คุณสมบัติด้านความต้านทานและกำลังรับแรงอัดของมอร์ต้าร์ผสมเถ้าลอยแม่เมาะ

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บทคัดย่อ

วัตถุประสงค์ของการวิจัยในครั้งนี้คือ การศึกษาถึงความลึกของปฏิกิริยาคาร์บอเนชั่น การหดตัวแบบออโตจีนัสและการหดตัวแบบแห้ง รวมทั้งได้ทำการทดสอบเพื่อหาค่ากำลังอัดของมอร์ต้าร์ผสมเถ้าลอยแม่เมาะ โดยพิจารณาทำการควบคุมอัตราส่วนการแทนที่ของเถ้าลอยต่อปริมาณปูนซีเมนต์ไว้ที่ร้อยละ 30 และ 60 และใช้อัตราส่วนน้ำต่อวัสดุผงคงที่

ในส่วนของการศึกษาคุณสมบัติความต้านทานต่อปฏิกิริยาคาร์บอเนชั่น การหดตัวแบบแห้ง และการหดตัวแบบออโตจีนัส ใช้ตัวอย่างทดสอบโดยการแทนที่ปูนซีเมนต์บางส่วนด้วยเถ้าลอยเพียงชนิดเดียว สำหรับการศึกษากำลังรับแรงอัดได้ใช้เถ้าลอย ซึ่งจำแนกได้ตามปริมาณของ SO_3 ที่แตกต่างกันรวม 3 ชนิด

จากผลการศึกษาพบว่า การเพิ่มปริมาณการแทนที่ของเถ้าลอย สามารถลดการหดตัวทั้งการหดตัวแบบแห้ง และการหดตัวแบบออโตจีนัสของมอร์ต้าร์ลงได้ แต่จะทำให้ความต้านทานปฏิกิริยาคาร์บอเนชั่นลดลง สำหรับผลการศึกษาด้านกำลังรับแรงอัด พบว่าปริมาณแคลเซียมออกไซด์เทียบเท่าในวัสดุผงมีความสัมพันธ์โดยตรงกับความสามารถในการรับแรงอัดของมอร์ต้าร์ผสมเถ้าลอยแม่เมาะ

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Durability and Compressive Strength of Mae Moh-Fly Ash Mortar

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Abstract

Objectives of this research were to investigate the carbonation resistance, autogenous shrinkage, drying shrinkage and compressive strength of mortar containing lignite fly ash from Mae Moh. The water-cementitious materials ratio was kept constant. The main parameter was the percentage of fly ash replacements, 30% and 60%. For carbonation, autogenous shrinkage and drying shrinkage tests, the specimens were made with the replacements of only one type of fly ash whereas for compressive strength test, 3 types of fly ash in different content of SO_3 were used. The test results indicated that when percentage of fly ash replacement increased, both types of shrinkage decreased. However, increasing in fly ash replacement ratio should be observed in the lowering of carbonation resistance the carbonation resistance. For the compressive strength result, the strength of fly ash mortar was related to the CaO-Equivalent in cementitious materials.

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Introduction

It is known that fly ash is one of pozzolan, which has great potential to be used in order to improve concrete quality in construction. In recent years, energy consumption in Thailand rises appreciably due to the industry expansion and economic growth, causing the increase in coal consumption for producing electricity, thus increasing the amount of fly ash which is waste product. Each year Mae Moh electricity generating plants use 14 million tons of lignite coal to produce the electricity. It generated a lot of coal ash but only a small amount was used. The remained amount may be harmful to the environment in term of dispersing in the air if disposing condition is unsuitable. If the utilization of fly ash increases, environmental problem can be alleviated.

This paper presents some advantages of using fly ash as a constituent in concrete mixtures in term of mechanical properties and durability.

Expreimental Details

Materials

Portland cement: Ordinary Portland Cement type 1 (OPC) was used. The properties and composition are shown in Table 1.

Fly ash: Three types of fly ash in various content of SO_3 (FH, FM, FL) from Mae Moh electricity generating plant were used. The properties and composition are also tabulated in Table 1.

