Use of ASTM Type-C Fly Ash and Limestone in Sand-Gravel Concrete

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Serious damage in concrete structures worldwide has been attributed to alkali-aggregate reactions. Field and laboratory work has demonstrated that silicious aggregates in wide regions in the midwestern United States can yield concrete with durability problems. This is the case for some sand-gravel aggregates in Kansas. To minimize durability problems, pozzolans, such as fly ash, and limestone have been suggested for use in concrete mixtures involving such aggregates. The use of two ASTM type-C fly ashes as 15 percent replacement of portland cement is evaluated. Also, the use of limestone (sweetener) from two sources as a 30 percent weight replacement of the sand-gravel is investigated. Thirty concrete mixtures were prepared with a water-to-cementitious materials ratio of 0.51. Eight approved and unapproved types of sand-gravel aggregates from different areas in Kansas were used. Concrete beams were cast and tested to determine the change in lengths and the modulus of rupture. Test results indicate that mixtures made with the two fly ashes have higher expansion and lower modulus of rupture when compared with mixtures containing no fly ash. Of the 16 concrete mixtures made with fly ash 15 failed to meet Kansas Department of Transportation specifications. The mixtures made with unapproved sand gravel and limestone had lower expansion and higher modulus of rupture when compared with concrete made with approved aggregates with no fly ash.

For the past 5 decades, deleterious chemical reactions between aggregates and cement paste in concrete have been observed. One of the most common forms of such reactions is that between some active silica ingredients that may exist in aggregates and the alkalis in cement, known as the alkali-silica reaction. This reaction results in an alkali-silicate gel that is characterized by a tendency to increase in volume (*1*). The reaction can lead to localized volume changes, cracking, pop-outs, loss of strength, and dislocation of structures (*2*). In some extreme cases, complete destruction of the concrete may occur (*2–4*). Severe alkali-aggregate reaction problems have been reported in several countries worldwide, including Japan, the United States, England, and Canada. In the United States, such problems are mostly associated with aggregates from the West and Southwest, as well as Kansas, Nebraska, Iowa, Alabama, and Georgia (*4*). Most of those aggregates contain significant amounts of volcanic and opaline materials known to be potentially alkali reactive (*5*).

More than 2 decades ago, the use of pozzolanic materials was suggested to minimize the problems associated with alkali-aggregate reactions. Fly ash, a pozzolanic by-product material from burning coal, is being used on a wide scale worldwide for that purpose. However, the chemical and physical properties vary significantly from one fly ash source to another. Therefore, the performance of concrete is affected by the characteristics and dosage of the fly ash used. It has been reported that certain dosages of some fly ash types do not minimize the alkali-aggregate reaction and can even exacerbate the problem (*6,7*). For that reason, use of fly ash (or any other pozzolans) is not recommended to reduce alkali-aggregate reaction unless its ability has been confirmed through testing.

The use of limestone as partial replacement of sand-gravel aggregate in concrete has been suggested to enhance concrete performance. The Kansas Department of Transportation (KDOT) Standard Specifications (*8*) allows the use of limestone (as a sweetener) in all sand-gravel concrete and requires limestone use if the sand-gravel aggregate is from an unapproved source.

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OBJECTIVE AND SCOPE

The work presented in this paper is part of an ongoing study carried out by KDOT to determine the effect of using fly ash in sand-gravel concrete. This study was undertaken to investigate the possibility of using two locally available type-C fly ashes and two limestones in sand-gravel concrete.

Concrete mixtures were prepared using sand-gravel aggregates from approved and unapproved sources in Kansas. Fly ash from two sources was used as 0 and 15 percent replacements, by weight, of portland cement. Limestone (as a sweetener) was used as a 30 percent replacement, by weight, of the sand-gravel aggregate in concrete made with unapproved aggregates. The concrete mixtures were evaluated by performing KDOT's wetting and drying test (*9*). In this test, concrete beams are prepared, and the change in length as well as the modulus of rupture are measured and evaluated.

MATERIALS

Cement

Type II portland cement (Ash Grove brand) was used. The cement had a specific gravity of 3.15 and a specific surface area (blaine fineness) of 3,780 cm^2/g. The Bogue compounds of the cement were as follows: C_3S = 53.1 percent, C_2S = 21.7 percent, C_3A = 7.7 percent, and C_4AF = 9.5 percent. The alkali content (as Na_2O equivalent) is 0.50 percent. The chemical analysis of the cement is provided in Table 1.

