Center for
By-Products
Utilization

BEHAVIOR OF HIGH-PERFORMANCE CONCRETE IN SUMMER WEATHER

By Tarun R. Naik and Rudolph N. Kraus

Report No. CBU-1999-06
REP-363
March 1999

Presented and Preprint published at the ACI Spring Convention Technical Session on High Performance Concrete Containing Fly Ash and Natural Pozzolans, March 14-19, 1999, Chicago, IL.

Department of Civil Engineering and Mechanics
College of Engineering and Applied Science
THE UNIVERSITY OF WISCONSIN-MILWAUKEE

BEHAVIOR OF HIGH-PERFORMANCE CONCRETE IN SUMMER WEATHER

by

Tarun R. Naik and Rudolph N. Kraus*

ABSTRACT

This research was carried out to investigate the effects of temperature on the strength and durability of high-performance concrete (HPC) systems. Two series of concrete mixtures were evaluated. Series I were selected from the existing mixtures presently used in a typical construction. The first concrete mixture of Series I (Mix 12.5P) was proportioned to produce an average compressive strength of 12,500 psi at the age of 28 days. It contained 20% Class C fly ash and 5% silica fume by the weight of total cementitious materials The second mixture of Series I (Mix 15P) was proportioned to attain an average compressive strength of 15,000 at the age of 28 days. It contained 14% silica fume and 9% Class C fly ash. Series II concrete mixtures were economically optimized mixtures based on previous investigations conducted at the UWM Center for By-Products Utilization. The first concrete mixture of Series II (Mix 12.5E) contained a blend of 30% Class C and 20% Class F fly ash (percentages on the basis of total cementitious materials). The second mixture of Series II (Mix 15E) contained a blend of 25% Class C fly ash, 17% Class F fly ash, and 6% silica fume. Series II concrete mixtures produced an equivalent compressive strength and durability as Series 1.

Two types of curing, the standard moisture curing and the Variable Temperature Curing Environment (VTCE), were used for all concrete test specimens. The VTCE was designed to simulate the temperature variation that occurs in summer in many parts in USA. Concrete: specimens were subjected to the temperature of 75 +/- 5 deg. F for 12 hours each day, and 110 +/- 5 deg. F for the remaining 12 hours each day They were protected from losing moisture during the curing.

For each mixture, the compressive strength, resistance to chloride penetration, air and water permeability, resistance to sulfate attack, and alkali-silica reaction were evaluated. Test results indicate that the concrete specimens subjected to VTCE curing had slightly higher strength than those subjected to standard curing up to the 28-day age. At the ages of 182-day and beyond a strength reduction was observed for all concrete mixtures cured in VTCE. All HPC mixtures with the designation “E” were considerably less costly due the use of blended fly ash and reduced amount of silica fume.

---

* Director and Assistant Director, respectively, UWM Center for By-Products Utilization, Civil Engineering and Mechanics Department, College of Engineering and Applied Science, the University of Wisconsin-Milwaukee, P0 Box 784, Milwaukee, WI 532O1 Phone: (414) 229-41O5; FAX: (414) 229-6958

INTRODUCTION

Conventionally, researchers have used strength properties of concrete as criteria for evaluating its performance. A concrete having high strength does not necessarily imply that it will have long-service life. Thus, it is now well recognized that concrete performance should be determined in terms of both strength and durability under anticipated environmental conditions. Various definitions exist for high-performance concrete (HPC). The ACI Committee on High-Performance Concrete (1) defines HPC as, "Concrete meeting special performance requirements which cannot always be achieved routinely using any conventional constituents and normal mixing, placing, and curing practices. These requirements may involve enhancements of the following: ease of placement without segregation, long-term mechanical properties, early-age strength, toughness, volume stability, and life in severe environments." Thus, HPC should have both high-strength and high-durability properties pertinent to an application.

In the USA and elsewhere, concrete structures are deteriorating at a faster rate than expected. This is primarily due to the fact that structures are subjected to higher loads than intended and/or subjected to an aggressive chemical environment. Moreover, concretes used in those structures were generally proportioned based on water to cementitious materials ratio alone to meet specified strength requirements. Many of them did not contain either mineral admixtures or high-range water-reducing admixtures that are needed in production of durable concrete. HPC appears to be an excellent candidate for use in many structures such as tunnels, ocean piers, off shore platforms, pipes, structures for confinements of solids and liquid wastes containing hazardous materials, etc. whose designs require to have both high-strength and high-durability.