Table 1 Composition and properties of cement and fly ash

Composition/Properties	OPC	FH	FM	FL
SiO_2 (%)	21.45	26.23	30.39	42.86
Al_2O_3 (%)	5.35	13.72	15.90	23.05
Fe_2O_3 (%)	3.01	9.99	10.53	8.75
CaO (%)	67.33	29.97	23.12	10.13
MgO (%)	1.52	3.16	3.26	2.93
K_2O (%)	0.33	1.70	2.00	2.55
Na_2O (%)	0.11	0.21	0.19	0.20
SO_3 (%)	2.31	6.01	4.17	1.17
MnO (%)	-	0.14	0.13	0.09
Specific Gravity	3.15	2.65	2.23	1.94
Bulk Density (kg/l)	1.02	1.13	1.00	1.00
Fineness, Retaining 45μm sieve (%)	8.60	30.22	35.68	42.68
Moisture Content (%)	0.11	0.08	0.14	0.07

Where as FH, high SO_3 fly ash : FM, medium SO_3 fly ash : FL, low SO_3 fly ash

Fine aggregate: Natural river sand passing ASTM sieve number 4 was used. A typical gradation analysis is shown in Fig. 1 and the sieving test was prepared in accordant with ASTM C128. The physical properties are shown in Table 2.

Mixing water: Ordinary tap water was used.

Table 2 Physical properties of fine aggregate

Properties	Value
Specific Gravity (SSD)	2.54
Absorption (%)	1.00
Moisture Content (%)	2.53
Fineness Modulus	2.82

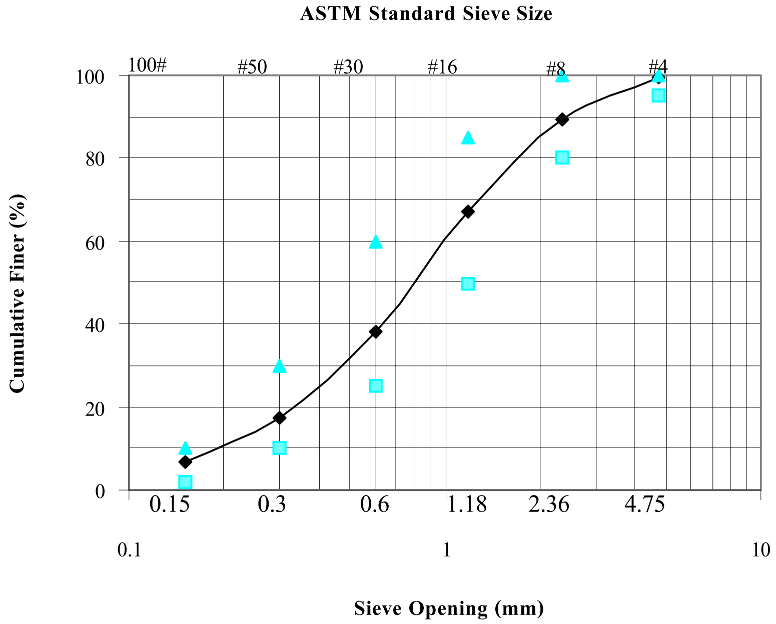

Fig. 1 Size distribution of fine aggregate

Mixture Proportioning

The mixture proportions using in determining of durability and compressive strength of mortar are summarized in Tables 3 and 4, respectively.

Table 3 Mixture proportioning ratios for shrinkage and carbonation tests

Fly Ash Replacement (%)	W/(C+F)	F/(F+C)	(F+C)/S	Type of Fly Ash
0	0.50	0.00	0.36	-
30	0.50	0.30	0.36	FL
60	0.50	0.60	0.36	FL