Fly Ash

Two type-C fly ashes, produced at two Kansas power plants (Jeffrey and LaCygne), were used. The specific surface areas of the two ashes (blaine fineness) are 3,760 and 4,200 cm^2/g, respectively. The alkali contents of the two fly ashes are (as Na_2O equivalent) 0.84

TABLE 1 Chemical Analysis of Portland Cement and Fly Ashes Used

Component	Portland Cement	F-1 fly ash (Jeffrey)	F-2 fly ash (LaCygne)
SiO_2	21.54	28.84	30.87
Al_2O_3	4.88	21.73	23.61
Fe_2O_3	3.12	5.16	3.94
CaO	64.07	31.75	30.88
MgO	2.23	6.76	5.52
SO_3	2.34	3.49	3.30
Na_2O	0.32	0.94	1.03
K_2O	0.28	0.15	0.18
L.O.I.	1.20	0.44	0.10

and 1.04 percent, respectively. The chemical analyses of the two fly ashes used are provided in Table 1. [Note: the two fly ashes (Jeffrey and LaCygne) will be referred to, respectively, as F–1 and F–2 in this paper.]

Aggregates

Sand-gravel aggregates from eight sources in Kansas were used. Five of these sand-gravel aggregates were from approved sources, and three were from unapproved sources. All eight aggregates were used in concrete mixtures made with and without fly ash. Limestone from two sources was used with the unapproved aggregates by replacing 30 percent of the sand-gravel with an equal weight of limestone.

Water

City of Topeka municipal water was used as the mixing water in the concrete mixtures.

TEST PROCEDURE

Concrete beams were prepared and tested for change in length and modulus of rupture in accordance with the KDOT Standard Specifications for Wetting and Drying Test of Total Mixed Aggregate Concrete (*9*).

Fifteen concrete mixtures were prepared using each of the five approved aggregates with 0 and 15 percent replacement, by weight, of cement with the two type-C fly ashes. Similarly, nine concrete mixtures were prepared using each of the three unapproved aggregates with 0 and 15 percent fly ash (from two sources). Six concrete mixtures were prepared using the three unapproved aggregates by replacing 30 percent of the sand-gravel aggregate with an equal weight of limestone (from two sources). All mixtures had a water-to-cement ratio of 0.51 and yielded a slump of 50 to 75 mm (2 to 3 in.). The identification of each mixture and the constituent materials for each mixture are presented in Table 2.

To perform the wetting and drying test, concrete beams were prepared and subjected to a scheme of wetting and drying. After casting, the beams were cured for 7 days in a moist room (curing room), followed by a 21-day air-drying period at room temperature, then submerged in water for 2 days. Beam lengths were then measured after 30 days. Three beams are moist-cured an additional 30 days and tested for flexural strength. The rest of beams were subjected to cycles of oven-heating for 8 hr at a temperature of 53.5°C, followed by 15.75 hr of being submerged in water at room temperature. Cycles (oven heating and water submerging) were carried out every working day, otherwise beams were kept in a water bath.

Beam lengths were measured at 60, 120, 240, 300, and 365 days. The changes in beam lengths were calculated using the 30-day beam lengths as the initial value for comparisons. Flexural tests were performed at 60 and 365 days, and the modulus of rupture calculated.

RESULTS

The result of the percentage of increase in length after 180 and 365 days and the modulus of rupture after 60 and 365 days are presented in Table 3 and illustrated in Figures 1 through 4. The results of the compressive strength of modified cubes after 60 and 365 days are also presented in Table 3.

