PORTLAND CEMENT ASSOCIATION

RESEARCH &
DEVELOPMENT
INFORMATION

5420 Old Orchard Road
Skokie, Illinois 60077-1083
VOICE 847.966.6200 FAX 847.966.8389
INTERNET www.portcement.org

PCA R&D Serial No. 2604

Use of Fly Ash in Concrete: Normal and High Volume Ranges

by Medgar L. Marceau, John Gajda, and Martha VanGeem

.

USE OF FLY ASH IN CONCRETE: NORMAL AND HIGH VOLUME RANGES

by Medgar L. Marceau, John Gajda, and Martha VanGeem*

INTRODUCTION

The use of fly ash in concrete can reduce the environmental impact of concrete and can improve certain properties of concrete. Cement is a manufactured product and its manufacturing process is energy intensive. Fly ash is a by-product of burning coal and it is usually disposed of in landfills. When fly ash is used to replace some of the cement in concrete, less total energy is used to make concrete† and less material is put into landfills.

CONCRETE

Concrete is a composite material made of aggregate (sand and gravel) and a binder.[1] The most common binder is portland cement. Supplementary cementitious material such as fly ash, silica fume, and blast furnace slag are increasingly being used to replace a portion of the binder.[2]

By volume, a concrete mix typically consists of 10 to 15 percent binder (cementitious material), 60 to 75 percent aggregate, and 15 to 20 percent water. Air voids that are intentionally entrapped in many concrete mixes may also take up another 5 to 8 percent. The constituents and proportions of concrete mixes are varied to achieve specific requirements of individual projects.

PORTLAND CEMENT

Portland cement is manufactured to meet strict product standards.[3] To manufacture cement, raw materials such as limestone (a source of calcium) as well as clay and sand (sources of silica, alumina, and iron) are mined and transported to the manufacturing facility. The raw materials are ground together and then heated in a rotating kiln at 1,500°C (2,700°F). At this temperature, the raw materials partially melt and recombine chemically to produce an intermediate material called *clinker*. Once cooled, the clinker is ground with a little gypsum into a very fine powder. This very fine gray powder is portland cement.

An average of 4.8 gigajoules‡ of fuel energy is required to produce enough clinker to make one metric ton of portland cement (this is equivalent to 4.1 million Btu per ton of cement).[4] The energy comes from burning coal, petroleum coke, natural gas, and/or post consumer wastes. This generates waste gases such as carbon dioxide (CO_2). Furthermore, one of the main chemical reactions in the kiln is the calcination of limestone—reducing limestone from $CaCO_3$ to CaO plus CO_2. So in total, for every metric ton of cement produced, about 900 kilograms of CO_2 are released to the atmosphere (this is equivalent to 1,800 pounds of CO_2 per ton of cement).

* Project Assistant, Senior Engineer, and Principal Engineer, respectively at Construction Technology Laboratories, Inc. (CTL), 5420 Old Orchard Road, Skokie, IL 60077, Phone: 847-965-7500, www.CTLgroup.com

† Total energy associated with concrete, including manufacturing and transporting constituents of concrete.

‡ 1 gigajoule is equivalent to the heat produced from burning approximately 40 kilograms of coal, and 1 million Btu is equivalent to the heat produced from burning approximately 90 pounds of coal.

FLY ASH AND ITS USE

Fly ash is a by-product of burning coal to generate electricity. It is a fine powder that is filtered out from emissions that otherwise would have gone out the exhaust stack and into the atmosphere.

