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혼화재 및 혼화제의 조절에 의한 서중 콘크리트의 효과적 관리

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The Effective Control of Hot Weather Concreting by Optimum Mineral and Chemical Admixtures

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Abstract : The undesirable effects of elevated external temperatures at placement on the properties of the fresh and hardened concrete are discussed briefly, and the possible use of the mineral admixtures to mitigate them and the association with water-reducing and retarding admixtures in terms of the mix design which are critical for minimizing slump loss and entrained air loss are examined in this study. To investigate the effects of such the mineral and chemical admixtures on the fresh and hardened properties of concrete exposed to high temperature, a series of concrete mixtures subjected to the high temperature were carried out and then fresh and hardened properties of the mixtures were analyzed and evaluated. Based on the results, new guide lines concerning the appropriate admixtures for hot weather are suggested.

초록 : 본 연구는 슬럼프 감소, 연행 공기 부족, 건조수축 균열, 강도감소 등 굳지 않은 콘크리트와 굳은 콘크리트의 성질에 대한 타설시 고온의 악영향에 대한 원인분석을 실시하고 이를 경감시키기 위한 감수제, 공기연행제, 지연제 등의 화학적 혼화제와 플라이 애쉬, 고로 슬래그 등의 무기질 혼화재의 다양한 적용이 검토되었다. 즉, 서중 콘크리트의 품질향상을 위한 다양한 콘크리트 배합이 설계되고 각 배합에서의 굳지 않은 콘크리트 및 굳은 콘크리트 에 대한 영향이 분석되고 몇 가지의 최적 배합이 도출되었다.

Key Words : hot weather concrete, mineral admixtures, chemical admixtures, fresh and hardened concrete property, mix design

1. Introduction

The mixing and placing concrete exposed to hot weather may have undesirable effect on both flesh and long term properties of concrete. Some of these causes relate to the mix design in terms of material and chemical admixtures, and others to the quality control such as the workability and the curing condition. Considerable concrete works in hot weather have been carried out with such hot weather problems about which extensive discussion have been for a long time.

The high temperature at placement increases the plastic concrete temperature and it adversely affects important properties of the fresh concrete. A number of measures have been used to mitigate undesirable effects under the high temperature[1,2]; the mix design with good performance in hot weather; cooling materials by chilled water and ice, or liquid nitrogen; concrete consistency that allows rapid placement and consolidation; and limiting the maximum in-place temperature. However, there have been many debates about the treatments; the temperature limit applied to concrete in hot weather is effective? ; the production cost of concrete is reasonable when ice or refrigeration is used?

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Mehta[3)]suggested that the replacement of cement by high volume fly ash helps to meet the required quality of fresh concrete, in the 32 to 38 ℃ range: and these changes could be even cost-effective than cooling the concrete[4,5)]. In addition, theoretical considerations and field experiences have showed that blended Portland cements containing high volume mineral admixtures provide a better approach to durable concrete structures [3)]. It was reported that in a concrete block replaced by the high volume fly ash, the temperature rise can be limited to 35℃, compared to 65℃ reached in the same size of concrete without mineral admixtures[6)]. Mehta and Langley[2)] reported the considerable elimination of thermal cracking at early ages under hot weather conditions by the 57% replacement of fly ash.

Accordingly, in modern concrete mixing, such mineral admixtures has become common practice (15~20 % of cement replacement) for the improvement of the flesh and hardened properties in concrete exposed to hot weather. In U.S., the specification, limiting concrete temperature at placement has been widely used for hot mix concreting, but it doesn't address mineral or chemical admixtures in most states. It might be appropriate for some conditions but unnecessary for others. Thus, the current practices for hot weather concreting are somewhat ambiguous and not readily employed.

In this study, to investigate the effects of mineral and chemical admixtures on the performance of fresh concrete at higher temperatures, a series of concrete mixtures subjected to the high temperature mixing procedure were carried out. Based on the results, new guide lines concerning the appropriate admixtures for hot weather are suggested. This research focuses on the proper design of mixing and placing concrete in hot weather and various aspects are examined: mixing portions, delay time between mixing and placing and admixtures. The effects of these factors on the strength of hardened concrete are also investigated. Thus, the objective of this study is to develop a better understating of the effects of higher temperatures on the properties of concrete with new finding.