The results (illustrated in Figure 1) show that the average percentage of increase in length for the concrete mixtures made with approved aggregates with no fly ash after 365 days (mixture nos. 1, 4, 7, 10, and 13) was 0.041. (Note: the maximum percentage of increase allowed by the specifications is 0.070 percent.) Also, the percentage of increase in length for the individual mixtures was less than the maximum allowed by the specifications. However, the average percentage of increase for mixtures made with approved aggregates with 15 percent F–1 fly ash (mixture nos. 2, 5, 8, 11, and 14) was 0.076 percent, which exceeds the maximum value allowed by the specifications (0.070). Also, the results of two of the five

TABLE 2 Composition of Concrete Mixtures Used in This Study

Mixture I.D.	Fly Ash		Sand-Gravel		Limestone	
	Percent	Source	Source	Approval	Percent	Source
1	0	-	Westhoff	Yes	0	-
2	15	Jeffrey (F-1)	Westhoff	Yes	0	-
3	15	LaCygne (F-2)	Westhoff	Yes	0	-
4	0	-	Blue River	Yes	0	-
5	15	Jeffrey (F-1)	Blue River	Yes	0	
6	15	LaCygne (F-2)	Blue River	Yes	0	-
7	0	-	Mueller	Yes	0	-
8	15	Jeffrey (F-1)	Mueller	Yes	0	-
9	15	LaCygne (F-2)	Mueller	Yes	0	-
10	0	-	Gaither	Yes	0	-
11	15	Jeffrey (F-1)	Gaither	Yes	0	-
12	15	LaCygne (F-2)	Gaither	Yes	0	-
13	0	-	Smith	Yes	0	-
14	15	Jeffrey (F-1)	Smith	Yes	0	-
15	15	LaCygne (F-2)	Smith	Yes	0	-
16	0	-	Moore	No	0	-
17	15	Jeffrey (F-1)	Moore	No	0	-
18	15	LaCygne (F-2)	Moore	No	0	-
19	0	-	Moore	No	30	Walker
20	0	-	Moore	No	30	Hallet
21	0	-	St. Francis	No	0	-
22	15	Jeffrey (F-1)	St. Francis	No	0	-
23	15	LaCygne (F-2)	St. Francis	No	0	-
24	0	-	St. Francis	No	30	Walker
25	0	-	St. Francis	No	30	Hallet
26	0	-	J&R	No	0	-
27	15	Jeffrey (F-1)	J&R	No	0	-
28	15	LaCygne (F-2)	J&R	No	0	-
29	0	-	J&R	No	30	Walker
30	0	-	J&R	No	30	Hallet

mixtures were well above the maximum value. Similarly, the average percentage of increase for mixtures made with 15 percent F–2 fly ash (mixture nos. 3, 6, 9, 12, and 15) was 0.071 percent, with two of the five mixtures exceeding the maximum allowed by the specifications. Thus, the mixtures made with fly ash yielded a higher percentage of increase in length than those with no fly ash.

The average percentage of increase in length for concrete beams made with unapproved sand-gravel aggregates with 0 percent fly ash and no limestone (mixture nos. 16, 21, and 26) was 0.075. (Note: as expected, the percentage of increase is higher for mixtures made with unapproved aggregates than for those made with approved aggregates.) The average percentage of increase for mixtures made with the unapproved sand-gravel aggregates with F–1 fly ash (mixture nos. 17, 22, and 27) was 0.204, and the average percentage of increase for mixtures made with F–2 fly ash (mixture nos. 18, 23, and 28) was 0.171. The concrete made with both ashes clearly exceeds the maximum value allowed by the specifications. In contrast, concrete mixtures made with unapproved sand-gravel aggregates with 30 percent of the aggregate replaced by a limestone sweetener (mixture nos. 19, 20, 24, 25, 29, and 30) yielded an average percentage of increase of 0.030, which is well below the maximum in the specifications. Also, all individual mixtures yielded a percentage of increase in length less than the maximum allowed by the specifications (as shown in Figure 2).

The average modulus of rupture after 365 days for mixtures made with approved aggregates with no fly ash was 4.6 MPa (666 psi), which exceeds the minimum value allowed by the specifications [Note: The specification minimum is 3.8 MPa (550 psi).] However, the two average values for mixtures made with the same aggregates but with 15 percent F–1 and F–2 fly ash were 3.1 and 3.2 MPa (451 and 461 psi), respectively. Also, all mixtures made with fly ash, except for one, failed to meet the minimum specification requirements, as shown in Figure 3.

