

LIST OF FIGURES

FIGURE	PAGE
3.1 Digital strain gauge	12
4.1 A comparison of autogenous shrinkage of type 1 and type 5 cement paste with water to cement ratio 0.30 at 25°C, 80% R.H.	17
4.2 A comparison of autogenous shrinkage of type 1 cement paste with fineness of cement of 3190, 5570, and 7430 cm ² /g and type 3 cement paste with fineness of cement of 4770 cm ² /g at water to cement ratio 0.30 at 25°C, 80% R.H.	18
4.3 A comparison of autogenous shrinkage of type 1 cement paste with water to cement ratio of 0.25, 0.30, and 0.40 at 25°C, 80% R.H.	19
4.4 A comparison of autogenous shrinkage of type 1 cement paste having 30% replacement of FM1 with water to binder ratio of 0.25, 0.30, and 0.40 at 25°C, 60% R.H.	19
4.5 A comparison of autogenous shrinkage of type 1 cement paste having 50% replacement of FM1 with water to binder ratio of 0.25, 0.30, and 0.40 at 25°C, 60% R.H.	19
4.6 A comparison of autogenous shrinkage of type 1 cement paste having 30% replacement of FM2 with water to binder ratio of 0.25, 0.30, and 0.40 at 25°C, 80% R.H.	20
4.7 A comparison of autogenous shrinkage of type 1 cement paste having 50% replacement of FM2 with water to binder ratio of 0.25, 0.30, and 0.40 at 25°C, 80% R.H.	20
4.8 A comparison of autogenous shrinkage of type 1 cement paste having 30% replacement of FT with water to binder ratio of 0.25, 0.30, and 0.40 at 25°C, 60% R.H.	20
4.9 A comparison of autogenous shrinkage of type 1 cement paste having 50% replacement of FT with water to binder ratio of 0.25, 0.30, and 0.40 at 25°C, 60% R.H.	21
4.10 A comparison of autogenous shrinkage of type 1 cement paste having 30% replacement of FM1, FM2, and FT with water to binder ratio of 0.30.	21
4.11 A comparison of autogenous shrinkage of type 1 cement paste having 50% replacement of FM1, FM2, and FT with water to binder ratio of 0.30	22
4.12 A comparison of autogenous shrinkage of type 1 cement paste cured at temperature of 25°C and 40°C with water to cement ratio of 0.30 and 0.40	23
4.13 A comparison of autogenous shrinkage of mortars at different volume concentration ratio of fine aggregate ($n_s/n_{s,max}$) with water to cement ratio of 0.30	24
4.14 A comparison of autogenous shrinkage of no-fine concrete at different volume concentration ratio of coarse aggregate ($n_g/n_{g,max}$) with water to cement ratio of 0.30	25

FIGURE	PAGE
4.15 A comparison of autogenous shrinkage of concrete at different sand to total aggregates ratio with volume concentration ratio of binary mixture ($n_a/n_{a,max}$) of 0.70 and water to cement ratio of 0.30	25
4.16 A comparison of autogenous shrinkage of concrete at different sand to total aggregates ratio with volume concentration ratio of binary mixture ($n_a/n_{a,max}$) of 0.50 and water to cement ratio of 0.30	25
4.17 A comparison of autogenous shrinkage of no-fine concrete at different maximum size (G_{max}) of coarse aggregate with water to cement ratio of 0.30	26
5.1 Illustration of concrete as a two-phase	27
5.2 Internal stress between paste and aggregate phases due to shrinkage	29
5.3 Concept of 2-phase material with perfect paste-aggregate interaction	30
6.1 Density function of contact angle	33
6.2 The 2-dimension displacement compatibility of a contact at contact angle θ showing initial as well as deformed configurations of a contact	33
6.3 The relationship between the coefficient of friction and the ratio of volume of water to surface area of crushed limestone coarse aggregate	35
6.4 The relationship between the coefficient of friction and the ratio of volume of water to surface area river sand	35
6.5 The comparison of coefficient friction between crushed limestone coarse aggregate and river sand	35
6.6 Relationship between the coefficient to govern the effect of water content on the contact area reduction of aggregates (α), volume concentration ratio of aggregates($n_a/n_{a,max}$), and water to cement ratio (w/c)	40
6.7 Relationship between the coefficient to govern the effect of maximum size of coarse aggregate on the initial contact area reduction (δ) and maximum size of coarse aggregate (G_{max})	41
6.8 Relationship between the coefficient to govern the effect of particle interference of fine aggregate on the contact area reduction of coarse aggregate, volume concentration ratio of fine aggregate ($n_s/n_{s,max}$), and volume concentration ratio of coarse aggregate ($n_g/n_{g,max}$)	44
7.1 Relationship between compressive strength of cement type 1 with fineness 3190 cm^2/g and age of testing at different water to cement ratio	46
7.2 Relationship between compressive strength of type 3 cement with fineness 4770 cm^2/g and age of testing at water to cement ratio of 0.30	46
7.3 Relationship between compressive strength of type 5 cement with fineness 3760 cm^2/g and age of testing at water to cement ratio of 0.30	47
8.1 Degree of hydration of type 1 cement with fineness 3190 cm^2/g , w/c=0.25 at 25°C	51
8.2 Degree of hydration of type 1 cement with fineness 3190 cm^2/g , w/c=0.30 at 25°C	51

