carbonate as the major component. The content of calcium carbonate is usually higher than 80% by weight of the powder. For effective use as cement replacing material, it is usually ground to a fineness higher than that of the cement. When added in concrete, it only slightly involves in reactions but the effectiveness is derived mainly from its physical properties i.e. physical acceleration of the reaction and filling effect (Kakali, Tsvivilis, Aggeli and Bati, 2000).

- **Effect of LP on Properties of Concrete (Kakali, Tsvivilis, Aggeli and Bati, 2000) (Kaewmanee, Tangtermsirikul and Kasemchaisiri, 2006)**

LP is known to accelerate the setting times of cementitious systems. The use of LP to replace a portion of cement or fly ash reduces both the initial and final setting times of pastes both with and without fly ash. Partially replacing cement with an appropriate amount of LP improves early strength of concrete. The appropriate amount usually ranges from 10 to not more than 20% depending on the fineness of the LP. The finer the LP, the higher this appropriate amount is. Studies on various concrete containing LP showed that many durability properties of the concrete were improved by the LP. The improved properties are such as autogenous shrinkage, drying shrinkage, sulfate resistance. One of the main merits of LP is the improved cracking resistance.

## **Ternary Binder System**

From the author's studies on use of many cement replacing materials, a plan has been made to introduce multi-binder system to the concrete industry, either in the manners of blended cements or CRMs. This concept is to optimize the use of various CRMs to obtain optimum performances and cost. For example, fly ash and LP can be used in combination to produce concrete which is better than cement-only concrete in almost all performances. This cannot be achieved by the use of only a single type of CRM. For example, shown in Figure 6 are the results of weight loss of mortar specimens in magnesium sulfate solution, showing that mixtures using fly ash as the only CRM show high weight loss (C80FA20 and C60FA40) while the ternary binder mixtures (C80FA15LP5 and C60FA30LP10) demonstrate low weight loss when compared to cement type 1 mortar (C1). Figures 7 and 8 show the test results of rapid chloride penetration test on mortars with w/b=0.4. It can be seen that when increasing the LP, the chloride penetration of mortars increases if only LP is used to replace cement (see Figure 7). However, when fly ash and LP are used in combination, it is possible to produce mortar with the lowest chloride penetration than all other single and binary mixtures (see C70FA25LP#04-5 in Figure 8). Performance evaluation of single, binary and ternary binder systems with cement, fly ash and LP are simply summarized for a quick comparison in Table 8.

## CONCLUSIONS

A concept of sustainable development for concrete construction is described in this paper. It was concluded that in order to obtain high quality structures with satisfactory service life, all four steps of practice should be well made. The four steps are 1) analysis and design, 2) material selection and specification, 3) construction and 4) maintenance. As an example, the durability design concept discussed in this paper is one of the important components to develop a more sustainable infrastructure development. The design equations are derived based on some mathematical models established by the research group of the author. Only design for chloride-induced corrosion, carbonation-induced corrosion and sulfate resistance specification were introduced.

For the aspect of development trend in term of materials, two cement replacing materials i.e. fly ash and limestone powder are introduced. Optimizing the use of cement replacing materials by the concept of ternary binder system of cement, fly ash and limestone powder is also demonstrated and proposed.

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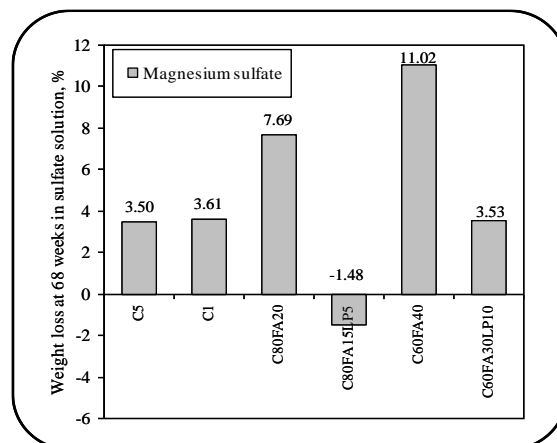


Figure 6. Weight Loss of Mortar Specimens in Magnesium Sulfate Solution

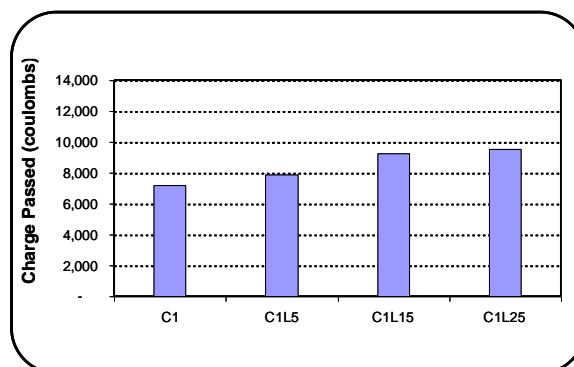
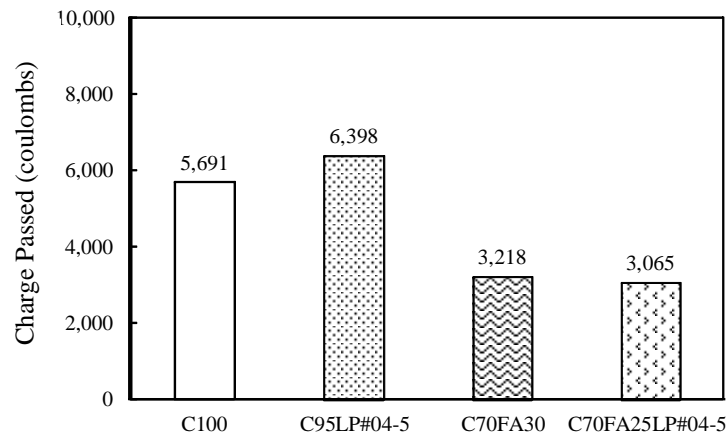