Table 4 Mixture proportioning for compressive strength test

Mortar	W/(C+F)	F/(F+C)	(F+C)/S	Type of Fly Ash	Curing Condition
CT(W)	0.50	0.00	0.36	-	W
CT(W-D)	0.50	0.00	0.36	-	W-D
FH-30(W)	0.50	0.30	0.36	FH	W
FH-30(W-D)	0.50	0.30	0.36	FH	W-D
FH-60(W)	0.50	0.60	0.36	FH	W
FH-60(W-D)	0.50	0.60	0.36	FH	W-D
FM-30(W)	0.50	0.30	0.36	FM	W
FM-30(W-D)	0.50	0.30	0.36	FM	W-D
FM-60(W)	0.50	0.60	0.36	FM	W
FM-60(W-D)	0.50	0.60	0.36	FM	W-D
FL-30(W)	0.50	0.30	0.36	FL	W
FL-30(W-D)	0.50	0.30	0.36	FL	W-D
FL-60(W)	0.50	0.60	0.36	FL	W
FL-60(W-D)	0.50	0.60	0.36	FL	W-D

Casting and Curing Environments

For compressive strength test, cubes of dimensions 50x50x50-mm were cast. Two curing conditions were used i.e. water curing (W) and cyclic wetting and drying condition (W-D). One cycle consists of 1-week wetting and 1-week drying periods. For wetting, the specimens were submerged in water. For drying, the specimens were put into a curing chamber.

For drying shrinkage test, prisms of dimensions 25x25x285-mm were cast. After demolding at 24±2 hours, water curing was applied for 30 days. Then, the specimens were put into a curing chamber.

It should be noted that the controlled temperature and relative humidity of chamber were 25±2 ^{o}C and 60±5 %, respectively.

For autogenous shrinkage test, prisms of dimensions 25x25x285-mm were cast. After demolding at 24±2 hours, the specimens were wrapped in a plastic sheet and put into a curing chamber having a controlled temperature of 25±2 ^{o}C and a relative humidity of 60±5%.

For carbonation test, cubes of dimensions 50x50x50-mm were cast. After demolding at 24±2 hours, water curing was applied for 30 days. Then, the specimens were placed in an office room having a CO_2 atmosphere, a controlled temperature of 25±2 ^{o}C and a relative humidity of 60±5%.

Testing of specimens

The compressive strength of specimens was tested in accordant with ASTM C409-89. The 200-ton Universal Testing Machine (UTM) was used. The speed of 1mm/sec speed was applied to all specimens. Compressive strength of specimens was calculated from a failure load divided by a surface area of specimens.

Two shrinkages of specimens, autogenous and drying shrinkage, were measured by a mechanical strain gauge. The initial lengths of specimens were immediately measured after the demolding of the specimens. For autogenous shrinkage test, the length changes of specimens were observed while keeping the specimens in a curing chamber. For drying shrinkage test, the length change of specimens was observed while the specimens were firstly submerged in water for 30 days and kept later in a curing chamber.

For carbonation test, the depth of carbonation was determined by using the pH indicator, phenopthalene diluted in a 1% solution of ethanol sprayed on a recently broken piece of mortar. For carbonated areas, in the area where CO_2 from the atmosphere reacts with $Ca(OH)_2$ in mortar, the color of mortar was not changed. For the non-carbonated area, which was the deeper area that CO_2 from atmosphere can not penetrate to react with $Ca(OH)_2$ in mortar, the color of the mortar was changed to a violet color.

Results and Discussion

Strength of mortar

It is observed from Fig. 2 and 3 that as comparing to the ordinary Portland cement mortar, the strengths of mortar having 30 and 60 percent replacements of fly ash at the early age. But in long term, mortar having 30 percent replacement of fly ash to ordinary Portland cement increased in strength due to the pozzolanic reaction which fully developed in long-term. Furthermore, the strength is observed be varied by the different amount of SO_3 in material composition. It has a tendency that the 90-day strengths of high SO_3 fly ash were higher than those of the low and medium SO_3 fly ash. The evident might be attributed to the different in amount of CaO which had the same trend as the amount of SO_3 in those fly ashes. The finer particles and higher amount of CaO in powder composition tended to increase the strength of mortar, significantly found in long term compressive strength of mortar containing high calcium fly ash (FH).