FIGURE	PAGE
8.3 Degree of hydration of type 1 cement with fineness 3190 cm ² /g, w/c=0.40 at 25°C	51
8.4 Degree of hydration of type 3 cement with fineness 4770 cm ² /g, w/c=0.30 at 25°C	52
8.5 Degree of hydration of type 5 cement with fineness 3760 cm ² /g, w/c=0.30 at 25°C	52
8.6 Degree of hydration of type 1 cement with fineness 5570 cm ² /g, w/c=0.30 at 25°C	52
8.7 Degree of hydration of type 1 cement with fineness 7430 cm ² /g, w/c=0.30 at 25°C	53
8.8 Degree of hydration of type 1 cement with fineness 3190 cm ² /g, w/c=0.30 at 40°C	53
8.9 Degree of hydration of type 1 cement with fineness 3190 cm ² /g, w/c=0.40 at 40°C	53
8.10 Average degree of hydration of type 1 cement with fineness = 3190 cm ² /g., w/c = 0.25, 0.30, and 0.40 at 25°C	54
8.11 Average degree of hydration of type 1, type 3, and type 5 cement with w/c = 0.30 at 25°C	55
8.12 Average degree of hydration of type 1 cement with fineness 3190, 5570, 7430 cm ² /g, w/c = 0.30 at 25°C	55
8.13 Average degree of hydration of type 1 cement with fineness = 3190 cm ² /g., w/c = 0.30 and 0.40 at 40°C	55
8.14 Degree of pozzolanic reaction of fly ash FM1 with r = 0.30, w/b = 0.25, 0.30 and 0.40 at 25°C	57
8.15 Degree of pozzolanic reaction of fly ash FM1 with r = 0.50, w/b = 0.25, 0.30 and 0.40 at 25°C	57
8.16 Degree of pozzolanic reaction of fly ash FM2 with r = 0.30, w/b = 0.25, 0.30 and 0.40 at 25°C	58
8.17 Degree of pozzolanic reaction of fly ash FM2 with r = 0.50, w/b = 0.25, 0.30 and 0.40 at 25°C	58
8.18 Degree of pozzolanic reaction of fly ash FT with r = 0.30, w/b = 0.25, 0.30 and 0.40 at 25°C	58
8.19 Degree of pozzolanic reaction of fly ash FT with r = 0.50, w/b = 0.25, 0.30 and 0.40 at 25°C	59
8.20 The example of pore size distribution of paste	61
8.21 Average pore radius of paste of type 1 cement with fineness = 3190 cm ² /g., w/c = 0.25, 0.30, and 0.40 at 25°C	62
8.22 Average pore radius of paste of type 1, type 3, and type 5 cement with w/c = 0.30 at 25°C	62
8.23 Average pore radius of paste of type 1 cement with fineness 3190, 5570, 7430 cm ² /g, w/c = 0.30 at 25°C	62
8.24 Average pore radius of paste with fly ash FM1 with r = 0.30, w/b = 0.25, 0.30 and 0.40 at 25°C	63
8.25 Average pore radius of paste with fly ash FM1 with r = 0.50, w/b = 0.25, 0.30 and 0.40 at 25°C	63
8.26 Average pore radius of paste with fly ash FM2 with r = 0.30, w/b = 0.25, 0.30 and 0.40 at 25°C	63