Mixtures made with unapproved aggregates with no limestone or fly ash had an average modulus of rupture of 3.4 MPa (487 psi) after 365 days. The average modulus of rupture for mixtures involving F–1 and F–2 fly ashes were 1.8 and 2.3 MPa (254 and 337 psi), respectively. Also, all of those mixtures, except one, yielded moduli of rupture that were significantly less than the minimum allowable value. On the other hand, mixtures involving the use of limestone had an average modulus of rupture of 4.8 MPa (708 psi), which represents the highest value for the sets of mixtures evaluated in this study.

DISCUSSION OF RESULTS

The results illustrate that the use of the two type-C fly ashes introduces an increase in concrete expansion. For example, the average percentage of expansion of the mixtures made with approved sand-gravel aggregates increased by more than 85 percent when 15 percent of the portland cement is replaced by the F–1 fly ash. (Note:

TABLE 3 Results of Wetting and Drying Test

Mixture I.D.	Change in Length		Modulus of Rupture		Compressive Strength	
	180 Days (%)	365 days (%)	180 Days (psi)	365 days (psi)	180 Days (psi)	365 days (psi)
1	0.035	0.036	670	720	5870	6560
2	0.038	0.062	632	505	5380	5510
3	0.047	0.067	609	450	5270	5290
4	0.033	0.038	679	582	5960	6620
5	0.038	0.069	560	443	5390	5410
6	0.058	0.058	573	515	5280	5870
7	0.036	0.049	674	626	6160	5440
8	0.040	0.093	605	419	5400	5260
9	0.036	0.080	570	381	5570	5470
10	0.031	0.042	612	680	4700	5930
11	0.042	0.093	566	427	5310	5020
12	0.042	0.096	528	367	5020	5070
13	0.033	0.400	644	720	5920	6890
14	0.031	0.062	593	459	5110	5430
15	0.031	0.055	634	590	5950	6170
16	0.033	0.051	639	532	5350	6170
17	0.069	0.158	562	240	4720	4100
18	0.076	0.196	588	279	5200	4620
19	0.029	0.029	664	679	5140	5560
20	0.029	0.033	643	673	5070	5420
21	0.040	0.116	620	372	5720	5550
22	0.089	0.371	567	154	5280	4040
23	0.062	0.251	580	227	5560	4320
24	0.031	0.031	680	695	5970	6630
25	0.029	0.033	627	702	5600	5860
26	0.033	0.058	650	557	5960	6580
27	0.033	0.082	609	368	5340	5240
28	0.040	0.065	658	506	5850	5630
29	0.020	0.025	719	743	5820	6420
30	0.025	0.031	670	758	5440	6110

the average percentage of increase in length for mixtures with 0 and 15 percent F–1 fly ash was 0.041 and 0.076, respectively.) Also, the use of the two fly ashes in this study resulted in a significant decrease in the modulus of rupture. For example, the average modulus of rupture for the concrete mixtures made with approved aggregates decreased by more than 32 percent when 15 percent of the cement was replaced by the F–1 fly ash. [Note: the two average moduli for mixtures with 0 and 15 percent fly ash were 4.6 and 3.1 MPa (666 and 451 psi), respectively.] The deterioration of concrete quality expressed by the higher percentage of increase in length and the lower modulus of rupture for the mixtures made with the two fly ashes was so significant that all those concrete mixtures, except for the one made with approved aggregate, failed to meet the specifications.

On the basis of those results, it is clear that replacing 15 percent of the portland cement by either of the two type-C fly ashes has a detrimental effect on the durability of the concrete. It has been reported by many investigators that the role played by pozzolans (such as slag, fly ash, and silica fume) in controlling the alkali-aggregate reaction depends on several parameters, including the chemical composition of the pozzolan used (fly ash in this study), the portland cement used, and the dosage of the pozzolan in the mix (*10–13*). In addition, it has been reported (*2*) that there is a pessimum dosage for the replacement of cement by type-C fly ash at which fly ash does not help control the alkali-aggregate reaction. The pessimum dosage can be discussed in the light of earlier work (*5,14*) as the dosage at which a definite alkali content is reached and that this alkali content would produce the maximum expansion in concrete. This expansion, however, would progressively decrease at higher and lower alkali contents (fly ash dosages). In that sense, it is not surprising that the behavior of fly ash concrete changes drastically as a function of fly ash dosage. In fact, it has been shown that a dosage of 15 percent replacement of cement by fly ash causes an increase in concrete expansion, and a dosage of 40 percent results in a significant decrease in expansion (improvement) when both are compared with concrete with no fly ash (*2*). Therefore, it should be emphasized that the results discussed in this study are associated with the parameters involved in this work. It is also recommended that the work presented in this study be extended to evaluate other fly ash replacement dosages. In fact, another study involving a higher percentage of fly ash replacement has been initiated by KDOT.