Table 5 Compressive strength and normalized compressive strength at 28 and 90 days

Specimens	Compressive Strength at 28 days (Mpa)	Normalized Compressive Strength at 28 days (%)	Compressive Strength at 90 days (Mpa)	Normalized Compressive Strength at 90 days (%)
CT(W)	44.4	100.00	61.5	100.00
CT(W-D)	45.7	100.00	63.3	100.00
FH-30(W)	32.7	73.59	58.6	94.39
FH-30(W-D)	36.7	80.18	60.5	98.45
FH-60(W)	25.8	58.09	51.5	83.84
FH-60(W-D)	20.4	58.10	45.5	74.02
FM-30(W)	36.5	82.09	54.2	88.18
FM-30(W-D)	42.2	92.39	52.2	84.99
FM-60(W)	23.3	52.47	38.2	62.15
FM-60(W-D)	26.4	57.67	40.2	65.47
FL-30(W)	39.6	89.13	57.4	93.43
FL-30(W-D)	39.9	87.17	57.6	93.75
FL-60(W)	21.2	48.43	36.7	59.64
FL-60(W-D)	21.6	47.34	37.0	60.22

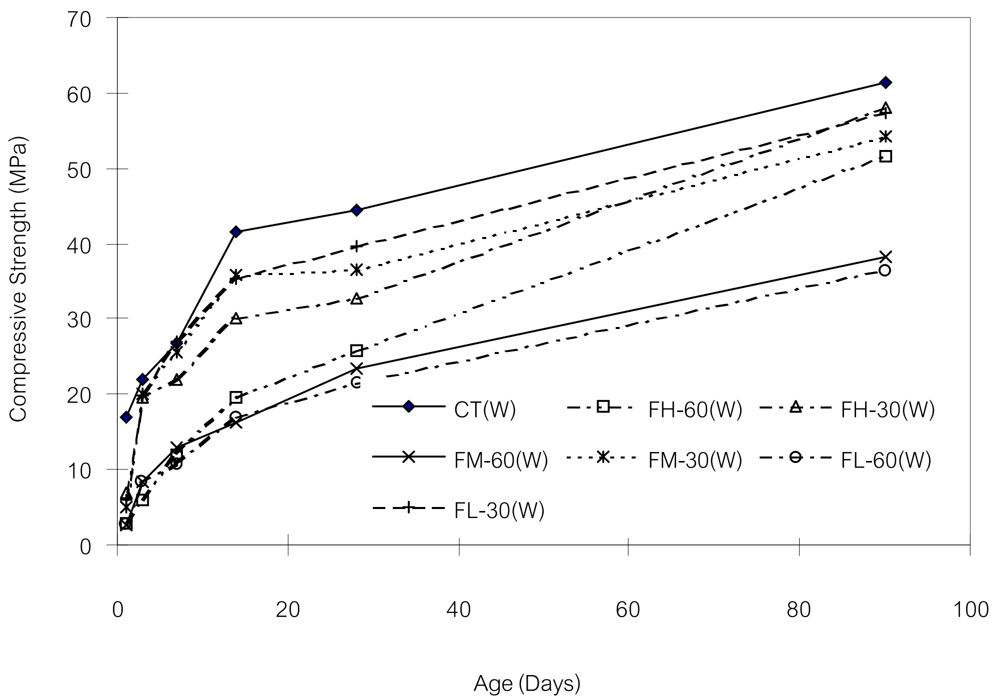

Fig. 2 Compressive strength of mortar having various amounts of SO_3 and percent replacements of fly ash to cement under water curing condition