FIGURE	PAGE
8.27 Average pore radius of paste with fly ash FM2 with $r = 0.50$, $w/b = 0.25, 0.30$ and 0.40 at 25°C	64
8.28 Average pore radius of paste with fly ash FT with $r = 0.30$, $w/b = 0.25, 0.30$ and 0.40 at 25°C	64
8.29 Average pore radius of paste with fly ash FT with $r = 0.50$, $w/b = 0.25, 0.30$ and 0.40 at 25°C	64
8.30 The effect of curing temperature on average pore radius	66
8.31 Chemical expansion of cement-fly ash paste with different replacement percentage of fly ash (r)	67
8.32 Chemical expansion of cement-fly ash paste with different SO_3 percentage	67
8.33 Chemical expansion of cement-fly ash paste with different water to binder ratio (w/b)	68
9.1 Test results of autogenous shrinkage of paste with water to cement ratio of 0.30 and 0.40	70
9.2 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of no-fine concrete with volume concentration ratio ($n_g/n_{g,\text{max}}$) of 1.0 and water to cement ratio of 0.30 ($G_{\text{max}}=20\text{mm.}$)	70
9.3 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of no-fine concrete with volume concentration ratio ($n_g/n_{g,\text{max}}$) of 0.80 and water to cement ratio of 0.30 ($G_{\text{max}}=20\text{mm.}$)	70
9.4 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of no-fine concrete with volume concentration ratio ($n_g/n_{g,\text{max}}$) of 0.60 and water to cement ratio of 0.30 ($G_{\text{max}}=20\text{mm.}$)	71
9.5 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of no-fine concrete with volume concentration ratio ($n_g/n_{g,\text{max}}$) of 0.40 and water to cement ratio of 0.30 ($G_{\text{max}}=20\text{mm.}$)	71
9.6 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of no-fine concrete with volume concentration ratio ($n_g/n_{g,\text{max}}$) of 0.40 and water to cement ratio of 0.30 ($G_{\text{max}}=8\text{mm.}$)	71
9.7 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,\text{max}}$) of 0.85 and water to cement ratio of 0.30	72
9.8 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,\text{max}}$) of 0.70 and water to cement ratio of 0.30	72
9.9 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,\text{max}}$) of 0.60 and water to cement ratio of 0.30	73
9.10 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,\text{max}}$) of 0.50 and water to cement ratio of 0.30	73

FIGURE	PAGE
9.11 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,max}$) of 0.40 and water to cement ratio of 0.30	73
9.12 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,max}$) of 0.80 and water to cement ratio of 0.40	74
9.13 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,max}$) of 0.65 and water to cement ratio of 0.40	74
9.14 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,max}$) of 0.50 and water to cement ratio of 0.40	74
9.15 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.70, sand to total aggregates ratio (s/a) of 0.25, and water to cement ratio of 0.30	75
9.16 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.70, sand to total aggregates ratio (s/a) of 0.50, and water to cement ratio of 0.30	75
9.17 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.70, sand to total aggregates ratio (s/a) of 0.75, and water to cement ratio of 0.30	76
9.18 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.50, sand to total aggregates ratio (s/a) of 0.25, and water to cement ratio of 0.30	76
9.19 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.50, sand to total aggregates ratio (s/a) of 0.50, and water to cement ratio of 0.30	76
9.20 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.50, sand to total aggregates ratio (s/a) of 0.75, and water to cement ratio of 0.30	77
9.21 Comparisons between test results of autogenous shrinkage and the model of paste with type 1, type 3, and type 5 cement in case of w/c = 0.30, at 25°C, 80% R.H.	77
9.22 Comparisons between test results of autogenous shrinkage and the model of paste with type 1 cement with fineness of 3190, 5570, and 7430 cm ² /g in case of w/c = 0.30, at 25°C, 80% R.H.	78
9.23 Comparisons between test results of autogenous shrinkage and the model of paste with type 1 cement in case of w/c = 0.25, 0.30, and 0.40 at 25°C, 80% R.H.	78
9.24 Comparisons between test results of autogenous shrinkage and the model of paste with type 1 cement with curing temperature of 25°C and 40°C in case of w/c = 0.30 and 0.40 at 80% R.H.	78

