Use of Fly Ash as Admixture in an Experimental Pavement in Kansas

W. M. STINGLEY and R. L. PEYTON
Respectively, Concrete Engineer and Assistant State Highway Engineer, State Highway Commission of Kansas

Although fly ash has been widely used as an admixture in mass concrete, its use in highway construction has been more limited. It has been used in Kansas as a replacement for a part of the cement in one experimental paving project which has been under traffic for 14 yr. Five brands of cement with dissimilar characteristics were used in combination with aggregate and fly ash, each from a single source. Although this project has been reported previously, no detailed study of the fly ash concrete sections has been published. Results varied widely with change in cement brand, but the reasons for the changed results are not clearly understood.

Evaluation of the effectiveness of the fly ash in decreasing map-cracking is based on the supposition that reductions in flexural strength accurately reflect increases in map-cracking as here defined.

•IN 1949 the Kansas Highway Commission, in cooperation with the U. S. Bureau of Public Roads and assisted by Kansas State University, constructed an experimental pavement with sections which included concrete containing fly ash. Twelve 488-ft sections were built in which fly ash was used to replace a portion of the cement. The project, near McPherson, has been reported previously (1, 2); this paper deals with the fly ash concrete sections in greater detail.

The test pavement is 22 ft wide, 9 in. thick, and mesh reinforced. Grooved contraction joints formed and finished manually are spaced at 20 ft 4 in. Only expansion joints and construction joints are doweled. The slab was placed on a dense-graded granular subbase, 4 in. thick. The subgrade soils are reasonably uniform throughout the project.

The aggregate chosen for this project was a fine-graded sand-gravel, hardly more than a coarse sand, furnished as a mixed or one-component material. The average fineness modulus was 3.58. It was produced from a deposit on the Republican River which heads in Colorado and flows into the Kaw River in central Kansas. Aggregate from this stream has long been considered to be responsible for severe map-cracking of concrete and its use is seldom permitted for other than below-ground structures such as culverts. Gibson (3) and Scholer and Gibson (5) showed that concrete containing this or similar aggregate could be made less subject to map-cracking by the addition of crushed limestone at the rate of 30 percent or more of the total weight of the aggregate, but a less expensive remedy was sought. The concrete was proportioned by absolute volumes with minimum cement content and maximum water controlled.

Fly ash was obtained from the Chicago area. It may not have complied in all respects with present ASTM requirements, and some tests now required were not made. Results of the tests that were made are as follows: reduction in alkali, 33.8 percent; compressive strength, 1,131 psi; fineness (Blaine), 4,000 sq cm; SiO_2, 45.65 percent; Al_2O_3, 19.89 percent; MgO, 0.94 percent; SO_3, 1.77 percent; and loss on ignition, 2.31 percent.

Five brands of cement with and without substitutions of fly ash or additions of crushed limestone were used in the project. The results changed sharply when one

Paper sponsored by Committee on Chemical Additions and Admixtures for Concrete.