2. Hot Weather Concreting

The high temperature incurs the increased water demand to impart the desired consistency to a given mix[7)]. Also due to the time interval between the time that the water is put to the mix and the time that the slump is determined, the mix somewhat stiffens, and this stiffening is greater at higher concrete temperatures. Hence, to overcome this stiffening, more water should be added to the mix. Such the water demand is undesirable because it increases the water cement ratio (W/C) and adversely affects other concrete properties.

Furthermore, adding the cement content, to maintain the required W/C ratio, is also unacceptable because of the rising cost and the drying shrinkage of the concrete that, in turn, increases its susceptibility to cracking. Therefore, in order to avoid the undesirable effects of the increased water demand, water-reducing admixtures (WR) or a high-range water reducer (HRWR) should be considered.

The stiffening of the fresh concrete, and the associated slump loss, are brought even by the hydration of the cement. Evaporation of the mixing water, in some cases, by the water absorption of dry aggregates made the problems worse. All these effects reduce the amount of the free water in the fresh concrete mix, and consequently the fluidity of the mix is decreased. The rate of the cement hydration increases with the rise of temperature and generally follows Arrhenius equation. It can be confirmed that, based on the equation, the rise of the hydration temperature from 20℃ to 40℃, happens, in the first few hours, setting the hydration rate factor to be 2.4[1)]. That is, the accelerating effect of temperature by the hydration of Portland cement is very significant in fact. It follows that a higher temperature by the cement hydration will result in shorter setting times and a higher rate of slump loss. It should be noted that the slump loss is further affected whenever loss of water through additional evaporation takes place. With above facts, it may be expected that the retarding admixtures, by slowing down the rate of hydration, would slow down the rate of slump loss and thereby counteract the accelerating effect of temperature. Hence, such admixtures should be considered under hot weather conditions. The use of water reducing together with retarding admixtures (WRR) (ASTM C 494, type D) should be considered rather than admixtures that merely reduce water demand and have no retarding effect .

3. Experimental Program

The objective of this study is to design and evaluate proper mixtures to maintain to suitable characteristics under a high temperature mixing and placement environment. A range of concrete mixtures were subjected to an extended high temperature mixing procedure. The mixtures contained different amounts and types of mineral and chemical admixtures. The performance of the fresh mixtures was evaluated by slump and air content tests. The compressive and split tensile strength of samples cast from the mixtures was also measured. The strength tests evaluate the ability of a mixture to maintain suitable characteristics under a high temperature mixing and placement environment. Tests to measure early-age cracking tendency such as the restrained ring shrinkage test and long-term material durability performance such as freezing and thawing resistance and scaling of the material were not carried out here. These issues should be studied to complete a comprehensive evaluation of the behavior of concrete subjected to high temperatures later.

3.1 Concrete Mixtures

Concrete mixtures were designed to consider various combinations of mineral and chemical admixtures. In all mixtures, Type I Portland cement, a natural quartz sand and crushed limestone coarse aggregate with CA 7 gradation were used. Here, CA means a gradation degree, which is classified as 1-19 by the Standard Specifications in United States of America. For an aggregate blend, the coarse aggregate portion is normally considered to be all material retained on or above the 4.75 mm (No.4) sieve. The plain mixture, without any mineral admixtures, satisfies IDOT (Illinois Department of Transportation) specifications[6), which is one of common provisions with regard to the construction requirement and improvement in the US, for pavement (PV) concrete. Mixtures with varying levels of Class C fly ash and ground granulated blast furnace slag, based on the plain mixture proportions, were designed to replace cement by mass. The component proportions of the mixtures are given in Table 1, and the dosages and detail on the admixtures are given in Table 2, unless specifically indicated in the footnotes in Tables 3. A given mixture contains all three types of chemical admixture: air-entraining admixture, superplasticizer and retarder at the listed dosages. In some cases however a mixture may contain only one or two chemical admixtures as indicated.

3.2 Mixing and Test Procedures

Two concrete mixing procedures were employed: a standard procedure and an extended high temperature

Table 1. Concrete mixture proportions expressed as kg/㎥(SSD)

Mixture	Plain	FA1 Class C (20%)	FA2 Class C (40%)	Slag1 (20%)	Slag2 (50%)	Ternary Class C, GGBS (25%)
water	150.8	150.8	150.8	150.8	150.8	150.8
cement	359.0	287.2	215.4	287.2	179.5	179.5
sand	671.2	670.6	665.3	674.8	671.8	666.5
CA 7	1091.4	1089.6	1080.1	1096.7	1092.0	1083.1
fly ash	0	71.8	143.6	0	0	89.8
slag	0	0	0	71.8	179.5	89.8

