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EFFECTS OF CEMENT ON THE STRENGTH AND ELASTICITY OF CONCRETESUBJECTED TO SUSTAINED ELEVATED TEMPERATURES UP TO 300℃

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ABSTRACT

Shielding concrete in nuclear power plants are subjected to sustained elevated temperature in normal operation. And low-heat type cements such as moderate-heat portland cement or portland fly-ash cement are usually used in order to reduce excessive temperature rise due to heat of hydration. However, technical papers dealing with the effects of sustained elevated temperature exposure on the strength of concrete containing low-heat type cement other than Portland fly-ash cement are limited.

This paper presents the results of 2 series of experimental studies carried out to determine the effects of low-heat type cement on the strength of concrete subjected to sustained elevated temperatures up to 300 C. In the series 1 experiment, specimens made of 4 mixtures of concrete with the water cement ratio of 50 %, containing ordinary and low-heat portland cement, portland fly-ash cement and portland blast-furnace slag cement were subjected to sustained elevated temperatures of 20, 50, 80, 110 and 300 C without seal for 91 days. Specimens before exposure were moist cured in water until 28 day old and sealed cured until 56 days old and then stored in air until 91-day old without seal. After exposure, specimens were tested for weight loss, compressive and tensile strengths and young's modulus.

In the series 2 experiment, 3 types of cements, ordinary portland cement, moderate-heat portland cement and portland fly-ash cement were used. The temperature, term and method of exposure were the same as in the series 1 experiment. While, curing of specimens were made in 2 ways, and sealed curing without moist curing was added, Tests of specimens after exposure were the same as in the series 1 experiments.

Elevated temperature exposure in the range of 50 to 300 C showed remarkable deteriorating effects on the strength of concrete. Reduction to in compressive strength after exposure showed the minimal points at 50 C and the maximal points at 80 C. The minimal compressive strength after exposure to 50 C was associated with the intermediate weight loss of 2.5 to 3.5 % due to evaporation of free water. Similar tendency was also observed on tensile strength. However, youngҀs modulus declined monotonously as the weight loss increased.

Weight loss and residual strength were affected with the type of cement. Ordinary and moderate-heat portland cements showed the same tendency in weight loss and residual strength. Low-heat portland cement showed the least weight loss, and largest reduction in compressive strength. Portland blastҍfurnace slag cement showed the greatest weight loss and greatest reduction in tensile strength and youngҀs modulus and was most affected with method of curing.

1. INTRODUCTION

Massive shielding concrete are subjected to sustained elevated temperature up to 65C or 90C in normal operation and temporarily to higher temperature up to 175C or 350C at accident. Usually low-heat type cements are used for concrete in nuclear power plants to reduce excessive temperature rise in massive concrete due to heat of hydration. However, technical papers dealing with the effects of sustained elevated temperature exposure on the strength characteristics of concrete containing low-heat type cement other than Portland fly-ash cement are still limited, as shown in the literature review by Naus (2005). A few papers by Carret et,al.(1968), described the effects of elevated temperature on the strength of concrete with Low-heat type cement.

Kasami et.al., (2012) presented the experimental results on the degradation of concrete containing ordinary portland cement, moderate-heat portland cement, Type B of portland fly-ash cement and Type B of portland blast-furnace-slag cement on the weight loss, residual compressive strength and youngồs modulus after exposure to sustained elevated temperatures in the range of 20 to 300 C with and without seal, as well as the changes in pore size distribution and in the powder XRD pattern, and concluded that concrete with moderate-heat Portland cement was less affected with drying by elevated temperatures, and concrete with type B of portland blast-furnace slag cement was most degraded by the drying effects due to elevated temperatures. Kasami et.al., (2013). Reviewed the authorsô previous papers on the effects of cement type on the degradation of concrete strength at 50 C, and concluded that the formation of minimal strength at 50 C associated with intermediate weight loss are caused by the increase of pore size and pore volume affected with the type of cement.