Fly ash is generally available throughout the United States; however, it is more widely available east of the Mississippi River. About 60 million metric tons (66 million tons) of fly ash were generated in 1999, of which, approximately 67% was landfilled.[5]

Fly ash varies in composition and carbon content. Regulations from the United States Environmental Protection Agency to reduce air pollutants (such as nitrogen oxides and sulfur dioxide) have resulted in an increase in the unburned carbon content of fly ash. With the continued implementation of these regulations, carbon contents of many fly ashes have increased dramatically and some fly ashes may become contaminated with ammonia.[6]

Fly ash can be used directly in concrete as an additive in a blended cement or as a raw material in cement manufacture. In all cases, the fly ash must have specific chemical and physical properties.[7]

When fly ash is used in concrete, it commonly replaces a portion of the portland cement. The two types of fly ash used in concrete are Class F and Class C. Class F fly ash is a by-product of burning bituminous coal, which is generally found in the eastern portion of the United States. Class F fly ash is high in iron, silica, and alumina, but low in calcium. It is a glassy material that needs to be activated by either cement or lime.

Class C fly ash is a by-product of burning sub-bituminous coal and lignite. It is higher in calcium content than Class F fly ash. Concrete with Class C fly ash generally develops strength much faster than concrete with Class F fly ash. For this reason, many ready-mix concrete suppliers prefer Class C fly ash to Class F fly ash.

Fly ash for use in concrete that will be subject to freezing and thawing should have low levels of unburned carbon in order to achieve an adequate air content. Specifications typically limit the unburned carbon content to a maximum of 6%; however, market forces currently limit this to less than 1%.

Fly ash can also be interground or blended with portland cement to make a *blended cement*.[8, 9] According to ASTM C595, the maximum fly ash content of a blended cement is 40%.[8] If additional fly ash or other supplementary cementitious materials are to be added to concrete containing blended cements, pre-testing should be performed to ensure that the engineering properties and durability of the concrete is not compromised. However, most blended cements today are designed to be used with additional fly ash added at the concrete plant.

Fly ash that is not suitable for direct use in concrete is sometimes used as a raw material for portland cement manufacture.[6] When used in this regard, the fly ash is allowed to have a high unburned carbon content, but it must be chemically compatible with the needs of the cement plant and it must be economically viable. The most important factor determining economic viability is the cost of transporting the fly ash from a coal power plant to the cement manufacturing plant.

FLY ASH IN CONCRETE

Fly ash is commonly used as a partial replacement for portland cement—or as an addition to portland cement—because it can enhance the placement, engineering properties, and durability of concrete.

Typical amounts of fly ash in concrete range from 15 to 25% by weight of the total cementitious materials, that is, the total of cement, fly ash, and other supplementary cementitious materials. Higher amounts of fly ash have been successfully used for specific applications on limited projects.

The amount of fly ash should be tailored to the specific constraints and requirements of individual applications. Some agencies limit the maximum fly ash content to 15% for all concrete.[10] For concrete exposed to deicing chemicals, the maximum fly ash content is limited to 25%§. [11] Special provisions for a particular project may increase the fly ash content of concrete for specific applications and needs.

Concrete has been successfully placed with up to 50% fly ash.[12] In some rare cases, concrete has been successfully placed with up to 80% fly ash. These mixes may use specific fly ashes that may not be readily available. Strength development is generally slower so construction schedules must accommodate the extra time required before forms and shoring are removed. Deicer scaling resistance has been noted to be poor.[13] Special precautions may also be needed in cold weather to ensure adequate strength development. Because this type of concrete is typically outside current specifications, the amount of pretesting that must be done to ensure durable concrete and satisfy building codes makes this concrete more expensive.[14] Caution is recommended for applications using concrete with high fly ash concentrations.

Incorporating fly ash in concrete can enhance the properties of concrete. Reported improvements to the properties of fresh concrete during placement include enhanced workability, reduced bleed water, and reduced slump loss. For hardened concrete fly ash can also increase the long-term strength, decrease the permeability, increase the durability, reduce the potential for sulfate attack, reduce the heat of hydration, reduce the potential for alkali-silica reactivity, and reduce shrinkage cracking. These positive aspects of incorporating fly ash in concrete are generalized; adding the wrong type or amount of fly ash can be detrimental to concrete.

Since fly ash properties vary, the project contractor and the concrete producer and should exercise sufficient judgment, testing, and control procedures to ensure good concrete performance.