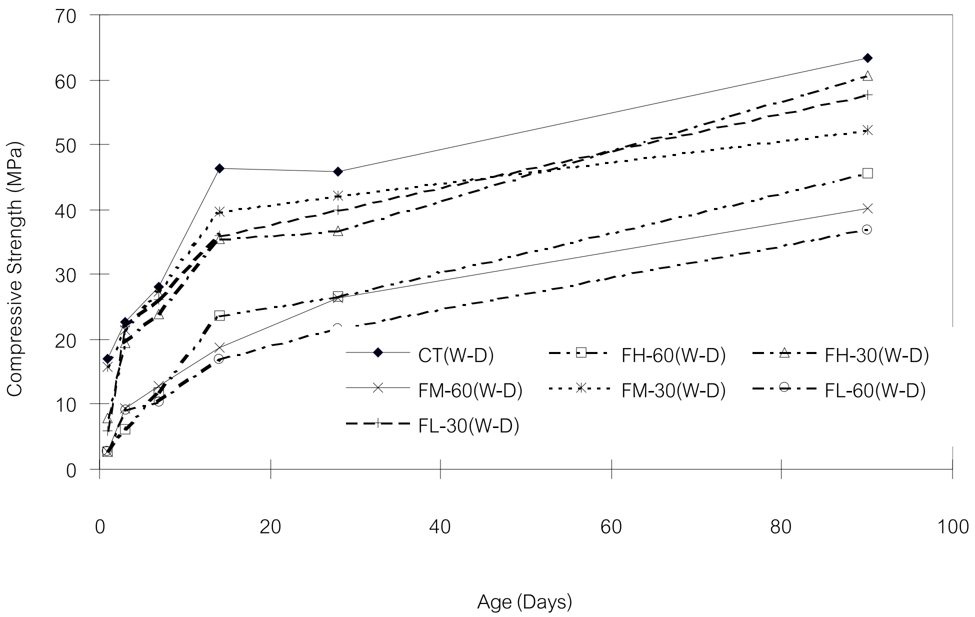

Fig. 3 Compressive strength of mortar having various amounts of SO_3 and percent replacements of fly ash to cement under cyclic wetting and drying curing condition

Fig. 4 to 7 illustrate that the relationship between the compressive strengths under two curing conditions of mortar containing percentages of fly ash equal to 30 and 60 are not significantly obvious which agrees with result of [2].

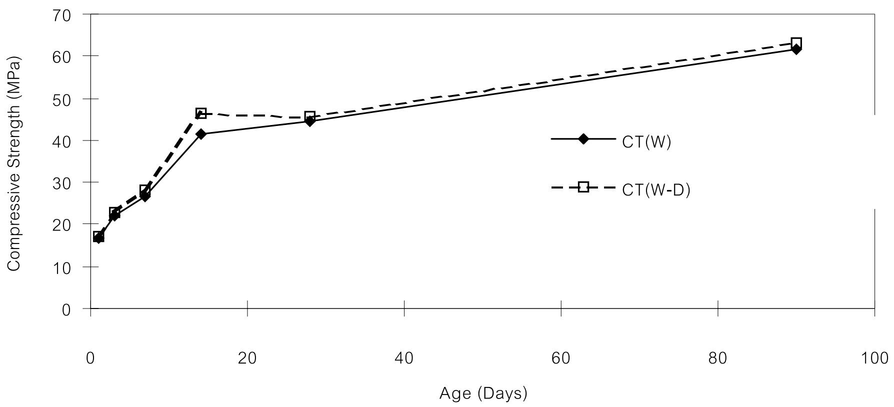

Fig. 4 Compressive strength of control under different curing conditions

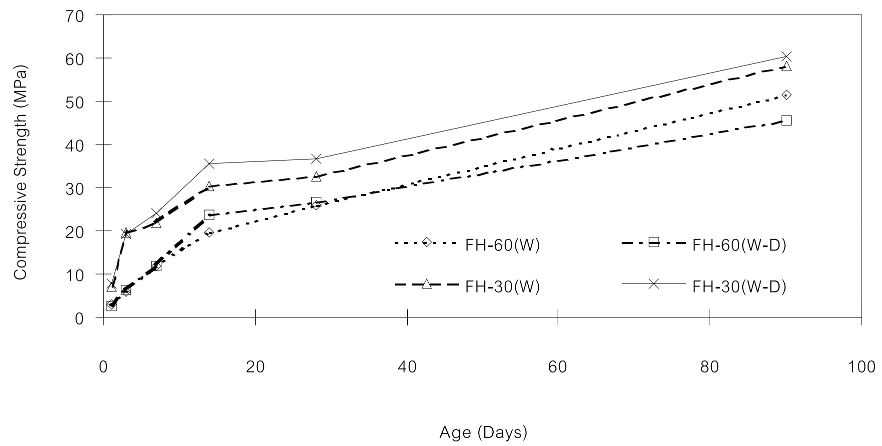

Fig. 5 Compressive strength of mortar containing high SO_3 fly ash under different curing conditions