However, those data obtained by Kasami et. al, (2012,2013) did not discussed degradation in strength other than compressive strength. This paper presents the results of 2 series of experiments on the effects of low heat type cements on the compressive and tensile strengths affected with curing method.

In the series 1 experiment, cylindrical specimens made of 4 mixtures of concrete containing ordinary (OP), low-heat (LP), type B of portland blast furnace cement (BB) and type B of portland fly-ash cement (FB) were subjected to sustained elevated temperatures of 20 50, 80, 110 and 300 C without seal for 91 days in constant temperature chambers. Specimens before temperature exposure were moist cured in water until 28 days old and then stored in air until 91 days old. After exposure, specimens were cooled down to room temperature. And were tested for weight loss, compressive strength and young's modulus.

In the series 2 experiment, cylindrical specimens made of 3 mixtures of concrete containing ordinary (OP), moderate-heat (MP), and Type B of portland fly-ash cement (FB) were cured in 2 ways, moist cured the same as in the series 1 and sealed curing until 91 days old.. The temperatures, term and method of elevated temperature exposure, and strength tests after exposure were the same as in the series 1 experiment.

2. OUTLINE OF EXPERIMENTAL PROGRAM

Table 1 shows the outline of 2 series of experimental studies.

In the series 1 experiment, carried out to make clear of the effects of low-heat type cements on the residual strength of concrete subjected to sustained elevated temperatures up to 300C, specimens made of 4 mixtures of concrete containing ordinary Portland cement (OP), low-heat portland cement (LP), Portland fly-ash cement Type B (FB) and Portland blast-furnace slag cement Type B (BB) were subjected to sustained elevated temperatures up to 300 C without seal, after moist curing until 28 days old and curing in air in air until 91 days old. Exposure temperatures were 20, 50, 80, 110 and 300 C and the exposure term was 91 days. After exposure, specimens were tested for weight loss, compressive and tensile strengths and youngồs modulus.

In the series 2 experiment, carried out to determine the effects of low-heat type cement usually used in nuclear power plants in Japan, ordinary Portland cement (OP), moderate-heat portland cement (MP), and Type B of Portland fly-ash cement were used. The temperature, term and method of exposure, and tests after exposure were the same as in the series 1 experiment.

Table 1: Outline and factors for experimental plan.

Factors	Series 1 experiment	Series 2 experiment
Cement	OP,LP,FB,BB	OP,MP,FB
Curing before exposure	moist curing	moist curing
	------	sealed curing until 91 days
Elevated temperature exposure	91day exposure at 20℃, 50℃, 80℃, 110℃, 300℃ without seal	

[note] moist curing ; moist curing until 28days & sealed curing until 56days & un-sealed curing in moist air until 91days

3. EXPERIMENTAL PROCEDURES

3.1 Materials of concrete

Table 2 shows the types of cement, physical properties and compound composition of the cements used in the series 1 and 2 experiments. OP, MP and LP conforming to JIS R 5210 (Portland Cement), FB conforming to JIS R 5212 (Portland Fly-Ash Cement) specified by the Japanese Industrial Standards. were used. OP and LP have substantially the same quality as Type I and TypeⅣ as that specified in ASTM C150. Blast-furnace slag cement and fly-ash cement are the same type cements as those specified in ASTM C595 M.

. Table 3 shows the physical properties of river sands and crushed sand stones used in series 1 and 2 experiments. An air-entraining water reducing agent conforming to JIS A 6204 (Chemical Admixtures for Concrete) and tap water were used for both experiments.

Table 2: Types and Quality of Cement.