Table 2. Description of chemical and mineral admixtures used

Admixture	Description	Dosage (ml/100 kg cement)	Dosage (gal/100 lb cement)
Air-Entrainer	ASTM C 260 (Grace Daravair 1400)	80	9.43
Super- plasticizer	ASTM C 494 Types A&F/ASTM C 1017 Type I (Grace ADVA Cast 575)	107	12.6
Retarder	ASTM C 494 Type D (Grace Daratard 17)	340	40.1
Fly ash	ASTM C 618 Class C (Lafarge)	----	
Slag	ASTM C 989 grade 100 (Prairie Materials)	----	

mixing procedure. The standard procedure follows the standard practice described by ASTM C 192. The extended high temperature mixing procedure, developed by the Florida Department of Transportation (FDOT)[7], was employed to evaluate the performance of the concrete mixtures and the procedure is summarized here. The area around the mixture is held at a constant air temperature between 94 to 98˚F (34.4 to 36.6℃). First, all dry mixture ingredients are pre-heated in this environment for several hours. Then the dry components are mixed together in a 2.5 ft^3. (0.0707 m^3) capacity pan mixer for 5 minutes (3 min initial mixing, 3 min rest, and 2 min follow up mixing) with hot water at 94˚F (34.4℃). The slump and air content of the mixture immediately after the preliminary mixing process are measured by ASTM C 143 and C 231, respectively. The remaining concrete in the mixer is then mixed for 30 seconds every 5 minutes while held at 94 to 98˚F (34.4 to 36.6℃) for 90 minutes. The objective of this process is to ensure that the plastic concrete maintains a temperature of at least 94˚F (34.4℃) throughout the process. During the rest periods, the mixture is covered to minimize moisture loss. After 90 minutes, the concrete slump and air content are measured again.

Fig. 1. Testing set-up used for the high temperature. extending mixing procedure: pan mixer and air temperature sensor control system (up), enclosed testing area around mixture showing space heaters and fresh concrete test equipment (down).

Controlled air temperature in an area around the pan mixer was maintained by an enclosed thermally insulated area, which includes enough space to carry out all fresh concrete tests, as shown in Fig.1. Three portable space heaters were used to maintain an air temperature between 94 to 98˚F (34.4 to 36.6℃) within the enclosed area. The air temperature was monitored using a multi-sensor system distributed within the enclosed space, and the average temperature was recorded. The temperature of the plastic concrete mixture was also measured at the end of the extended mixing procedure.

3.3 Hardened Concrete tests

In most cases, 4×8 inch (100×200 mm) cylinder samples of the concrete were made for subsequent strength tests. The cylinder samples were kept in the 94 to 98˚F (34.4 to 36.6℃) for 24 hours, after which they were demolded and transferred to a room with a maintained environment of 73˚F (22.7℃) and 100% humidity until the time of the strength tests. Standard compressive and split tensile strengths, ASTM C 39 and C 496 procedures, respectively, were measured at ages of 3, 7, and 14 days. For each strength type and age, the average value from three samples was reported.

4. Results and Discussion

The high temperature extended mixing procedure developed by FDOT was successfully applied to several different concrete mixtures with varying mineral and chemical admixture content. Slump and air content were measured before and after the extended procedure for each mixture, and strengths of companion samples were measured at 3, 7, and 14 days. According to IDOT specifications for “PV” (pavement) concrete, slump should be between 2 to 4 inches (50.8 to 101.6 mm), corrected air content between 5 to 8% and 14-day compressive

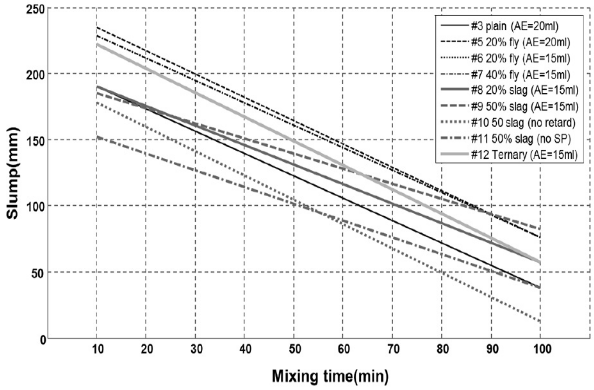

Fig. 2. Slump loss versus high temperature mixing time for various concrete mixtures. (AE = air entraining admixture, SP = Superplasticizer).

strength should be above 3500 psi (24.1 MPa). All tested concrete mixtures with mineral (class C fly ash and ground granulated blast-furnace slag) and chemical (air entraining admixture, superplasticizer, and retarder) admixtures met the minimum 14-day compressive strength requirement for “PV” concrete specification.

