Overview of the Use of Fly Ash Concrete in Highway Construction

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An overview of opportunities and concerns on the use of fly ash as a pozzolan in hydraulic cement concrete in constructing highways and other transportation facilities is presented. It is derived primarily from more detailed information given in *NCHRP Synthesis of Highway Practice 127.* Some of the early concerns related to the loss of entrained air in fly ash concrete, shipment-to-shipment uniformity of fly ash, and more careful selection of by-products marketed as pozzolans. Significant differences between the by-products from burning bituminous coal and subbituminous coal have been identified, and more fundamental information is being developed. The need to use a more rational method of proportioning ingredients for concretes containing fly ash based on performance characteristics is discussed. A more rational approach can provide opportunities for more efficient utilization of fly ash as a pozzolan in hydraulic cement concrete.

Probably the greatest drawback to full utilization of fly ash concrete in highway construction is a perception that substituting fly ash for part of the portland cement constitutes the addition of an adulterant to the product. The idea that 25 to 30 percent of a plentiful, inexpensive by-product can replace a more expensive, carefully manufactured material with the resulting end product having superior performance characteristics contradicts a widely held concept that "more expensive is better." Yet, this is basically the situation with respect to use of fly ash as a pozzolan in concrete. However, the use of fly ash in concrete for highways or other transportation facilities has both advantages and disadvantages. This paper reviews some of these and recent developments to provide a perspective on the optimum utilization of fly ash concrete in the construction of transportation facilities.

BACKGROUND

Renewed interest in the overall use of fly ash in concrete grew from efforts to increase the utilization of the ash from burning pulverized coal (*1*). In the United States, this renewed interest was triggered by passage of the Resources Conservation and Recovery Act (RCRA) in 1976. Worldwide interest has also been generated by the energy and environmental concerns of other countries.

The entire problem relates to potential uses for all of the coal ash. This is illustrated in Figure 1 using the information reported by Golden (*2*). He stated that the amount of such ash generated annually in the United States is 71 million tons, with expectations of substantial increases in the future. Approximately 57 million tons of this ash is fly ash, of which only about 15 million tons is used in any form, and only a small percentage of this is pozzolan usage in hydraulic cement concrete. Evidently, using fly ash as a pozzolan in concrete is only a small part of the total concern of power plants to develop suitable uses for their by-product, yet full development of its potential could have a significant impact on highway concrete technology.

As a part of the implementation of RCRA, the Environmental Protection Agency issued guidelines for procuring concrete. These guidelines prohibit specifications that exclude the use of fly ash in materials used in federal construction projects unless a technical reason exists for such exclusions. This applies to all federal-aid highway construction.

Considerable efforts have been made by the Federal Highway Administration, the Transportation Research Board, the American Concrete Institute, the American Concrete Coal Ash Association, the Electric Power Research Institute (EPRI), and fly ash marketers to provide information on how best to utilize fly ash in day-to-day operations.

NCHRP Synthesis of Highway Practice 127: Use of Fly Ash in Concrete (*1*) reviews the history of the use of fly ash concrete in highway construction and summarizes potential advantages of using fly ash as well as the potential problems facing state transportation agencies in its use. That report summarized the state of the art at the beginning of 1986. Since its publication, the second conference on the use of fly ash, silica fume, slag, and natural pozzolans in concrete and the eighth international ash utilization symposium have been held (*3,4*). Although the large proportion of these conference papers dealt with matters other than the use of fly ash in concrete, those papers that were concerned with its utilization in concretes confirmed trends and concerns reported in Synthesis 127. The purpose of this paper is to briefly review some of the major concerns reported in Synthesis 127 and to evaluate recent developments affecting such concerns.