	Cem entty pe	specfic gravity (g/cm^3)	specific surface (cm^2/g)	compressive strength(Mpa)		compound composition(%)			fly-ash or slag content(%)
				7d	28d	C_3S	C_2S	C_3A	
Series 1 experiment	OP	3.16	3360	44.3	60.7	50	26	8	-----
	LP	3.24	3660	11.6	49.4	29	55	2	-----
	BB	3.04	3810	33.2	60.2	-----	-----	-----	50
	FB	2.96	3210	39.4	60.4	-----	-----	-----	18
Series 2 experiment	OP	3.16	3360	44.3	60.7	56	19	9	-----
	MP	3.21	3660	24.3	56.1	46	32	3	43
	FB	2.96	3210	37.4	60.4	47	16	8	15

Table 3: Type and Quality of Aggregate.

	Type of aggregate		Maxsize (mm)	Oven-dry density (g/cm^3)	Absorption (%)	Percentage of solid volume (%)	F.M
Series 1 experiment	fine	natural sand	5	2.58	1.30	----	2.64
	coarse	crushed sandstone	20	2.66	0.94	63.4	6.51
Series 2 experiment	fine	natural sand	5	2.58	1.3	----	2.97
	coarse	crushed sandstone	20	2.66	0.94	63.4	6.51

3.2 Concrete Mixture

Table 4 shows the mix proportion and test results of fresh concrete and strength before elevated temperature exposure. Water cement ratio was 50%. Target slump was 180 mm and air content was 4.5%. Sand ï total aggregate ratio (s/a) is a ratio of absolute volume of sand to that of sand plus gravel expressed in volume percent.

Table 4: Mix Proportion and Test Results of Concrete before elevated Temperature Exposure.

	Cement type	W/C	s/a	Unit content (kg/m^3)		Fresh concete		Curing	Comp.st(Mpa)		tensile st. 91d	youm's mod. 91d
		(%)	(%)	Water	Cement	Slump (mm)	Air Content (%)		28d	91d		
Series 1 experiment	OP	50	44.3	174	348	190	4.4	moist	52.6	54.4	4.85	36.2
	LP		44.9	171	342	185	4.3		43.4	55.2	3.64	33.5
	BB		44.2	172	344	190	4.1		44.7	51.7	4.7	34.7
	FB		44.0	172	344	190	4.1		44.6	51.4	4.46	34.4
Series 2 experiment	OP	50	45.4	180	360	190	4.7	moist	44.5	51.7	4.6	33.7
								sealed	39.5	46.2	3.86	35.1
	MP		46.2	175	350	185	4.5	moist	43.8	55.3	4.85	32.2
								sealed	35.4	46.5	4.41	34.6
	FB		45.5	175	350	185	4.6	moist	40.5	50.9	4.54	31.3
								sealed	35.5	46.3	4.62	35.0

3.3 Preparation of test specimens.

Cylindrical specimens, 100 mm in diameter and 200 mm in length were made for compressive strength, and cylinders 100 mm in diameter and 150 mm in length were made for splitting tensile strength. Moist cure specimens were cured in water at 20 C until 28 day old, and then sealed cured with polyethylene film until 56 day old, and then stored in air at 20 C and 65 %, R.H. until 91 day old. Sealed cure specimens were sealed with polyethylene film, and then stored in air at 2o C and 85 % relative humidity without seal until 91 day old. Specimens for sealed cure were sealed with polyethylene film and stored in air at 20 C and 85 % relative humidity until 91 day old.

Standard cured specimens for control were moist cured in water at 20 C, and were tested for compressive strength and youngŝ modulus at the age of 7, 28 and 91 days and were tested for splitting tensile strength at the age of 28 and 91 days.

3.4 Elevated temperature exposure.

At the age of 91 days, specimens for elevated temperature exposure were subjected to elevated temperatures of 20 C, 50 C, 80 C, 110 C and 300 C in constant temperature chambers. Relative humidity of 20 C chamber was held constant at 65 % relative humidity. Temperatures in the elevated temperature chambers were raised slowly to the target temperatures at the rate of 10 C per hour, and were held constant within 2 C of target temperatures, at as shown in Fig.1. Moisture in the specimens was allowed to evaporate freely.