Clearly, the mixtures made with unapproved sand-gravel aggregates fail to meet the standard specifications as expressed by their relatively high percentage of increase in length or their relatively low moduli of rupture, or both. Yet, a significant improvement in

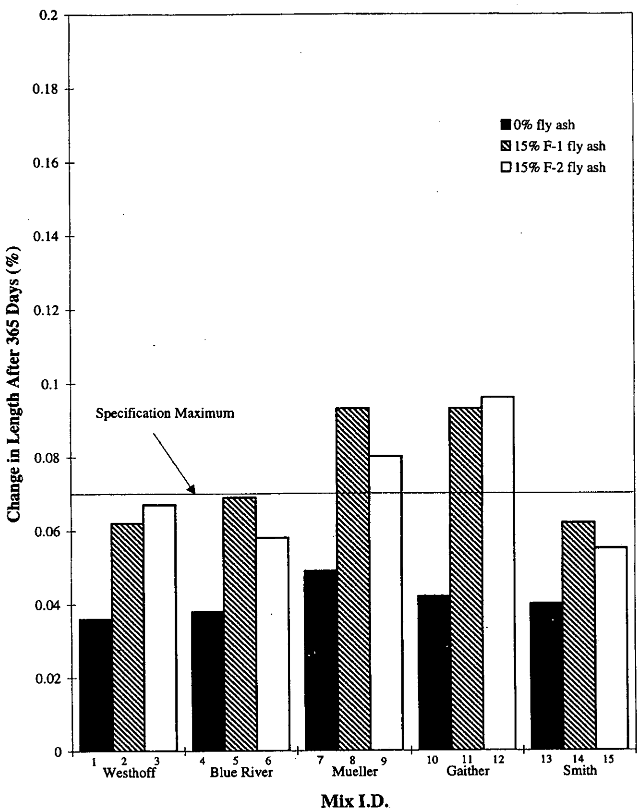

FIGURE 1 Change in length of specimens made with approved aggregates.

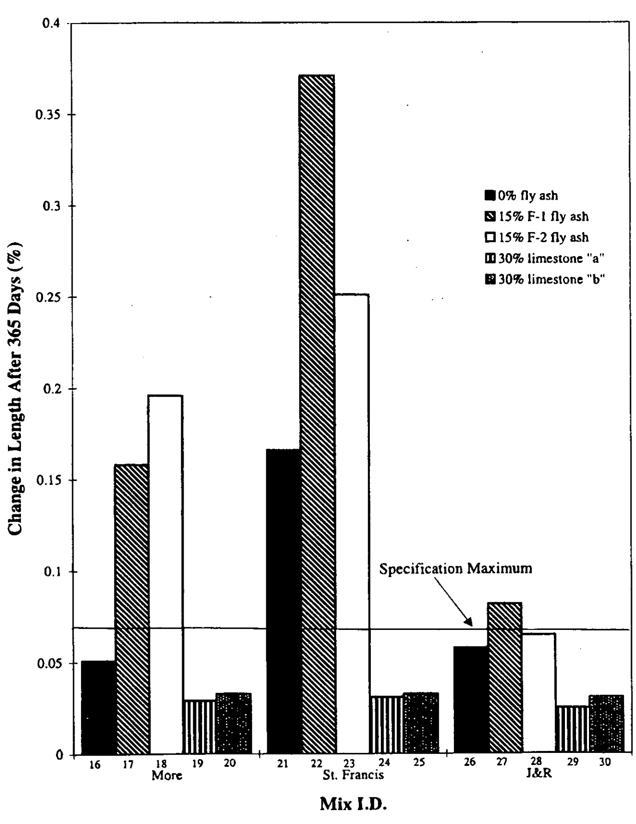

FIGURE 2 Change in length of specimens made with unapproved aggregates.