The fresh concrete properties for the high temperature mixing procedure are listed in Table 3. As expected, all mixtures suffered considerable slump loss during the extended, high temperature mixing procedure, which can be seen in Fig. 2. It should be noted that the effective working time of the superplasticizer is not known. Since it is possible to meet the target slump at the end of the mixing process by beginning with a high slump in anticipation of the slump loss a more effective evaluation process may be to identify mixtures that exhibit the smallest slump loss as a result of the extended mixing procedure. The addition of retarding admixture (ASTM C 494 Type D) is critical for minimizing slump loss and extending placement and finishing time of concrete mixtures exposed to extended high temperatures. Mixtures without retarding admixture suffered the highest levels of slump loss, and in some cases all slump was lost. This slump loss is likely due in part to accelerated hydration processes since it is clear that mixtures without retarding admixture exhibited the highest mixture temperature after the extended procedure (see Table 3).

Together with retarding admixture(ASTM C 494 Type D), high percentage replacement of cement with granulated blast furnace slag(ASTM C 989 grade 100) significantly reduced the slump loss of the concrete for the material combinations tested and resulted in the highest compressive strength at 14 days as presented in Fig 2. This behavior is similar to the results by Chini and

Table 3. Fresh concrete test results for concrete using extended high temperature mixing procedure

Mix No.	Mixture type	Slump before (inch/mm)	Slump after (inch/mm)	Air before (%)	Air after (%)	Slump loss (inch/mm)	Air loss (%)	Mix temp (˚F/℃)
1	Plain[1], no retarder	5.0 / 127	0	4.0	2.7	complete	1.3	101.5 / 38.6
2	Plain, no retarder	5.5 / 139.7	0	6.8	2.8	complete	4.0	100.2 / 37.9
3	Plain[2]	7.5 / 190.5	1.5 / 38.1	7.3	7.0	6.0 / 152.4	0.3	95.7 / 35.4
4	Plain	8.0 / 203.2	2.0 / 50.8	5.0	7.7	6.0 / 152.4	-2.7	98.0 / 36.7
5	FA1[2] Class C	9.25 / 234.9	3.0 / 76.2	4.4	8.3	6.25 / 158.8	-3.9	95.6 / 35.3
6	FA1 Class C	9.0 / 228.6	3.0 / 76.2	3.3	8.0	6.0 / 152.4	-4.7	95.7 / 35.4
7	FA2 Class C	9.0 / 228.6	3.0 / 76.2	3.0	7.1	6.0 / 152.4	-4.1	97.9 / 36.6
8	Slag1	7.5 / 190.5	2.25 / 57.2	5.8	7.2	5.25 / 133.4	-1.4	95.4 / 35.2
9	Slag2	7.3 / 185.4	3.25 / 82.6	4.4	6.5	4.25 / 108	-2.1	96.5 / 35.8
10	Slag2 no retarder	7.0 / 177.8	0.5 / 12.7	4.7	2.7	6.5 / 165.1	2.0	100.0 / 37.8
11	Slag2 no SuperP	6.0 / 152.4	1.5 / 38.1	7.8	4.7	4.5 / 114.3	3.1	96.5 / 35.8
12	Ternary Class C, GGBS no SuperP	8.75 / 222.3	2.25 / 57.2	6.8	4.6	6.5 / 165.1	2.2	97.2 / 36.2

[1]Air = 29 ml/ckg (3.4 gal/100 lb); SuperP = Super Plasticizer = 54 ml/ckg (6.4 gal/100 lb), [2]Air = 107 ml/ckg (12.6 gal/100 lb)

Acquaye[8], showing that the mix with slag had the longest time-to-failure among all mixtures including other mineral admixtures in hot temperature. The mixtures with fly ash (ASTM C 618 Class C) partially replacing cement were able to achieve the target placement slump at the end of the mixing period as long as the initial slumps were high enough. However, the fly ash based mixtures including even a retarding admixture did not affect the slump loss rate of concrete mixtures like the slag mixtures. This behavior has been seen in a recent study[9] with regard to recycled concrete aggregates and may be specific to the particular Class C fly ash used in the laboratory.