After 91-day exposure, the temperatures of constant temperature chambers were cooled down slowly at the rate of 10 C per hour. Specimens after exposure were tested for weight loss, compressive strength and youngôs modulus and splitting tensile strength.

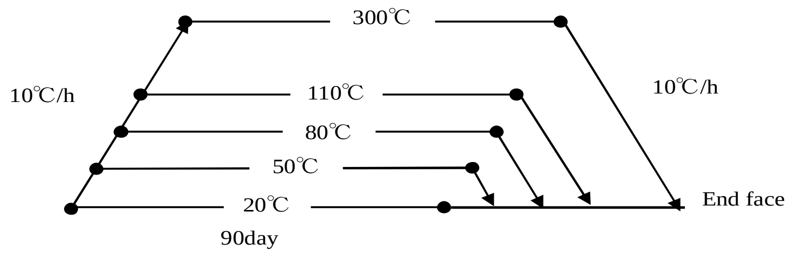


Fig 1. Schematic drawing of elevated temperature exposure process.

3.5 Tests on concrete specimens before and after elevated temperature exposure.

Weight of specimens for compressive strength was measured before and after exposure. Weight loss was determined by the percentage of weight reduction to the weight of the specimens before exposure.

Youngôs modulus was determined by the secant modulus of elasticity at the stress of one third of compressive strength during compressive strength test. Tensile strength was determined by splitting tensile tests.

4. EXPERIMENTAL RESULTS

4.1 Results of series 1 experiment

Fig. 2 shows development of compressive strength with age, and change in compressive strength after elevated temperature exposure for each temperature and for each type of cement.

Fig. 3 shows the relationship between exposure temperature and weight loss. Weight losses after exposure increased monotonously with the exposure temperature rise. Concrete with LP showed the least weight losses and concrete with BB showed the greatest weight losses at each temperature.

Fig.4 shows the relationship between exposure temperature and residual ratio of compressive strength for each cement. Residual strength ratios were determined by the percentage of residual strength to the strength before exposure at the age of 91 days. Compressive strength did not decline monotonously with exposure temperature, but showed the minimal points at 50 C and the maximal points at 80 C to 110 C. Reduction in compressive strength was found to be 15 to 25 % at 50 C and to be 40 to 45 % depending on the cement type. Similar phenomena were reported by Brouene et,al.(1975,2012), Kasame,et,al. and Shnyder et,al.(1981) Concrete with LP showed the smallest reduction and concrete with BB showed the largest reduction at each temperature.

Tensile strength indicated 10 to 45 % reduction at 50 C and 15 to 40 % reduction at 80 C and 25 to 50 % reduction at 300 C, depending on the cement type. Tensile strength after exposure showed the same minimal points as the compressive strength. However, the minimal points of tensile strength was 50 C for concrete with OP and FB, and was 80 C for concrete with LP and BB. Reduction in tensile strength was greater than in compressive strength. Concrete with BB showed the greatest reduction in tensile strength upon elevated temperature exposure.

Youngôs modulus showed monotonous reduction with temperature rise. Indicating 25 to 40 % reduction at 50 C and 50 to 75 5 reduction at 300C. Concrete with BB showed the greatest reduction in youngôs modulus at each temperature.

Fig. 5 shows the relationship among weight loss, residual ratio of compressive strength, tensile strength and youngôs modulus and type of cement. The minimal compressive strength at 50 C was found to be associated to intermediate weight loss of 2.5 to 3.5 %.