At high temperature, concrete microstructure is negatively affected. Poor microstructure is associated with generation of undesirable configuration of C-S-H crystals, reduced degree of hydration, and increased cracking at high temperature curing. Generally, the C-S-H crystals grow long and thin/narrow and occupy less space in the matrix at high temperatures, resulting in decreased density of the microstructure. The reduced degree of hydration at elevated temperature occurs as a result of rapid water loss due to evaporation, leaving unhydrated cement particles within the concrete matrix. The increased microcracking is the result of high thermal stresses that are generated due to the induced temperature gradients. Thus, homogeneity and density of concrete microstructure are adversely affected due to the aforementioned factors. Consequently, long-term strength and durability-related properties are negatively affected for concrete subjected to curing at high temperatures.

HPC is a relatively new class of advanced cement-based material. There is a lack of data on design and performance of HPC, especially under controlled hot weather conditions. Therefore, this work was directed toward investigating the effects of curing temperature on behavior of HPC.

PREVIOUS STUDIES

It is now well established that a very dense homogeneous concrete microstructure, especially in the interface region between hydrated paste and aggregate, is required in order to produce HPC (2-15). This is generally achieved through the use of low water to cementitious materials ratio (0.20-0.30) with the help of superplasticizers that can produce slumps ranging from 75 to 125 mm (3 to 5 in.). Additional densification and homogeneity of the interfacial region are achieved through the inclusion of mineral admixtures such as fly ash, silica fume, etc. These mineral admixtures are known to improve the concrete microstructure, due to both pore as well as grain refinements. In general, studies reported in recent publications (8, 9, 12, 14, 15), have indicated that concretes made with good quality aggregates and other constituent materials at low water to cementitious materials ratio (around 0.25 ± 0.05) exhibit high strength and low permeability. The permeability dictates the rate at which aggressive agents such CO_2 gas and/or liquids carrying deleterious substances (deicers, acid rain, sea water, sulfate rich water, etc.), penetrate into concrete, causing various types of expansive reactions. The stresses generated due to such reactions often cause damage to concrete. Therefore, the measure of permeability is directly related to the durability of concrete to improve its quality or performance.

High-strength concrete (HSC) up to 55 MPa can be produced using locally available materials and conventional concrete production technology at low water to cementitious materials ratio (2, 5, 6, 9, 10, 11). The required workability of such mixtures is obtained using high-range water-reducing admixtures, generally called superplazticizers. For HPC above 70 MPa (10,000 psi), special constituent materials, mixture proportioning, production technologies, etc. are needed in order to ensure long-service life. This may involve the use of special aggregates (small size, closely graded, high-strength), low heat of hydration cement, special admixtures, and special care in mixing, handling, and placing. Mehta and Aitcin (6) reported that for very high strength levels, particularly above 100 MPa, aggregate size should not exceed 10 to 12 mm. Naik and his co-workers (4, 8, 9, 10, 11) have developed HPC mixtures for strengths up to 100 MPa using coarse aggregates with size ranging between 12 and 20 mm.

Studies (17, 18, 19), have indicated that the use of Class F fly ash and silica fume improves concrete resistance to sulfate. Some studies (16, 17) reported that inclusion of Class C fly ash reduces ability of concrete to resist sulfate attack. However, Mehta (18, 20) indicated that irrespective of calcium content, it is the amount of reactive alumina content contributed by a fly ash that controls the presence of mineral highly vulnerable to sulfate attack. ACI Committees 201 and 318 offer recommendations to stem the effects of sulfate attack (21, 22).

The alkali hydroxides generated during cement hydration can react with amorphous silica containing aggregates, resulting in formation of expansive products. Generally, use of Class F fly ash and silica fume, either individually or combined in concrete, suppresses alkali-silica reactions. Numerous investigations (23, 24, 25) have reported influence of temperature on concrete performance due to exposure to high temperatures.

Sarkar (26) reported complementary and synergistic effects of mineral admixtures such as fly ash, slag, and silica fume on concrete microstructure. Silica fume is most reactive and thus it contributes to early-age densification of the cementitious matrix including the transition zone. Therefore, silica fume has the most dominant effect on the early-age strength among other cementitious materials used. Progressive hydration of slag or fly ash contributes to the later-age strength. Further densification of the concrete microstructure occurs due to pore filling effects of slag or fly ash. Therefore, in order to derive favorable microstructure of HPC, it is desirable to use binary or ternary combination of mineral admixtures to obtain the best results.