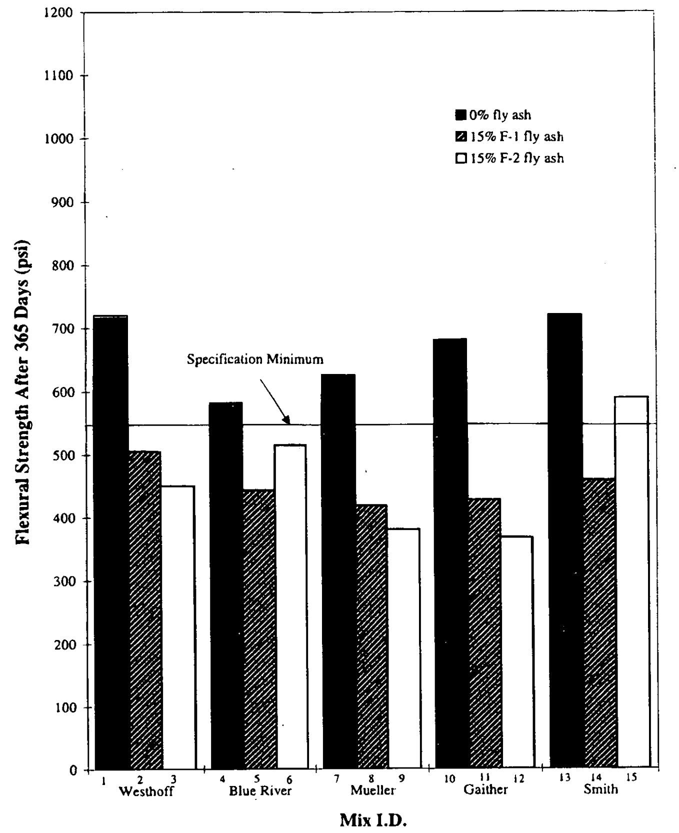

FIGURE 3 Modulus of rupture of specimens made with approved aggregates.

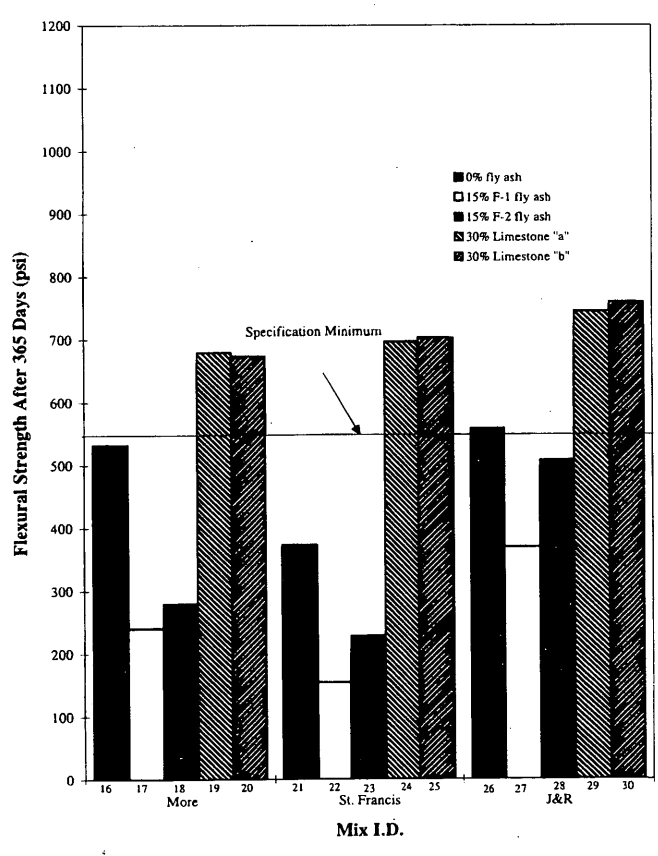

FIGURE 4 Modulus of rupture of specimens made with unapproved aggregates.