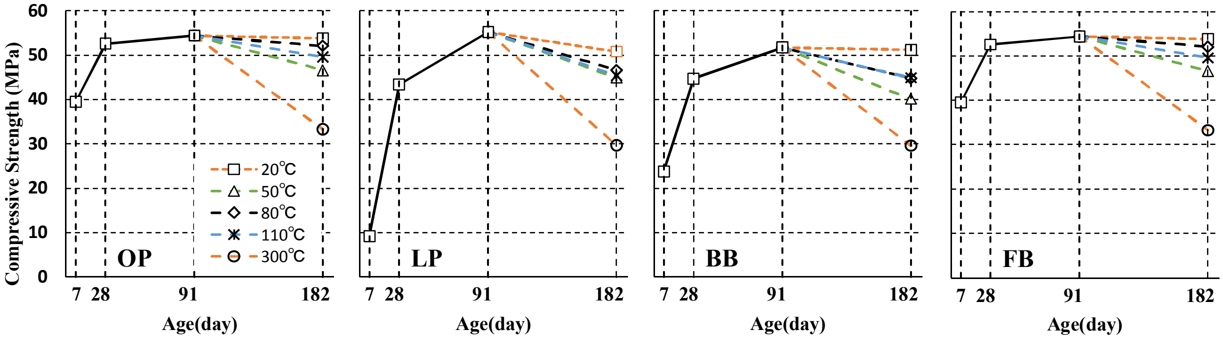
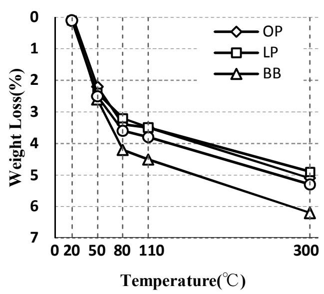
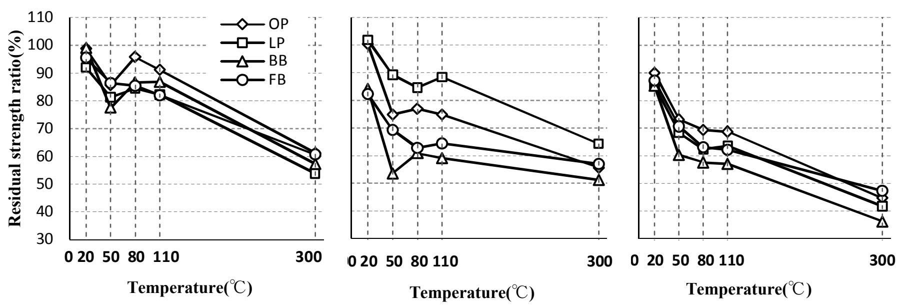


Fig 2. Development of compressive strength with age and exposure temperature.

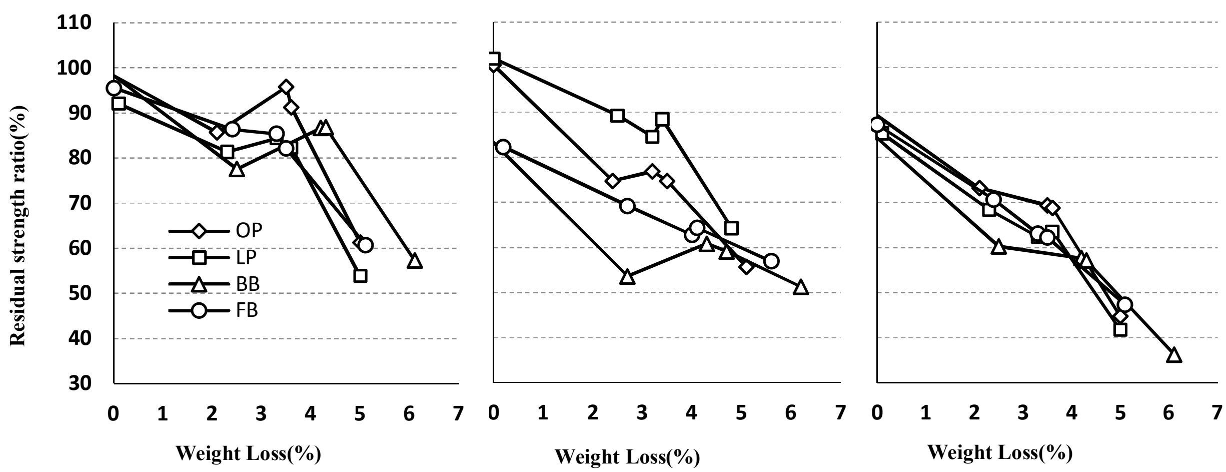




(a) Compressive Strength (b) Tensile Strength (c) Youmôs modulus

Fig.3 Weight Loss vs exposure temperature

Fig.4 Residual strength ratio vs exposure temperature



(a) Compressive Strength (b) Tensile Strength (c) Youmôs modulus

Fig.5 Residual strength ratio vs weight loss.