CONCERNS RELATING TO HIGHWAY APPLICATIONS

Potential for Air Entrainment Problems

In early trial uses of fly ash concrete, the need for an additional amount of air-entraining agent to incorporate the proper amount of air into the concrete was not recognized. Improper air entrainment resulted in early deterioration from freezing and thawing and economic losses resulting from having to replace portions of the concrete (*1*). Loss of entrained air after initial tests for air entrainment at mixing plants and job sites has

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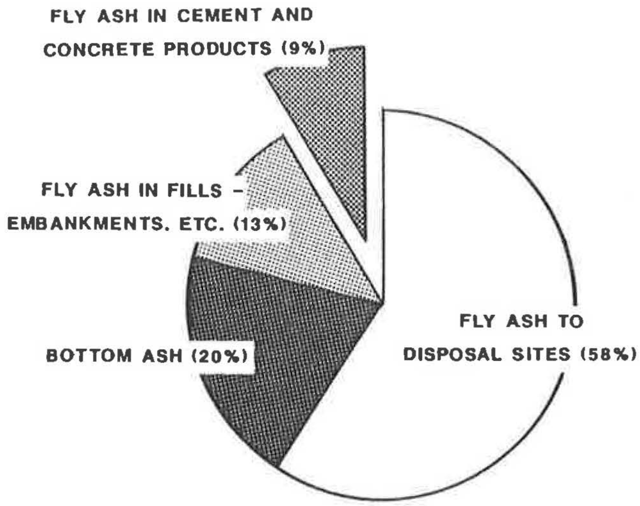

FIGURE 1 Estimate of coal ash in the United States in 1985 [Total Volume = 71 Million Tons (*2*)].

also been a problem (*5*). The magnitude of this problem apparently has been reduced by recent trends toward the lower carbon content (loss on ignition) of fly ash that has resulted from more efficient burning and the elimination of "upset load" projects from the fly ash to be sold as a pozzolan. Development of an air-entraining agent that is less affected by the carbon in the fly ash has also been reported (*6*). However, careful testing is still required to determine the air content of the concrete when placed until the pattern shown by the materials being used on a job has been established.

Uncertainties Relating to Uniformity of Fly Ash Supply

Uniformity of fly ash from the same source was a concern for many of the early users. Complete testing of the pertinent characteristics of each fly ash shipment was (and is) impractical, and the effect of variations in fly ash was not fully known. This problem has been lessened by the development of a fly ash marketing industry that is developing standards of acceptability and a willingness to certify uniformity within reasonable standards [see Appendix C, *NCHRP Synthesis of Highway Practice 127* (*1*)]. Such standards now generally provide adequate shipment-to-shipment uniformity of the product so that its effect on concrete characteristics does not vary significantly. Most organizations utilizing a certification acceptance procedure after complete initial testing have had satisfactory results. Generally, fineness [amount retained on a No. 325 (45-μm) sieve] and the loss on ignition are spot-checked during the construction of a project.

Cold and Hot Temperature Placements

In recognition of the known slowdown of pozzolanic reactions at low temperatures, state highway agencies customarily establish a cutoff date after which fly ash concrete is not placed in pavements or structures. However, in recent studies in West Virginia, the initiation of freeze-thaw tests on specimens 1 to 3 days old did not indicate poor performance (*7*). The fly ash concretes were at least as good as the control.

Although the extent to which cutoff dates could be eliminated or extended in other geographical areas cannot be determined from this result, reevaluation of cold weather limitations is indicated. At the other end of the scale, some studies at the Virginia Transportation Research Council have shown a large increase in the resistance of fly ash concrete to chloride-ion penetration when specimens were cured at 100°F rather than the standard 73°F (*8*). Although not yet confirmed by field tests, the implication is that use of fly ash in hot weather would avoid detrimental results known to occur with ordinary portland cement concrete when placed and cured at elevated temperatures.

Differences in Class F and Class C Fly Ashes

Before 1970, most of the literature on fly ash was concerned with materials designated as Class F in accordance with ASTM Specification C 618. This material is a by-product of the burning of bituminous or anthracite coal that acts as a pozzolan but has no self-hardening properties. Substantial use of subbituminous coal began in the United States in the 1970s. The fly ash from burning these coals often has very high lime (CaO) content and exhibits self-hardening characteristics. These are designated as Class C; however, a number of them would also meet the Class F requirements.

Class F and Class C fly ash have been shown to vary considerably in their effect when used in concretes. Many of the principles established for using the by-products from burning bituminous coal are not completely valid for by-products from burning subbituminous coals. This has confused the classification picture, and although a number of suggestions have been made, no agreement has been reached concerning a classification system for fly ash that will better indicate its performance in concrete.