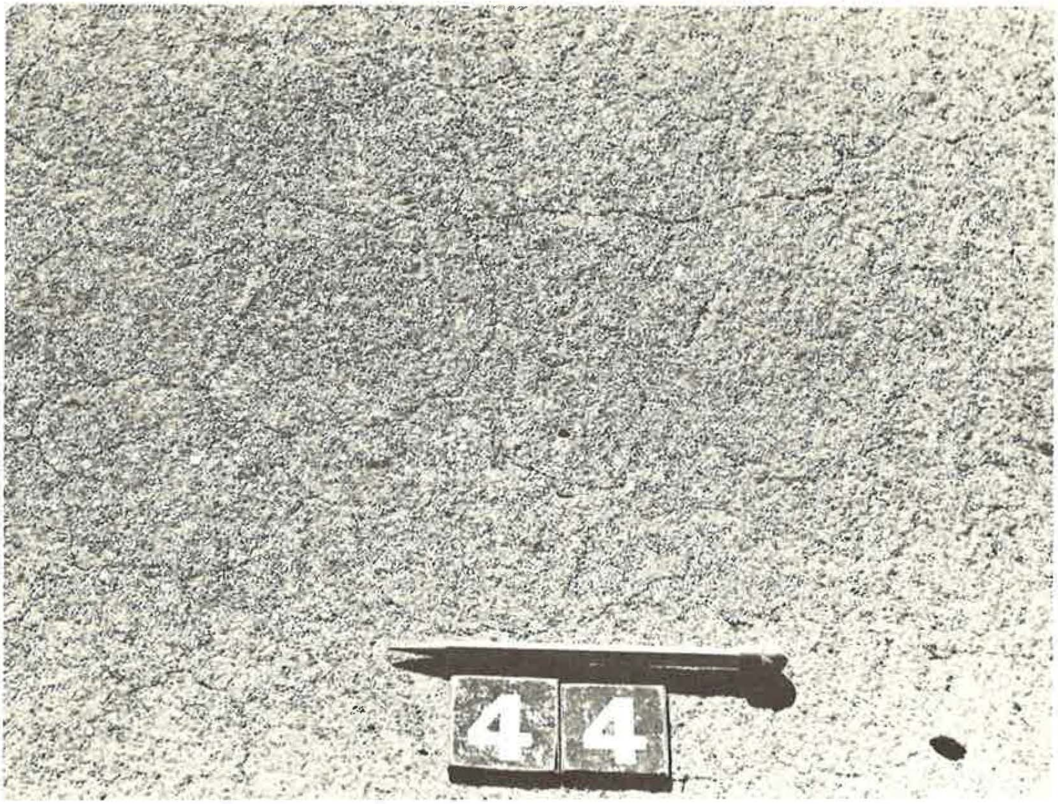

Figure 1. Shallow pattern cracking.

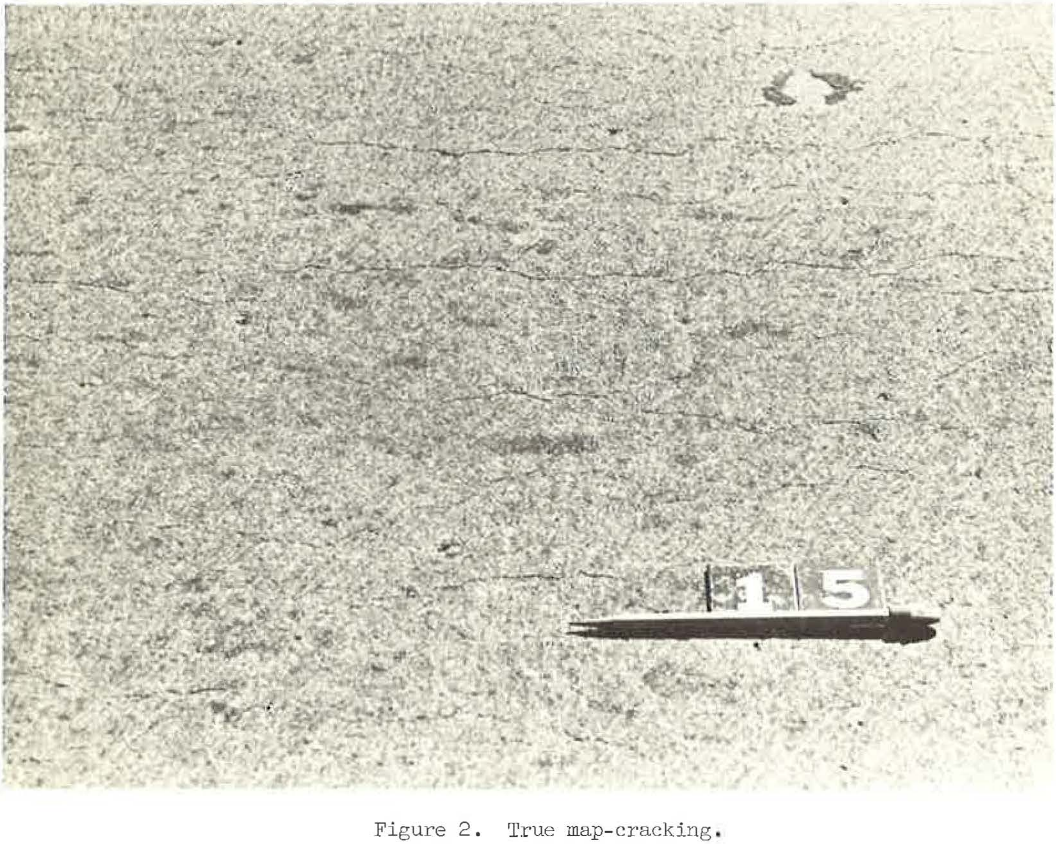

Figure 2. True map-cracking.

brand of cement was substituted for another. Concrete containing each cement was benefited by the fly ash to some extent, but the improvement varied from slight with one cement to marked with others. Test sections were constructed with and without air entrainment.