4.2 Results of series-2 experiment

Fig.6 shows development of compressive strength with age and change in compressive strength after elevated temperature exposure for moist cured specimens and sealed cured specimens for each cement. .

Fig.7 shows the relation ship between exposure temperature and weight loss after exposure for moist cured and sealed cured specimens. Weight losses were less affected with cement type at each exposure temperature. While, moist cured specimens showed larger weight losses than sealed cured specimens by 1 % at each temperature. The discrepancy can be due to the difference in moisture content of concrete.

Fig.8 to 10 shows the relationship between exposure temperature and residual ratio of compressive and tensile strengths and youngôs modulus. Residual compressive strength was less affected with cement type., and showed the minimal points at 50 C and the maximal points at 80 C, regardless of the cement type. Sealed cured specimens showed higher residual strength than moist cured specimens by 5 to 10 %, which can be due to that sealed cured specimens contained more moisture in concrete and kept hydration and strength development during elevated temperature exposure than moist cured and air dried specimens.

Tensile strength showed rapid reduction between 20 and 50 C and gentler reduction between 50 to 300 C, A combined effects of cement and curing was found for FB cement, indicating 10 % lower strength than OP and MP.

Youngôs modulus showed much the same tendency as in the series 1, indicating monotonous reduction with temperature. Sealed cured specimens showed 5 to 10 % lower youngôs modulus than moist cured and air-dried specimens regardless of cement type.

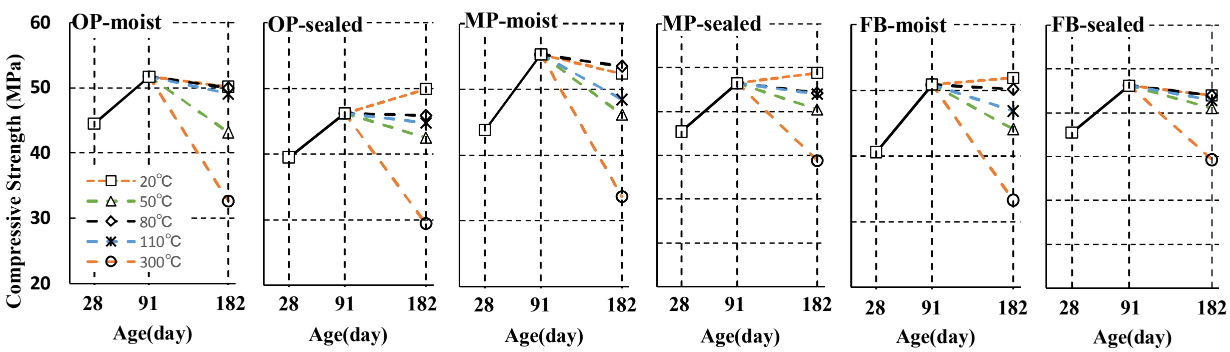
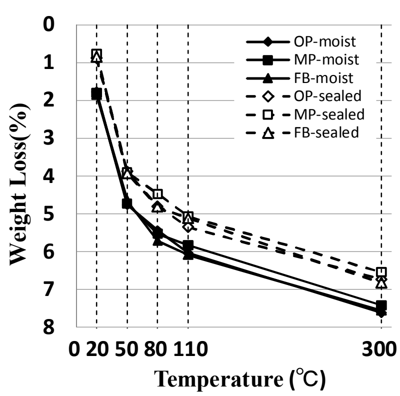


Fig.6 Development of compressive strength with age and exposure temperature.