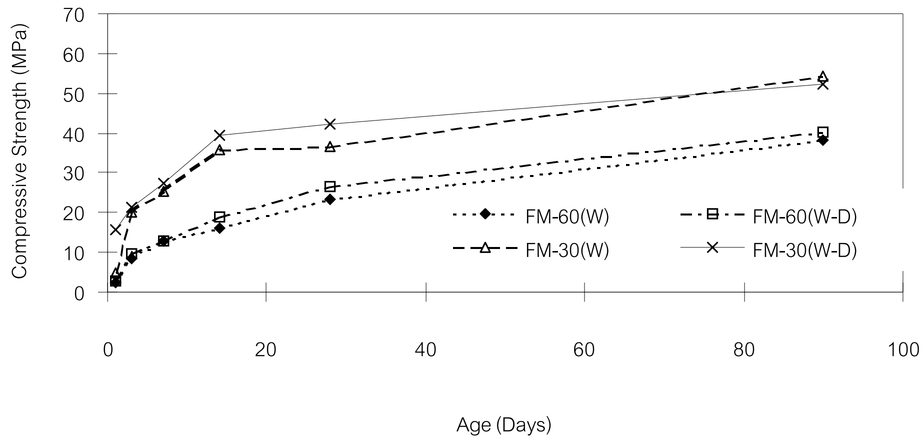

Fig. 6 Compressive strength of mortar containing medium SO_3 fly ash under different curing conditions

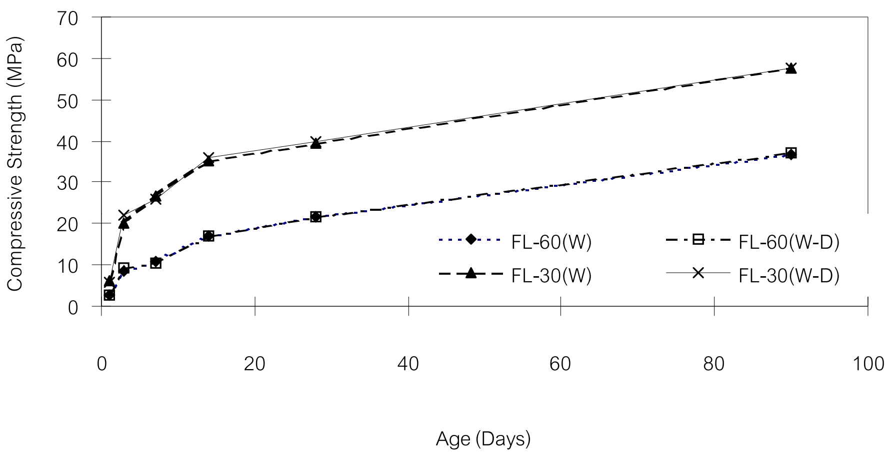

Fig. 7 Compressive strength of mortar containing low SO_3 fly ash under different curing conditions

Drying shrinkage of mortar

Fig. 8 shows that the mortars containing fly ash exhibit smaller drying shrinkage than that of the control especially when the percentage of fly ash replacement is larger because the water requirement for maintaining equal consistency of mortar with fly ash is smaller. So, it can be noted that the water to cementitious materials ratio of the mixtures containing higher amount of fly ash can be reduced in practice and the drying shrinkage is simultaneously reduced [2].