Flexural strength was obtained by testing 6- by 9- by 48-in. beams made at time of construction from concrete taken from the paving mixer. A 4- by 10-ft slab, 9 in. thick, was cast near the boundary of the right-of-way near each experimental section. These slabs had partial-depth wood dividers at 6-in. centers to separate the slab into test beams having, roughly, an I-beam cross-section. The slabs were cured in an identical manner with the pavement proper and were given no special attention thereafter, other than an occasional shouldering up. Tests were normally made each spring and fall, a total of 40 tests for each section, but a few beams were lost through breakage or were stolen.

Although other pozzolans were used in the test road, only the fly ash concrete sections are considered here, along with appropriate control sections in which only the basic aggregate was used or to which limestone aggregate was added. The comparisons will be based on the premise that increased map-cracking is reflected in decreased flexural strength. Some of the earlier work on sand-gravel concrete deterioration done in the area was reported by the Engineering Experiment Station of Kansas State College and by the Portland Cement Association (4).

A description of map-cracking is taken from that report:

> The deterioration which is occurring in some sand-gravel pavements and structures in Kansas, Nebraska, Iowa and Missouri is evidenced by abnormal expansion, map cracking, and loss of flexural strength.
>
> The first visible evidence of this deterioration is usually a series of connected cracks on the top surface of a pavement, visible to the naked eye after a light application of water as the surface begins to dry. The map cracking usually forms oblong boundaries with an area of eight to twenty square inches inside the cracks. The cracking starts on the exposed surface of a pavement or structure and deepens as the deterioration progresses.
>
> In the advanced stages, the cracks may progress until they reach the bottom side of the pavement. These cracks tend to form lines parallel to the centerline of the pavement. This type of cracking should not be confused with cracks developing on the surface of concrete pavement directly above the wire mesh where the reinforcing has been placed too near the surface. Neither should this cracking be confused with surface checking, shrinkage or cracking due to settlement and loads, nor with cracks caused by unsound coarse aggregate.

Varying amounts of shallow pattern cracking were observed in all test sections but did not appear to indicate declining utility of the pavement. Figure 1 shows this type of cracking. However, true map-cracking, shown in Figure 2, is usually a forerunner of slab disintegration. Measures to reduce or retard it, while necessary, are at some locations so costly as to preclude the use of concrete pavement.

The substitution of fly ash for approximately 25 percent of the weight of cement tended to produce concrete of adequate flexural strength with each cement for each age at which tests were made. Figure 3 is a plot of flexural strength and elapsed time after construction for one of the cements. Each point is an average of two tests made on one beam. It will be noted that there are strength variations from spring to fall and from year to year, and that these variations are large when fly ash is used. The minimum values were still, in most cases, higher than attained by test beams taken from the companion sections of concrete not containing fly ash.

Figures 4 through 8 are similar plots, but the values have been consolidated and smoothed to show trends more clearly. Figures 4, 5, and 6 are flexural strength-time plots for cements C, N, and H, respectively. These cements are of similar chemical composition and respond in a similar manner when a portion is replaced by an equal

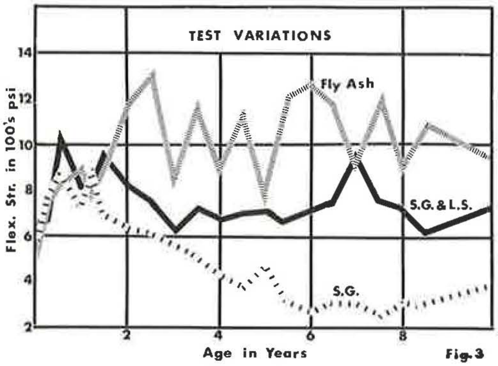

Figure 3.

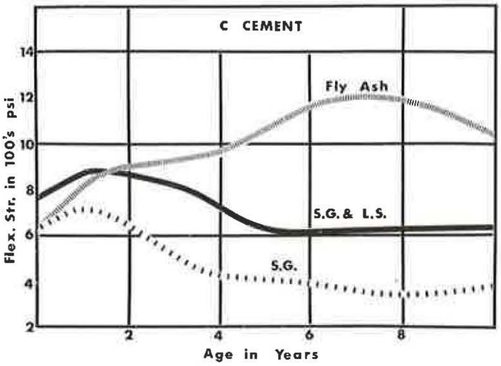

Figure 4.