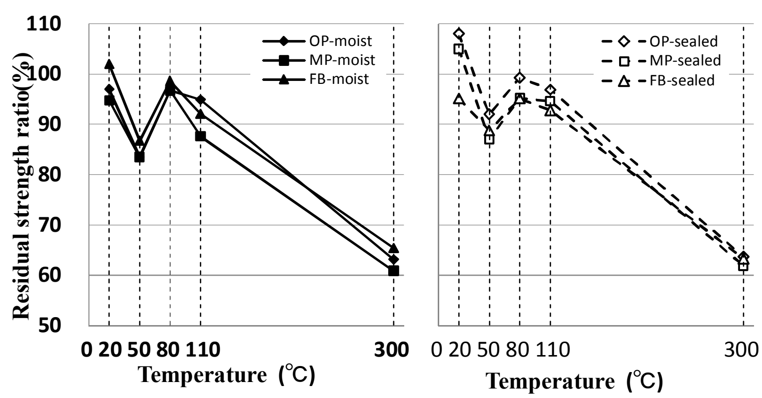


Fig.7 Weight loss vs exposure temperature

Fig.8 Compressive residual ratio vs exposure temperature

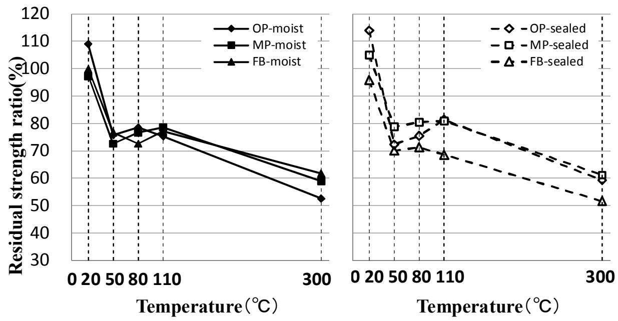


Fig.9 Tensile residual ratio vs exposure temperature

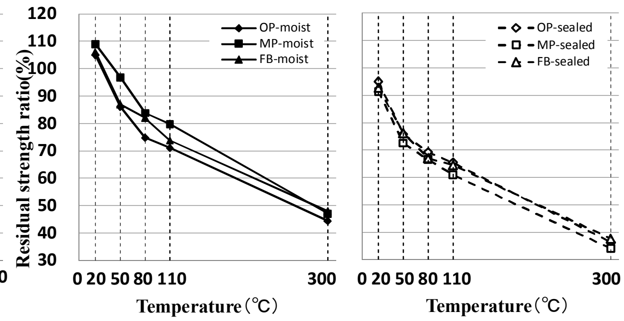
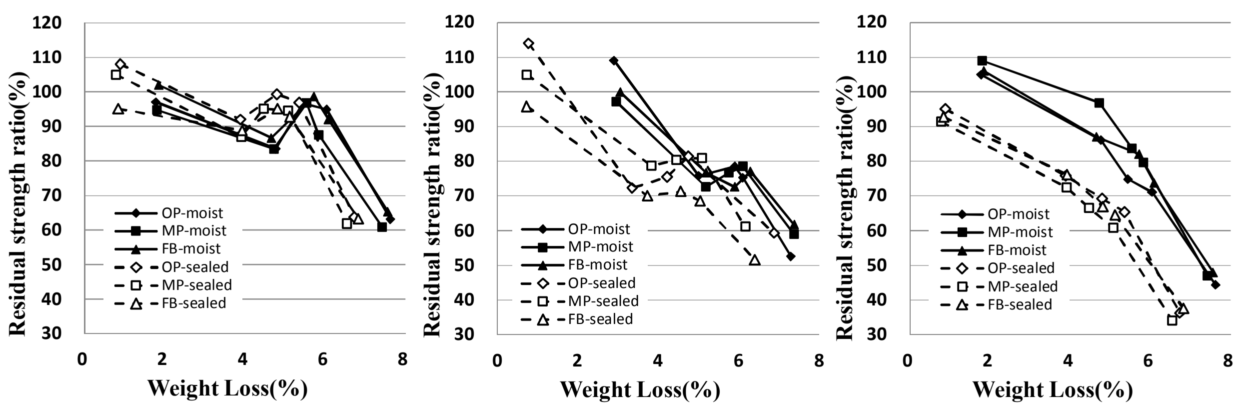