SUMMARY

The use of fly ash in concrete can reduce the environmental impact of concrete and can actually improve the quality of the concrete. Fly ash is commonly used in concrete in proportions of 15 to 25% of the cementitious materials. It is used for economic reasons and to enhance the properties of concrete. Fly ash must conform to certain chemical and physical standards to be suitable for use in concrete. Since fly ash properties vary, the project contractor and the concrete producer and should exercise sufficient judgment, testing, and control procedures to ensure good concrete

§ This is the general limit. The fly ash content can be increased if resistance to deicer chemicals is demonstrated in laboratory or field tests. However, a 25% content may be too high for some fly ashes, aggravating scaling. In any case, the maximum water to cementitious materials ratio should not exceed 0.45.

performance. Due to EPA pollution control regulations, less fly ash may be available in the future that is suitable for use in concrete.

If it is intended to encourage the use of fly ash in a particular project, the project specifications should carefully explain the concrete quality required and the limits on amounts of fly ash. Limits are placed based on experience and concrete performance in the field or laboratory. Contact your local ready-mix concrete supplier to determine what fly ash is available and to verify its performance in quality concrete.

ACKNOWLEDGEMENTS

The research reported in this paper was conducted by Construction Technology Laboratories, Inc, with the sponsorship of the Portland Cement Association (PCA R&D Serial No. 2604). The contents of this paper reflect the views of the authors, who are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the views of the Portland Cement Association.

REFERENCES

1. *Design and Control of Concrete Mixtures – 14th Edition*, Portland Cement Association, Skokie, IL, 2002.

2. *Survey of Mineral Admixtures and Blended Cements in Ready Mixed Concrete*, Portland Cement Association, Skokie, IL, 2000.

3. ASTM C150-00, "Standard Specification for Portland Cement," American Society for Testing and Materials (ASTM), West Conshohocken, PA, 2001.

4. Nisbet, Michael A., VanGeem, Martha G., Gajda, John, and Marceau, Medgar L., "Environmental Life Cycle Inventory of Portland Cement Concrete," PCA R&D No. 2137, Portland Cement Association, Skokie, IL, June 2000.

5. "1999 Coal Combustion Product (CCP) Production and Use (Short Tons)," American Coal Ash Association, 6940 South Kings Highway, Suite 207, Alexandria, VA.

6. CTL's ongoing fly ash in cement manufacture projects for the Illinois Clean Coal Institute, ICCI Project Nos. 01-1/3.1B-1, 00-1/3.1A-1, 99-1/2.1A-1, and 98-1/3.1C-2, Illinois Clean Coal Institute, Carterville, IL, 1998-2002.

7. ASTM C 618-00, "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete," American Society for Testing and Materials (ASTM), West Conshohocken, PA, 2001.

8. ASTM C 595-00, "Standard Specification for Blended Hydraulic Cements," American Society for Testing and Materials (ASTM), West Conshohocken, PA, 2001.

9. ASTM C1157-00, "Standard Performance Specification for Blended Hydraulic Cement," American Society for Testing and Materials (ASTM), West Conshohocken, PA, 2001.

10. *Standard Specifications – State of California Business, Transportation, and Housing Agency*, California Department of Transportation, Sacramento, CA 1999.

11. ACI 318-99, “Building Code Requirements for Structural Concrete,” American Concrete Institute (ACI), Farmington Hills, MI, 2000.

12. Proctor, D., “How Much Fly Ash,” *Concrete Construction*, Vol. 46, No. 12, December 2001, pp 59-63.

13. Malhotra, V. M., and Ramezanianpour, A. A., *Fly ash in Concrete – 2nd Edition,* Publication No. MSL 94-45(IR), CANMET, Ottawa, Ontario, Canada, 1994.

14. Personal communication between Al Kaufman of RMC Pacific Materials and John Gajda of CTL, September 20, 2001.