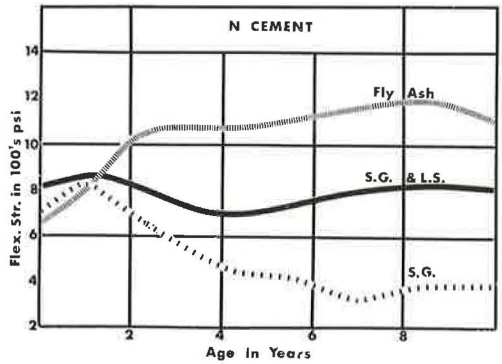

Figure 5.

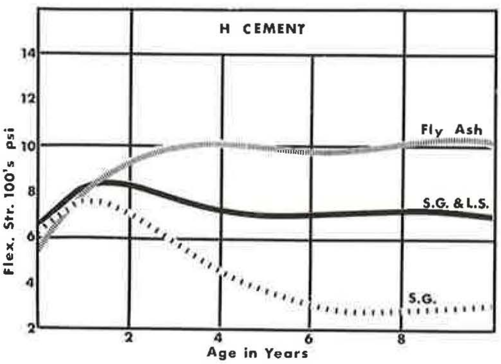

Figure 6.

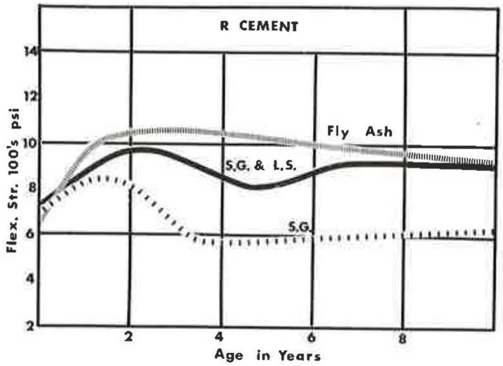

Figure 7.

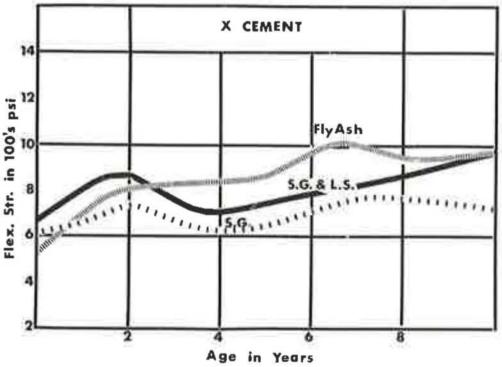

Figure 8.

TABLE 1

CEMENT COMPOSITION

Brand	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Ign. Loss (%)	Na_2O (%)	K_2O (%)	Tot. Alk. (%)	C_3S (%)	C_2S (%)	C_3A (%)	Al: Fe
C	20.8	5.6	2.9	63.5	3.1	2.4	0.9	0.24	0.55	0.60	52.0	20.4	9.9	1.93
N	20.7	6.0	3.4	63.2	3.0	2.0	1.1	0.25	0.45	0.55	49.3	22.2	10.1	1.76
H	22.4	5.8	2.8	64.5	0.6	1.7	1.2	0.29	0.51	0.63	44.5	30.8	10.0	2.07
R	22.4	4.3	2.8	62.2	4.1	1.8	1.7	0.16	0.59	0.55	44.4	30.9	6.3	1.53
X	21.4	5.6	2.9	64.4	1.8	1.7	1.4	0.25	0.37	0.49	51.4	23.0	10.0	1.93

weight of fly ash. Without additions of fly ash or limestone, peak flexural strength is reached during the first year or shortly thereafter, and the strength of each declines at nearly the same rate for the remainder of the 10-yr period. When limestone is added, the peak strength may be somewhat higher and is attained later, and the decline occurs at a slower rate, leveling off at higher values. The concrete containing fly ash does not reach the level of flexural strength attained by the reference concrete during the first few months, but the flexural strength is adequate during this period. During the remainder of the test, the flexural strength of concrete containing fly ash is much higher than that of the reference concrete.