CONCLUSIONS

Based on the experimental investigation completed in this study, the following main conclusions can be drawn.

1. Both HPC mixtures (Mix 15P and 15E) showed high rate of strength development up to 28 days. Beyond 28 days, the rate of strength development decreased significantly, and after 56 days of curing in either environment, the rate of strength gain became insignificant.
2. Generally, VTCE-cured specimens achieved higher rate of strength development compared to moist-cured specimens for all mixtures.
3. Both HPC mixtures exhibited high early-age strengths, exceeding 46 MPa at the age of three days in either curing

environment. At 28 days, compressive strength varied between 84 and 99 MPa for moist-cured specimens and between 88 and 100 MPa for VTCE-cured specimens.

4. Mix 15P showed a strength of 104 MPa and Mix 15E attained 93 MPa under moist-curing environment at the age of 56 days. The corresponding VTCE-cured mixtures showed compressive strength of 101 MPa and 96 MPa at 56 days.
5. The resistance to chloride-ion penetration increased with increased amount of silica fume from 6% to 14% of total cementitious materials.
6. In general, concrete resistance to chloride-ion penetration increased with age, i.e., with increase in strength of concrete.
7. The use of the VTCE increased concrete resistance to chloride-ion penetration. This trend was also reported by Cabrera et al. (24). The temperature effect was dominant at the ages up to 56 days. Beyond 56 days, the effect of temperature was negligible. All concrete mixtures were rated to have a very high resistance to chloride-ion penetration ("very low" chloride-ion penetration in accordance with ASTM C 1202 criteria) at the age of 56 days and beyond.
8. The air and water permeabilities data recorded by using the Figg method were inconsistent. Therefore, the Figg method was found to be inadequate for evaluating permeability of HPC mixtures.
9. The influence of curing type on sulfate resistance of the HPC mixtures was insignificant. Both HPC mixtures attained very high resistance to sulfate attack as no appreciable change in length and density values were observed due to their exposure to the sulfate solution (10% sulfate ion). In fact, performance of these mixtures improved due to their curing in the sulfate-enriched liquid. Both mixtures exhibited increases dynamic modulus values with age during their immersion in the sulfate solution.