The air content was a difficult property to control in the concrete laboratory mixtures as seen in Table 3. Mixtures that contained both the superplasticizer and retarding admixture showed an increase in air content as a result of the extended mixing procedure. This was a result of unintended chemical interaction between these two admixture types. It can be seen that multiple mixtures had negative admixture interactions which increased the air content at the end of the mixing time. The fly ash mixtures appeared to be most affected by this interaction. When retarder and superplasticizer were not used simultaneously in a mixture, the air content in the mixture decreased with mixing time as expected. A similar negative interaction between certain Class C fly ash, certain water reducers, and cement types has been reported by Kohn and Tayabji[10] for hot temperature paving mixtures. They also suggested testing the proposed mixtures at higher temperatures to determine if a negative interaction exists. If it does, changing the water reducer type, cement source, or fly ash source should rectify the problem.

To verify that the high temperature mixtures didn't have adverse strength that would affect long-term performance, several of the mixtures were mixed at 70°F (21.1℃) as shown in Table 5. All these mixtures had an approximate 6% initial air content and 6 inches (152.4mm) slump. The air entraining agent and superplasticizer was varied to achieve these targets and retarder was not added at this mixing temperature. These batches didn't follow the 90 minute mixing procedure and the specimens were cast immediately. All the mixtures in Table 5 met the minimum compressive strength of 3500 psi (24.1 MPa) at 14 days except mixture 5 with Class F fly ash. When comparing similar mixtures in Table 4 (high temperature conditions) with Table 5, the strengths are consistently higher at 3 and 14 days for extended mixing. This can be attributed to better mixing and uniformity afforded by the addition of superplasticizer and retarder, and also that the higher initial mixture temperature promotes higher early strength gain. The strength results at 70°F (21.1℃) confirm the reasonableness of the high temperature mixture strategies and data presented in Table 4.

To sum up, the high temperature concrete mixing procedure proposed by the FDOT showed merit and potential for evaluating the effectiveness of certain mixture changes on the fresh and hardened properties of the concrete. This process demonstrated that concrete

Table 4. Strength test results for samples using extended high temperature mixing procedure

Mix number	3-day comp. (psi/Mpa)	7-day comp. (psi/Mpa)	14-day comp. (psi/Mpa)	3-day split tensile (psi/Mpa)	7-day split tensile (psi/Mpa)	14-day split tensile (psi/Mpa)
1	n/a	n/a	n/a	n/a	n/a	n/a
2	n/a	n/a	n/a	n/a	n/a	n/a
3	3600 / 24.80	3690 / 25.42	4635 / 31.94	344 / 2.37	448 / 3.09	571 / 3.93
4	3080 / 21.22	3525 / 24.29	3950 / 27.22	391 / 2.69	425 / 2.93	444 / 3.06
5	n/a	n/a	n/a	n/a	n/a	n/a
6	2260 / 15.57	3005 / 20.70	3595 / 24.77	249 / 1.72	316 / 2.18	432 / 2.98
7	2090 / 14.40	2915 / 20.08	3880 / 26.73	280 / 1.93	383 / 2.64	437 / 3.01
8	3235 / 22.29	3635 / 25.05	5255 / 36.21	287 / 1.98	429 / 2.96	432 / 2.98
9	2455 / 16.91	3685 / 25.39	4230 / 29.14	262 / 1.81	398 / 2.74	405 / 2.79
10	n/a	n/a	n/a	n/a	n/a	n/a
11	2670 / 18.40	3685 / 25.39	5305 / 36.55	227 / 1.56	430 / 2.96	438 / 3.02
12	2640 / 18.19	3405 / 23.46	5185 / 35.72	200 / 1.38	422 / 2.91	380 / 2.62

Table 5. Strength test results for samples using standard mixing procedure (ASTM C 192) At 70° F (21.1° C)

Mix number	3-day comp. (psi/Mpa)	14-day comp. (psi/Mpa)	28-day comp. (psi/Mpa)
11	3287 / 22.65	4181 / 28.81	4782 / 32.95
52 Type C	2744 / 18.91	4531 / 31.22	5088 / 35.06
53 Type F	2332 / 16.07	3258 / 22.45	4067 / 28.02
74	2005 / 13.81	3776 / 26.02	4533 / 31.23
85	2429 / 16.74	4070 / 28.04	4746 / 32.70
106	1583 / 10.91	3882 / 26.75	4760 / 32.80