Figure 7 is a plot of flexural strength and time for concrete containing cement R, which is a Type II cement. Here fly ash appears to have been unnecessary. All three classes of concrete produce nearly the same flexural strength, and the pavement sections they represent appear to be of equally good quality. Even here, however, there is some advantage shown for the fly ash concrete sections over those with basic aggregate and those with limestone.

Figure 8 supplies the same information for the concrete containing cement X. Brand X is not a Type II cement but exhibits results similar to those obtained with brand R. The chemical composition of cement X is not unlike that of cements C, N, and H, but there appears to have been little need for the modifying influence of fly ash as far as flexural strength is concerned. The pavement proper, however, represented by these test beams, is showing signs of distress in the basic aggregate section, though at a slower rate and in a somewhat different manner. The crack pattern, although not a fully developed map-cracking, is more extensive and the cracks are deeper and more stained than the surface cracking found in the cement R section without fly ash or limestone. However, the pattern does not approach in severity the cracking observed in the sections containing cements C, N, and H in which no admixture was used. When cement X is combined with fly ash, a shallow surface cracking occurs similar to that found in the limestone aggregate sections.

Table 1 is a tabulation of cement composition. Average values are shown for all tests made on each cement during construction. Variations of individual tests from the averages were small.

No work was done with widely varying amounts of fly ash, the amount substituted being between 24 and 27 percent. It is possible that different proportions of fly ash and cement would perform in a different manner, and some additional economy may be possible.

Control of air entrainment in the fly ash sections was difficult. Much larger than normal amounts of air-entraining admixtures were required, and there are some differences in the manner in which flexural strength of the three classes of concrete under consideration vary with time. The margin of superiority in flexural strength of the air-entrained fly ash concrete sections over the air-entrained limestone and basic aggregate sections is less than with the non-air-entrained classes, but still exists. Although air entrainment tended to smooth the flexural strength curves of the basic aggregate and limestone aggregate concrete sections, it did not when combined with fly ash concrete. This may be due to smaller moisture changes in the air-entrained concrete, but why this does not also apply to the air-entrained fly ash concrete is uncertain. It may be that moisture change is reduced to the same degree, but that fly ash concrete is simply more sensitive to a given amount of change. It may also be true that the amount of air entraining may vary to a greater extent in the fly ash concrete because, as mentioned, control was difficult.

Although air entrainment seemed to increase transverse and longitudinal cracking in most of the other test sections, such an effect was not observed in the sections in which fly ash was used.

CONCLUSIONS

1. The substitution of fly ash for 25 percent of the weight of cement reduced surface cracking and eliminated map-cracking as defined.
2. Flexural strength at early ages of concrete containing fly ash was less than for the reference concrete but was adequate and much higher at all later ages to 10 yr.
3. Cement brand appeared to be an important factor in the degree to which fly ash was beneficial, but some improvement was noted with all the brands used in the test.
4. Air entrainment tended to reduce but not eliminate the advantage shown for flexural strength of the fly ash sections over the reference concrete sections.
5. Many large areas in the central plains, considered poor in concrete aggregate, have abundant supplies of coarse sands comparable to the aggregate used in this project. As mentioned earlier, although referred to as a sand-gravel, it contains little gravel as ordinarily defined. Whereas concrete composed of such aggregate barely qualifies as concrete by definition and is often subject to map-cracking, it has been demonstrated that it is capable of good performance in a pavement slab with a reasonable amount of cement and fly ash.

REFERENCES

1. Peyton, R. L., Stingley, W. M., and Myer, Richard C. Effect of Pozzolans Added to Sand-Gravel Concrete Pavement. Highway Research Board Proc., Vol. 34, pp. 301-319, 1955.
2. Stingley, W. M., McNeal, John D., and Peyton, R. L. The McPherson Test Road: Tenth Year Report. Highway Research Board Proc., Vol. 39, pp. 191-204, 1960.
3. Gibson, W. E. Effect of Various Aggregates upon the Cement-Aggregate Reaction. ACI Journal, pp. 44-51, June 1948.
4. A Study of Special Concrete Problems in Kansas, Nebraska, Iowa and Western Missouri. Engineering Experiment Station, Kansas State College and Portland Cement Assoc., May 1946.
5. Scholer, C. H., and Gibson, W. E. Effect of Various Coarse Aggregates upon the Cement-Aggregate Reaction. Proc. Amer. Conc. Inst., Vol. 44, pp. 1009-1032, June 1948.