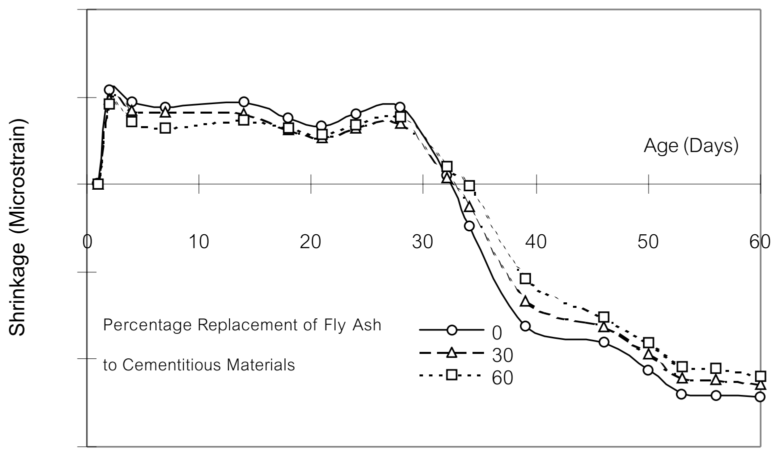

Fig. 8 Drying shrinkage of mortar containing fly ash

Autogenous shrinkage of mortar

Fig. 9 shows the comparison of length change of mortar specimens containing fly ash replacement ratio of 30 and 60 percent to that of the control. It is shown that all specimens with higher replacement ratio of fly ash exhibit smaller autogenous shrinkage than that of the control, since the autogenous shrinkage is a result of water consumption in hydration process. It can be seen that the use of higher content of fly ash provides higher reduction of autogenous shrinkage. It might be attributed to the spherical shape of fly ash which results in less amount of retained water than that of the cement particles [2]. Larger free water content is available in the mixture with fly ash when being compared with the mixture without fly ash.

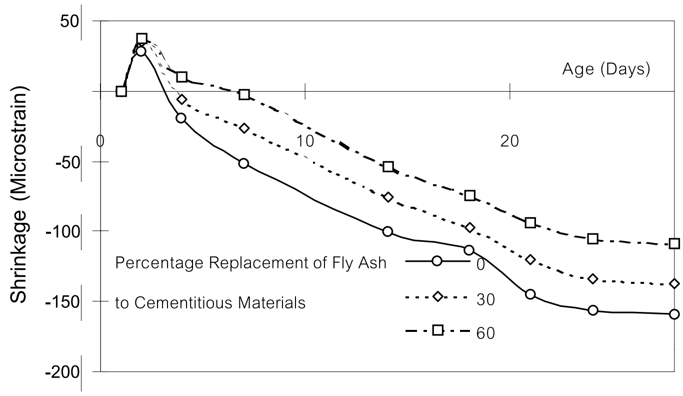

Fig. 9 Autogenous shrinkage of mortar containing fly ash

Carbonation of mortar

Fig. 10 illustrates that carbonation of mortar containing fly ash is larger than that of the control and it becomes higher when increasing the amount of fly ash. It is the reason that the increasing of fly ash in mixture proportion led to the higher $Ca(OH)_2$ content remained from hydration. Furthermore, $Ca(OH)_2$ that reacts with CO_2 in atmosphere to form the carbonated compound, so that, the carbonation area or carbonation depth is increased [1]. The carbonation reaction equation was shown below.

$$2Ca(OH)_2 + 2CO_2 + 2H_2O \longrightarrow 2CaCO_3 + 4H_2O$$

Moreover, the carbonated area may possible increase by the reduction of gel and/or liquid phase in pore caused by the pozzolanic reaction. This effect may increase the rate of carbon dioxide and air diffusion through mass of cementitious paste.