[1] Air = 57 ml/ckg (6.7 gal/100 lb); SuperP = 104 ml/ckg (12.3 gal/100 lb)
[2] Air = 73 ml/ckg (8.6 gal/100 lb); SuperP = 41 ml/ckg (4.8 gal/100 lb)
[3] Air = 28 ml/ckg (3.3 gal/100 lb)
[4] Air = 103 ml/ckg (12.1 gal/100 lb)
[5] Air = 33 ml/ckg (3.9 gal/100 lb); SuperP = 19 ml/ckg (2.2 gal/100 lb); Retarder = 0 ml
[6] Air = 33 ml/ckg (3.9 gal/100 lb); SuperP = 38 ml/ckg (4.5 gal/100 lb); Retarder = 0 ml

mixtures that are not altered during high temperature application will certainly lead to potential problems with placement, compaction, and finishing, and in all likelihood, future durability issues also. For this study, the FDOT procedure identified the combination of material constituents that were able to achieve workable, compactable, and finishable concrete that meets IDOT specifications. It also was able to indicate potential interactions that could result in problems in the initial construction or long-term durability.

5. Conclusions

Fresh concrete mixtures were subjected to the high temperature mixing procedure developed by FDOT. Air content and slump were measured before and after the 90-minute mixing procedure as well as compressive and splitting tensile strengths at various ages. The principal goals of the tests were to determine the effects of mineral and chemical admixtures on the performance of fresh concrete at high temperatures and to meet the minimum strength at 14 days. Tests to measure early-age cracking tendency and long-term material durability performance of the material were not carried out here, but still need to be conducted.

- At the end of the 90 minute high temperature mixing procedure, “PV” concrete without retarder, Superplasticizer (= High-range water-reducing admixture), or mineral admixtures was not able to meet the specified fresh concrete properties.
- All tested concrete mixtures with mineral (Class C fly ash and ground granulated blastfurnace slag) and chemical (air entraining admixture, superplasticizer, and retarder) admixtures met the 14-day strength requirement for “PV” concrete.
- The addition of retarding admixture (ASTM C 494 Type D) is critical for minimizing slump loss and entrained air loss and extending placement and finishing time of concrete mixtures exposed to extended high temperatures during mixing, placement, and finishing.
- Together with retarding admixture (ASTM C 494 Type D), high percentage replacement of cement with ground granulated blast-furnace slag (ASTM C 989 grade 100) significantly reduced the concrete slump loss over the mixing time for the material combinations tested.
- Together with retarding admixture (ASTM C 494 Type D), cement replacement with fly ash (ASTM C 618 Class C) did not notably affect the slump loss rate of concrete mixtures exposed to extended high temperature mixing. However, this finding may be specific to the particular fly ash that was utilized.

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References

1) ACI Committee 305, Hot Weather Concreting, American

Concreting Institute, Farmington Hills, Michigan, 2002.
2) P. K. Mehta and W. Langley, “Monolith Concrete Foundation: Built to Last a 1000 Years”, Concrete International, Vol. 22, No. 7, pp. 27-32, 2000.
3) P. K. Mehta, “Performance of High Volume Fly Ash Concrete in Hot Weather”, Innovations in Design with Emphasis on Seismic, Wind, and environmental Loading; Quality Control and Innovations in Materials / Hot Weather Concreting, Proceedings, ACI Fifth International Conference, Cancun Mexico, December, 2002.
4) M. Samarai, S. Popovics and V. M. Malhotra, “Effect of High Temperatures on the Properties of Fresh Concrete”, Transportation Research Record, Vol. 924, pp.42-50, 1983.
5) W. Ma, D. Sample R. Martin and P. W. Brown, “Calorimetric Study of Cements Blends Containing Fly Ash, Silica Fume and Slag at Elevated Temperatures”, Cement Concrete and Aggregates, Vol. 16, No. 2, pp. 93-99, 1994.
6) Illinois Department of Transportation, “Standard Specifications for Road and Bridge Construction”, IDOT, 2007.
7) Florida Department of Transportation, “Standard Specifications for Road and Bridge Construction”, FDOT, 2009.
8) A. R. Chini and L. Acquaye, “Effect of Elevated Curing Temperatures on the Strength and Durability of Concrete”, Materials and Structure, Vol. 38, No. 8, 673-679, 2005.
9) A. Salas, J. Roesler and D. Lange, “Properties of Recycled Aggregate Concrete”, Technical Note 43 for O’Hare Modernization Program, University of Illinois, 2009.
10) S. D. Kohn and S. Tayabji, “Best Practices for Airport Portland Cement Concrete Pavement Construction (Rigid Airport Pavement)”, Report IPRF-01-G-002-1, An IPRF Research Report Innovative Pavement Research Foundation Airport Concrete Pavement Technology Program, 2003.