FIGURE	PAGE
9.25 Comparisons between test results and the model of autogenous shrinkage of paste with type 1 cement and replaced by 30% FM1 in case of w/b = 0.25, 0.30, and 0.40 at 25°C, 60% R.H.	79
9.26 Comparisons between test results and the model of autogenous shrinkage of paste with type 1 cement and replaced by 50% FM1 in case of w/b = 0.25, 0.30, and 0.40 at 25°C, 60% R.H.	79
9.27 Comparisons between test results and the model of autogenous shrinkage of paste with type 1 cement and replaced by 30% FM2 in case of w/b = 0.25, 0.30, and 0.40 at 25°C, 80% R.H.	79
9.28 Comparisons between test results and the model of autogenous shrinkage of paste with type 1 cement and replaced by 50% FM2 in case of w/b = 0.25, 0.30, and 0.40 at 25°C, 80% R.H.	80
9.29 Comparisons between test results and the model of autogenous shrinkage of paste with type 1 cement and replaced by 30% FT in case of w/b = 0.25, 0.30, and 0.40 at 25°C, 60% R.H.	80
9.30 Comparisons between test results and the model of autogenous shrinkage of paste with type 1 cement and replaced by 50% FT in case of w/b = 0.25, 0.30, and 0.40 at 25°C, 60% R.H.	80
9.31 Comparisons between test results and the model of autogenous shrinkage of no-fine concrete with volume concentration ratio ($n_g/n_{g,max}$) of 1.0, 0.80, 0.60, and 0.40, and water to cement ratio of 0.30 ($G_{max}=20$ mm.)	81
9.32 Comparisons between test results and the model of autogenous shrinkage of no-fine concrete with volume concentration ratio ($n_g/n_{g,max}$) of 0.40, and water to cement ratio of 0.30 ($G_{max}=8$ mm.)	82
9.33 Comparisons between test results and the model of autogenous shrinkage of mortars with volume concentration ratio ($n_s/n_{s,max}$) of 0.85, 0.70, 0.60, 0.50, and 0.40, and water to cement ratio of 0.30	82
9.34 Comparisons between test results and the model of autogenous shrinkage of mortars with volume concentration ratio ($n_s/n_{s,max}$) of 0.80, 0.65, and 0.50, and water to cement ratio of 0.40	83
9.35 Comparisons between test results and the model of autogenous shrinkage of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.70, sand to total aggregates ratio (s/a) of 0.25, 0.50, and 0.70, and water to cement ratio of 0.30	83
9.36 Comparisons between test results and the model of autogenous shrinkage of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.50, sand to total aggregates ratio (s/a) of 0.25, 0.50, and 0.70, and water to cement ratio of 0.30	84
9.37 Comparisons between test results and the model of drying shrinkage tested by Deesawangnade (1994) (specimen size 40×40×160 mm, 27 days water curing)	84
9.38 Comparisons between test results and the model of drying shrinkage tested by Deesawangnade (1994) (specimen size 100×100×500 mm, 28 days water curing)	85

FIGURE	PAGE
9.39 Comparisons between test results and the model of drying shrinkage tested by Deesawangnade (1994) (specimen size 100×100×500 mm, 28 days water curing)	85
9.40 Comparisons between test results and the model of drying shrinkage tested by Srichoo (1997) (specimen size 100×100×500 mm, 27 days water curing)	85
9.41 Comparisons between test results and the model of drying shrinkage tested by Sayamipuk (1994) (specimen size 100×100×500 mm, 28 days water curing)	86
9.42 Comparisons between test results and the model of drying shrinkage tested by Tassanakosol (1999) (specimen size 25×25×285 mm, 28 days water curing)	86
9.43 Comparisons between test results and the model of drying shrinkage tested by Suzuki (1993) (specimen size 100×100×500 mm, 7 days water curing)	86
D.1 Pore size distribution of cement type 1 paste with water to cement ratio of 0.40 at 7 days	D-3
D.2 Pore size distribution of cement type 1 paste with water to cement ratio of 0.40 at 28 days	D-5
D.3 Pore size distribution of cement type 1 paste with water to cement ratio of 0.30 at 7 days	D-7
D.4 Pore size distribution of cement type 1 paste with water to cement ratio of 0.30 at 28 days	D-9