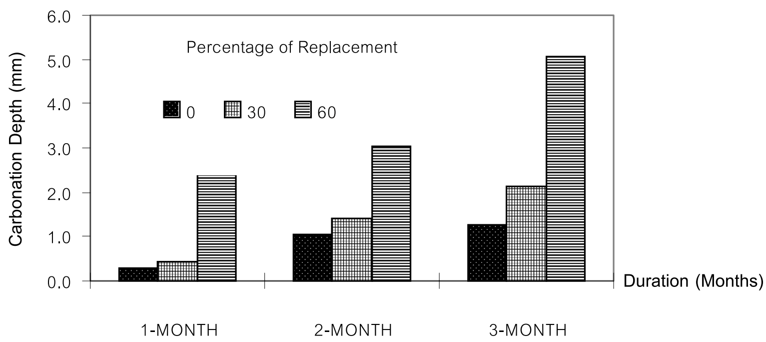

Fig. 10 Carbonation depth of mortar

Relationship between the compressive strength and $CaO_{Equivalent}$

The parameters affecting the strength of mortar are type of fly ash and percent replacement of fly ash to cement. When the affecting parameters are changed, strength of mortar will be changed. Generally, the crucial portion of chemical composition affecting to the strength of the mixture is CaO and SiO_2 in cementitious materials contents, as known in the hydration reaction. Refer to Table 1, the controlled compound affecting the strength of mix is CaO. The CaO affecting the strength of the mixture is called as $CaO_{Equivalent}$ comprising CaO from cement powder and from fly ash.

In this study, the strength of mortar having the water to cementitious materials ratio equal to 0.5 was expressed by a linear regression analysis from strength data, percent replacement of fly ash to cementitious materials and $CaO_{Equivalent}$.

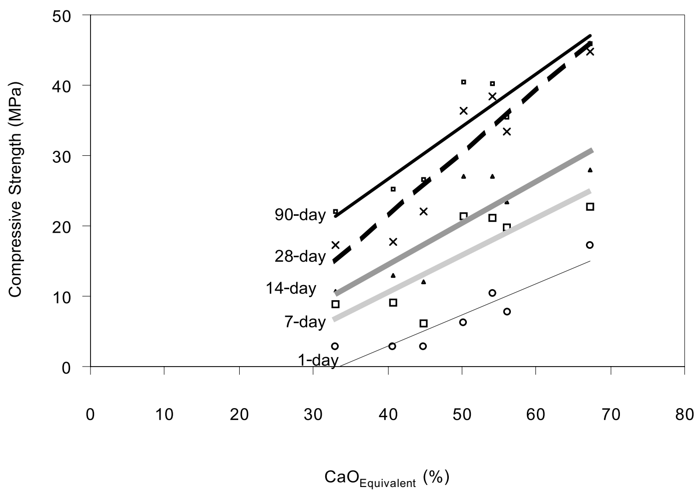

Fig.11 Relationship between compressive strength of mortar and $CaO_{Equivalent}$

From Fig. 11, the strengths of mortar can be represented by the following equations.

$$ST_1 = 0.4399(CaO_{Equivalent})-14.658$$

$$ST_7 = 0.5261(CaO_{Equivalent})-10.442$$

$$ST_{14} = 0.5982(CaO_{Equivalent})-9.4456$$

$$ST_{28} = 0.9094(CaO_{Equivalent})-14.989$$

$$ST_{90} = 0.7466(CaO_{Equivalent})-3.241$$

Where as $CaO_{Equivalent} = (1-r)(CaO_c)+(r)(CaO_f)$

CaO_c is percent by weight of CaO in cement powder

CaO_f is percent by weight of CaO in fly ash

r is the weighed ratio of fly ash by cementitious materials [F / (F+C)]

Conclusions

1. By replacing the fly ash to cement at 30 percent by weight, early age strength of mortar is lower whereas 90-day strength is nearly the same as the control. However, at fly ash replacement ratio equal to 60 percent, the strength is remarkably reduced.
2. At the same percentage of fly ash replacement, the compressive strength of mortar tends to vary with the content of CaO in fly ash, the higher content of CaO in fly ash, the higher the strength of mortar.
3. Under wet and cyclic wetting-drying curing conditions of mortar containing fly ash at 30 or 60 percent by weight, the strength is slightly different.
4. The autogenous and drying shrinkage can be reduced by increasing the fly ash replacement in the mortar mixture.
5. The carbonation of mortar containing fly ash is larger than that of the control and it becomes higher when the amount of fly ash in the mortar mixture is increased.

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