The recently completed comprehensive study sponsored by EPRI provides excellent data on characteristics of the fly ash now being produced in various regions of the United States (*9*). However, the predictive models for compressive strength of fly ash concrete developed in this study are not useful as a basis for a system that could classify fly ash by purpose.

Any evaluation of the efficiency of fly ash in developing strength in concrete must account for both the characteristics of the particular fly ash involved and the characteristics of the particular cement used. The same fly ash often reacts differently with different cements.

ECONOMIC LOSS OR GAIN

Cost savings resulting from the use of fly ash concrete are usually emphasized because a portion of the portland cement is replaced by fly ash, which on a ton-for-ton basis, costs less. However, other factors enter into the total cost of fly ash concrete.

1. Relative transportation costs. The distance fly ash must be hauled has a large effect on its cost and thus the cost of producing fly ash concrete.
2. Normally, a mass of fly ash greater than the mass of the cement replaced is added to the concrete mix.
3. Additional air-entraining agents are required when fly ash is used.
4. Additional production costs for the concrete producer result from the necessity of maintaining a separate storage facility for fly ash and an apparatus to add it to the concrete mixes.
5. Additional control and acceptance testing is required when fly ash is used.

Thus, depending on the circumstances, the bid price of fly ash concrete may be equal to or even greater than the bid price of portland cement concrete without fly ash.

DESIGN OF FLY ASH CONCRETE FOR OPTIMUM CHARACTERISTICS

Although many researchers have indicated a need for a rational design of concrete mixtures containing fly ash to ensure optimum concrete characteristics and cost-effectiveness, most state highway agencies establish maximum amounts of cement that can be replaced with fly ash in highway applications. It is also customary to require that the mass of fly ash added be greater than the mass of cement removed. In judging the suitability of the fly ash, the procedure most often used is to compare the strength difference at early ages between control concretes containing the usually specified minimum mass of cement with the fly ash concrete at the same water-to-cementitious-material ratio. This procedure overlooks two important facts. The first is that there are a number of ways in which strength of the fly ash concrete at early ages (1 to 27 days) can be increased; for example, water-to-cementitious ratios can be water-reducing admixtures, or other changes could be made in mix proportions. Thus, establishing the levels of performance needed in concretes at specific ages without regard to the amount of cement being replaced is necessary. This approach will probably demonstrate that present levels of fly ash usage are well below optimum and that restrictions on the fly ash-cement ratio for some applications prevent the use of optimum amounts of materials leading to maximum benefits.

The second fact overlooked is that different types and brands of cements may react differently with the same fly ash. Thus, the optimum conditions for different fly ash–cement combinations may be different. Despite the fact that this principle is well established, there appears to be a reluctance on the part of some state highway agencies to make trial mixtures with the actual fly ash–cement combinations that will be used in a project. A potential solution to this problem that is currently receiving considerable attention is the establishment of performance specifications. Such specifications would permit a concrete supplier much leeway in the materials used as long as performance requirements are met. It is necessary to consider the durability of the concrete as well as the strength. A strong concrete under laboratory test conditions may not perform satisfactorily if it is subjected to damage from chlorides and sulfates or damage from freezing and thawing.

DEVELOPING TECHNOLOGY

The increased interest in fly ash usage has led to more studies and improved evaluation of the potential benefits of fly ash in concrete. In particular, the special characteristics of self-hardening fly ash are being evaluated. In general, these materials contribute to high strengths but may not always provide the increased sulfate resistance that is expected from Class F materials (*10,11*).

Studies on the chemical reactions taking place during hydration and within the liquid solutions of the hardened concrete are being performed, and their relation to physical properties is being determined. Determinations are also being made about the effects of combining fly ash and slag or fly ash and silica fume and how these combinations could provide cost-effective solutions to problems. Early results of a Virginia Transportation Research Council study with combinations of fly ash and small amounts of silica fume indicate that very high resistance to chloride-ion penetration can be obtained at early ages, thus counteracting adverse effects from the addition of fly ash alone.

Although it is not possible to predict how this developing technology will ultimately affect the use of fly ash concrete in highway construction, better knowledge of fundamental reactions and interactions of different cements with different fly ashes should permit optimization of mixture proportions for designated performance requirements that will also provide optimum environmental and economic benefits.

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