Fig.10 Youmĝs modulus residual ratio vs exposure temperature

Fig. 11 shows the relationship between weight loss and residual ratio of compressive and tensile strengths and youngĝs modulus.

The effects of curing method of specimens were varied among compressive strength, tensile strength and youngĝs modulus. The minimal points of compressive strength at 50 C and the maximal points at 80 C were found to be associated with 5 % and 6 % weight losses respectively for moist cured and air dried specimens and with 4 % and 5 % weight losses respectively for sealed cured specimens.

The minimal points of tensile strength were found to be associated with 5 % weight losses for moist cured and air-dried specimens, indicating slight effects of cement type. However, weight loss to residual tensile strength ratio relationship was much more affected with cement type, indicating larger reduction for FB and smaller reduction for MP than for OP cement.



(a) Compressive Strength (b) Tensile Strength (c) Youmĝs modulus

Fig.11 Residual strength ratio vs weight loss.

6. DISCUSSIONS on The Effects of Cement Type and curing method before exposure

The experimental results obtained in the series I and 2 experiments indicated that weight loss and residual compressive strength ratio were less affected than those of tensile strength.

The effects of cement type and curing of specimens were found to be the same as those presented by Kasami, et.al., (2012, 2013). The data indicated that reduction in compressive strength after elevated temperature exposure was greater for LP cement than OP, MP and FB cement, which can be due to that

91 day curing is too short for to sufficiently hydrate for LP cement with larger $3CaO.2SiO_2$ and less $3CaO.Al_2O_3$ than OP and MP cement.

The effects of cement type were greater for tensile strength after elevated temperature exposure, than for compressive strength, and greater reduction in tensile strength were found for BB and FB cement than OP, MP and LP cement. And concrete with FB cement is most affected with curing method, When specimens with FB cement is moist cured and air dried before exposure, greater reduction in tensile strength, which suggests the necessity of sufficient moist curing for Fb cement.

7. CONCLUSIONS

The following conclusions were drawn from the experiments presented above on the effects of low-heat type cement on the compressive and tensile strengths and youngҁs modulus of concrete subjected to sustained elevated temperatures up to 300 C.

1) Exposure to sustained elevated temperatures in the range of 59 to 300 C showed not small deteriorating effects on the strengths of concrete when moisture in concrete is allowed to evaporate.

2) Compressive strength of concrete with ordinary, moderate-heat and low-heat portland cement, portland fly-ash cement and portland blast-furnace slag cement did not decline monotonously with temperature rise and were minimal upon exposure at 50 C associated with the intermediate weight losses and maximal upon exposure at 80 C regardless of cement type.

3) Tensile strength of concrete declined rapidly upon exposure at 50 C and gently declined at 50 to 300 C, and was much more affected with cement type than compressive strength.

4) Youngҁs modulus of concrete declined monotonously with exposure temperature rise and was less affected with the cement type.

5) Concrete with low-heat portland cement showed greater reduction in compressive strength than concrete with other cements, because low-heat cement needs sufficient maturity.

6) Concrete with moderate-heat Portland cement showed least reduction in compressive and tensile strength upon elevated temperature exposure, as well as ordinary Portland cement.

7) Concrete with Portland blast-furnace slag cement showed larger weight loss and larger reduction in compressive and tensile strengths upon elevated temperature exposure.

8) Concrete with Portland fly-ash cement showed larger reduction in tensile strength when moist curing is inadequate and dried before elevated temperature exposure.

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