REFERENCES

1. *Planning Committee for the Nationally-Coordinated Program on High-Performance Concrete and Steel*, *High-Performance Construction Materials and Systems*: An Essential Program for America and Its Infrastructure, Technical Report No. Report 93-5011, April 1993
2. Mehta, P.K. Concrete Technology at the Crossroads - Problems and Opportunities, *Proceeding of the V. Mohan Malhotra Symposium on Concrete Technology - Past, Present, and Future, P.K. Menta, Ed., ACI SP-144*, 1994, pp. 1-30
3. Naik, T.R., and Ramme, B. High Early Strength Fly Ash Concrete for Precast/Prestressed Products, *PCI Journal*, Vol. 35, No. 6, Nov./Dec., 1990, pp. 72-78
4. Naik, T.R., and Patel, V., and Brand, L. Performance of High-Strength Concrete Incorporating Mineral Admixtures, *Presented and Pre-print published at ACI National Spring Convention*, Washington, D.C., 1992
5. Naik, T.R., Singh, S.S., and Mohammad M. Properties of High Performance Concrete Incorporating Large Amounts of High-Lime Fly Ash, *International Journal of Construction and Building Materials,* U.K., Vol. 9, No., 6, 1995, pp. 195-204
6. Aitcin, P.C., and Neville, A. High-Performance Concrete Demystified, *ACI Concrete International*, January 1993, pp. 21-26
7. Mehta, P.K., and Aitcin, P.C. Principles Underlying Production of High-Performance Concrete, *Cement, Concrete, and Aggregates*, ASTM, Vol. 12, No. 2, Winter, 1990, pp. 70-78
8. Beffel, J. Curing Temperature Effects on High-Performance Concrete Properties, University of Wisconsin - Milwaukee, *M.S. Thesis*, 1995
9. Olson, Jr., W.A. Temperature Effects on the Permeability of High-Performance Concrete, University of Wisconsin-Milwaukee, *M.S. Thesis*, 1994
10. Patel, V. Full-Scale Beam Tests for Shear Strength of High-Strength Concrete, University of Wisconsin-Milwaukee, *M.S. Thesis*, 1992
11. Brand, L. Shear Strength of Reinforced Concrete Beams for High-Strength Concrete, University of Wisconsin-Milwaukee, *M.S. Thesis*, 1992
12. Aitcin, P.C., Sarkar, S.L., Regourd, M., and Hornain, H. Microstructure of a Two-Year-Old Very High Strength (100 MPa) Field Concrete, *Proceedings, Symposium on High-Strength Concrete*, Tapir Publishers, Trondheim, Norway, 1987, pp. 99-109
13. De Larrand, F., Ithurralde, G., Acker, P., and Chavel, D. High-Performance Concrete for a Nuclear Containment, *Proceedings of the Second International Symposium on High-Strength Concrete*, *SP-121*, ACI, 1990, pp. 5549-5576
14. Gjorv, O.E. High Strength Concrete, *Advances in Concrete Technology,* V.M. Malhotra, Ed., CANMET, Ottawa, Canada, 1994, pp. 19-82
15. Aitcin, P.C. Durable Concrete - Current Practice and Future Needs, P.K. Mehta, Ed., SP-144, ACI, 1994, pp. 85-104
16. Naik, T.R., and Singh, S.S. Use of High-Calcium Fly Ash in Cement-Based Construction Materials, *Proceedings of the Fifth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete*, Milwaukee, WI, 1995, Supplementary Proceedings, V.M. Malhotra, Ed., pp 1-44
17. Malhotra, V.M. Fly Ash, Slag, Silica Fume, and Rice Husk in Concrete: A Review, *ACI Concrete International*, Vol. 15, No.4, April 1993, pp.23-28
18. Mehta, P.K. Pozzolanic and Cementitious By-Products in Concrete - Another Look, *Proceedings of the Third CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete*, Trondheim, Norway, V.M. Malhotra, Ed., ACI SP-114 1989, pp.1-43
19. Tikalsky, P.J., and Carrasquillo, R.L. Influence of Fly Ash on Sulfate Resistance of Concrete, *ACI Materials Journal*, Vol. 89, No. 1, January - February 1992, pp. 69-75

20. Mehta, P.K. Effects of Fly Ash Composition on Sulfate Resistance of Cement, *ACI Materials Journal,* Vol. 83, No.6, 1986, pp. 94-100
21. ACI Committee 201: Guide for Durable Concrete, *American Concrete Institute*, Detroit, Michigan
22. ACI Committee 318: Building Code Requirements for Reinforced Concrete *(ACI 318-95), American Concrete Institute*, Detroit, Michigan
23. Owen, P.L. Effect of Temperature Rise and Fall on the Strength and Permeability of Concrete Made with and without Fly Ash, Temperature Effects on Concrete, ASTM STP 858, T.R. Naik., Ed., *American Society for Testing Materials*, Philadelphia, 1985, pp. 134-149
24. Cabrera, J.G., Dodd, T.A.H., and Nwaubani, S.O. The Effect of Curing Temperature on the Chloride Diffusion of Superplasticised Cement and Fly Ash Cement Pastes, *ACI SP 139-4*, 1993, pp. 61-76
25. Naik, T.R., and Singh, S.S. "Curing Temperature Effects on Properties of Class F Fly Ash Concrete, *a paper presented and preprint published at the ACI Spring Conference*, Tarpon Springs, FL, March 1994, 36 pages
26. Sarkar, S.L. Role of Silica Fume, Slag, and Fly Ash in the Development of High-Performance Concrete Microstructure, *Proceeding of the ACI International Conference, Singapore, ACI SP-149*, V.M. Malhotra, Ed., 1994, pp. 449-460
27. Figg, J.W. Methods of measuring the air and water permeability of concrete, *Magazine of Concrete Research*, Vol. 25, No. 85, December 1973, pp. 213-219
28. Cather, R., Figg, J.W., Marsden, A.F., and O'Brien, T.P. Improvements to the Figg Method for Determining the Air Permeability of Concrete, *Magazine of Concrete Research*, Vol. 36, No. 129, December 1984, pp. 241-245