Figure 7. Rapid Chloride Penetration Test Results of Mortars with and without Limestone Powder (w/b=0.4, 7 days)



**Figure 8. Rapid Chloride Penetration Test Results of Mortars with Ternary Binder (w/b=0.4, 28 days)**

**Table 8. Summary of Performances of Various Binder Systems**

Binder systems Properties	Single		Binary		Ternary
	Type I	Type V	C+LP	C+FA	C+FA+LP
Compressive strength					
- Early age	●●●	-	●●●●	●	●●●
- Long-term	●●●	-	●	●●●●	●●●
Slump	●●	-	●	●●●●	●●●
Autogenous shrinkage	●	-	●●	●●●●	●●●
Drying shrinkage	●	-	●●	●●●●	●●●●
Carbonation	●●●●	-	●●●	●	●●
Chloride resistance	●●	-	●	●●●●	●●●
Sulfate resistance					
- Sodium sulfate	●	●●●	●●	●●●●	●●●●
- Magnesium sulfate	●●●	●●●●	●●●	●	●●●●

Remarks: ●●●●= best performance, ... , ● = worst performance

FA content  $\geq 30\%$ , LP content  $\leq 10\%$ , LP size ( $d_{50}$ ) ranges from 2 – 11  $\mu$  m

## REFERENCES

- Tangtermsirikul, S., Kaewkhluab, T., and Kaewmanee, K. (2003). "Information acquisition and structural health monitoring of bridges in Bangkok." *Proceedings of the Second International Symposium on New Technologies for Urban Safety of Mega Cities in Asia*. 30-31 October 2003, Tokyo, Japan, pp.1333-140.
- Tangtermsirikul, S. (2004). "Durability design for concrete structures for urban safety in Thailand." *Proceedings of the 3rd International Symposium of New Technologies for Urban Safety of Mega Cities in Asia*, 18-19 October 2004, Agra, India, pp.177-184.
- Khunthongkeaw, J. and Tangtermsirikul, S. (2005). "Model for simulating carbonation of fly ash concrete." *ASCE Journal of Materials for Civil Engineering*. 17(5), 570-578.
- Samranwanich, T. and Tangtermsirikul, S. (2004). "A model for predicting time dependent chloride binding capacity of cement-fly ash binder system." *Materials and Structures, RILEM*. 37(270), 387-396.
- Tangtermsirikul, S., Sumranwanich, T., Krammart, P., Khuthongkaew, J. and

- Sahamitmongkol, R. (2006). "Durability design concept for sustainable concrete structures in Thailand." *Proceedings of the 5th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia (USMCA 2006)*, Phuket, Thailand, 16-17 November 2006, pp.291-300.
- Krammart, P. and Tangtermsirikul, S. (2004). "Expansion, strength reduction and weight loss of fly ash concrete in sulphate solution." *ASEAN Journal on Science and Technology for Development*. 21(4), 373-390.
- Tangtermsirikul, S., Sudsangium, T. and Nimityongsakul, P. (1995). "Class C Fly Ash as a Shrinkage Reducer for Cement Paste." *Proceedings of the 5th CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete*, 4-9 June 1995, Milwaukee, Wisconsin, USA, Vol.1, pp.385-401.
- Tangtermsirikul, S. and Chatveera, B. (1997). "Expansion of cement paste and mortar using lignite fly ash." *Supplementary Papers of the 3rd CANMET/ACI International Symposium on Advances in Concrete Technology*, 24-27 August 1997, Auckland, New Zealand, pp.321-329.
- Samranwanich, T. and Tangtermsirikul, S., (2004). "A model for predicting time dependent chloride binding capacity of cement-fly ash binder system." *Materials and Structures*, RILEM, Vol.37, No.270, July 2004, pp.387-396.
- Yamamoto, T. and Kanazu, T. (1998). "Accelerated chemical assessing method for pozzolanic activity of fly ash." *Abiko Research Laboratory Report No. U98047*, Central Research Institute of Power Industry, Japan.
- Jakpaisal, V. and Limsuwan, E. (2003). "Development of shrinkage-compensating cement." *Proceedings of the 1st National Concrete Convention, Kanchanaburi*, 14-16 May 2003, pp.23-27.
- Kakali, G., Tsvivilis, S., Aggeli, E. and Bati, M. (2000). "Hydration products of C<sub>3</sub>A, C<sub>3</sub>S and Portland cement in the presence of CaCO<sub>3</sub>." *Cement and Concrete Research*, 30, 1073-1077.
- Kaewmanee, K., Tangtermsirikul, S., and Kasemchaisiri, R. (2006). "Effect of particle size of limestone powder on properties of normal concrete and special concrete." *Proceedings of the 11th National Convention on Civil Engineering*, Engineering Institute of Thailand, Phuket, 20-22 April 2006, CD Rom, Abstract, pp.195.