concrete performance is observed when 30 percent of the aggregate is replaced with limestone. For example, the average percentage of increase in length for the concrete made with unapproved aggregates with no limestone (sweetener) is 0.075 percent, whereas an average of 0.028 percent is obtained when limestone is used (63 percent decrease). The average modulus of rupture for mixtures made with unapproved aggregate is 3.4 MPa (487 psi) and an average of 4.9 MPa (708 psi) is obtained when limestone is used (a 45 percent increase). All individual mixtures made with unapproved sand-gravel aggregates and limestone sweetener met the requirements of the standard specifications. It is interesting that most of the mixtures made with the three unapproved aggregate types and limestone yielded significantly better results than the mixtures made with approved aggregates. This points out the effectiveness of the use of limestone in minimizing alkali-aggregate reaction problems.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the data obtained and the parameters involved in this study, the following conclusions and recommendations are warranted:

- The use of the three unapproved sand-gravel aggregates resulted in concrete of inferior durability. Therefore, the mix design should be adjusted by selecting other constituent materials or changing the mix proportions before allowing their use.
- The replacement of 15 percent of portland cement by an equal weight of either of the two type-C fly ashes used in this study resulted in concrete of higher expansion and lower modulus of rupture when compared with concrete with no fly ash.
- The use of limestone sweetener is an effective method to minimize the expansion of sand-gravel concrete. Furthermore, the use of limestone sweetener in concrete made with unapproved sand-gravel aggregates, in most cases, yields concrete of superior quality than concrete made with approved aggregate (with no fly ash or limestone). Further research should be carried out to evaluate the optimum dosages, types of limestone, and the economic aspects of its use to enhance the durability of sand-gravel concrete.

REFERENCES

1. Neville, A. M. *Properties of Concrete*. Pitman Publishing Inc., Marshfield, Mass., 1983.
2. Lee, C. Effects of Alkalies in Class C Fly Ash. *Proc., 3rd International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete*, Vol. 1, Norway, 1989, pp. 417–441.
3. Diamond, S. A Review of Alkali-Silica Reaction and Expansion Mechanisms. *Cement and Concrete Research*, Vol. 5, 1975, pp. 329–346.
4. Mindess, S., and F. Young. *Concrete*. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1981.
5. Hadley, D. W. Field and Laboratory Studies on the Reactivity of Sand-Gravel Aggregates. *Journal of the Portland Cement Association Research and Development Laboratories*, Jan. 1968.
6. Kansas Department of Transportation Internal Report. Bureau of Materials and Research, Topeka, Nov. 1985.
7. Kobayashi, S., Y. Hozumi, T. Nakano, T. Yanagida. Study on the Effects of the Quality of Fly Ash for Controlling Alkali-Aggregate Reaction. *Proc., 3rd International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete*, Vol. 1, Norway, 1989, pp. 403–415.
8. Requirements for Sweetened Basic Aggregates. Kansas Department of Transportation Standard Specifications, 1980 ed. Sec. 1100, Subsec. 1102(b)(2), Topeka, 1980.
9. Wetting and Drying Test of Total Mixed Aggregate Concrete. Kansas Department of Transportation Standard Specifications, 1980 ed., Sec. 1100, Subsec. 1116(t), Topeka, 1980.
10. Perry, C., and J. E. Gillott. The Feasibility of Using Silica Fume to Control Concrete Expansion Due to Alkali-Aggregate Reactions. *Durability of Building Materials*, Vol. 3, No. 2, Nov. 1985, pp. 133–146.
11. Alasali, M. M., Alkali-Aggregate Reaction in Concrete: Investigation of Concrete Expansion from Alkali Contributed by Pozzolans or Slag. *Proc., 3rd International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete*, Vol. 1, Norway, 1989, pp. 431–451.
12. Hobbs, D. W. Expansion due to Alkali-Silica Reaction and the Influence of Pulverized fuel Ash. *Proc., 5th International Conference on Alkali-Aggregate Reaction in Concrete, Cape Town, South Africa*, March-April 1981.
13. Kawamura, M., K. Takemoto, and S. Hasaba. Effects of Pozzolanic Additive on Alkali-Silica Reaction in Mortar Made with Two Types of Opaline Reactive Aggregates. *CAJ Review*, 1984, p. 92.
14. Vivian, H.E. Studies in Cement-Aggregate Reaction, Part XIII. The Effect of Added Sodium Hydroxide on the Tensile Strength of Mortar. *Bulletin 256*, Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia, 1950, pp. 48–52.

Publication of this paper sponsored by Committee on Admixtures and Cementitious Materials for Concrete.