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DEVELOPMENT OF HIGH-STRENGTH CONCRETE MIX DESIGNS IN SUPPORT OF THE PRESTRESSED CONCRETE REACTOR VESSEL DESIGN FOR A HTGR STEAM CYCLE/COGENERATION PLANT

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Abstract

Design optimization studies indicate that a significant reduction in the size of the PCRV for a 2240 MW(t) HTGR plant can be effected through utilization of high-strength concrete in conjunction with large capacity prestressing systems. A three-phase test program to develop and evaluate high-strength concretes (>63.4 MPa) is described. Results obtained under Phase I of the investigation related to materials selection-evaluation and mix design development are presented.

prestressed concrete reactor vessel

1. Background

Design optimization studies by GA Technologies Inc. have indicated that a significant size reduction (~1.3 m) can be effected in the PCRV for a 2240 MW(t) HTGR through the use of 55 MPa concrete in conjunction with 13.3 MN capacity vertical prestressing tendons. This can lead to substantial cost savings (≈$5.7 M) in both the PCRV and containment. However, in order to realize this cost savings it must be demonstrated that concrete mix designs can be developed which have the desired mechanical and thermal properties.

2. Objective and Scope

The objective of the overall test program is to develop and evaluate high-strength concretes (>63.4 MPa)* utilizing materials which are in close proximity to areas representing potential sites for an HTGR plant. The overall program is to be conducted in three phases. Phase I involves the selection and evaluation of materials, identification of optimum cement contents, evaluation of the selected aggregate materials and the effects of partial cement replacement by fly ash, and final mix selection and determination of strength and elastic properties. Phase II is concerned with an evaluation of the effect of elevated temperatures up to 316°C on both sealed and unsealed specimens fabricated using the mix designs developed under Phase I. Phase III involves a determination of the creep characteristics of the concretes developed under Phase I when subjected to loadings representing either 30%, 45%, or 60% of their control strengths at temperatures to 71°C. Thermal properties and the effects of thermal cycling on strength and elastic properties

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*Reference [1] requires that an average compressive strength at least 8.3 MPa greater than the specified strength be produced in the laboratory.

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will also be evaluated under this phase. Results in this paper will be restricted to Phase I which is nearing completion.

3. Factors Related to the Production of High-Strength Concrete

To achieve high-strength concrete optimization of the following factors is required: (1) characteristics of the cementing medium; (2) characteristics of the aggregate; (3) proportions of the paste; (4) paste-aggregate interaction; (5) mixing, consolidation and curing; and (6) testing procedures. Choice of type and brand of cement is probably one of the most important factors in the selection of materials and should be on the basis of long-term strength development. Durable aggregate materials free of deleterious substances and having good thermal and mechanical properties must be utilized. Development of high strengths requires use of the lowest possible water-cement ratio (0.30-0.40) and high cement factors (>450 kg/m^3). Appropriate procedures must be followed to ensure that the concrete is thoroughly mixed, adequately consolidated, and properly cured. By utilizing the above considerations in conjunction with a comprehensive quality assurance/quality control program consistent production and placement of ready-mix concretes having compressive strengths in excess of 75 MPa should be achievable.

4. Material Selection and Evaluation

Representative concrete-making materials conforming as closely as possible to requirements presented in the previous section have been selected for use in this study. These materials include cement, fly ash, water reducing and retarding admixtures and aggregates.

ASTM Type II moderate heat of hydration and low alkali content portland cement having a 7-d mortar cube strength >29 MPa was selected.

ASTM Class C fly ash having a loss on ignition <3% and a high pozzolanic activity index (>100% at 28-d) was chosen for use as a partial replacement for cement.

Selection of Pozzolith 300-R as the admixture was on the basis of it being the most compatible of the three ASTM Type D water reducing-retarding admixtures evaluated with the type and brand of cement procured. Strength and workability results from a series of trial mixes were utilized to evaluate cement compatibility and also to determine the dosage.

Since aggregate materials generally occupy 60 to 80% of the volume of concrete, their availability and quality represent a key ingredient in the production of high-strength concrete. Results of a survey conducted in conjunction with this program indicate that high-strength concretes can be produced anywhere in the U.S., but certain areas (e.g. Florida) may require the use of imported aggregate at a cost penalty of up to \$52/m^3. In order to establish bounds on concrete properties obtainable from aggregate materials available in the U.S., four sites were selected which correspond to areas which are candidate locations for the HTGR-SC/C plant and local aggregate materials were obtained. These sites included: the Pennsylvania-Delaware border area; Florida City-Turkey Point, Florida; Port Arthur, Texas; and Blythe, California area.

4. Optimum Cement Content Determinations

As noted in ref. [2] there is an optimum cement factor for concrete mixes of equal workability and the same consistency which uses a specific aggregate of a certain maximum

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size. The optimum cement factor used in this study was evaluated through a series of laboratory mixes utilizing the Pennsylvania-Delaware border area aggregate materials [38-mm and 9.5-mm maximum size aggregate (MSA)]. Cementitious materials contents (90% cement plus 10% fly ash, by weight) ranged from 7 to 12 sacks/cu. yd. (390 to 670 kg/m^3). In the mixes the MSA was held constant, the water content was adjusted to maintain the slump at 89 ± 13 mm, and the fine aggregate content was adjusted to account for the changing cement and water contents. Cement contents of 586 kg/m^3 and 530 kg/m^3 were selected for the 38 mm and 9.5 mm MSA, respectively, based on results present in Figs. 1 and 2.

5. Aggregate and Fly Ash Evaluation Testing

In this series of tests each of the four aggregate sources was evaluated as well as the effect of partial replacement of cement with fly ash. Utilizing results from the optimum cement content test series, concrete mixes were fabricated for each of the aggregate sources. Cement replacement by fly ash in the mixes varied from 0 to 40%, by weight, and each mix was designed for equal workability by adjusting the water content to maintain the slump at 89 ± 13 mm. Fine aggregate contents were adjusted to account for the changing volume from mix to mix of the cement, fly ash and water. Figures 3 and 4 present strength results obtained from 38-mm and 9.5-mm Pennsylvania-Delaware border area aggregate materials, respectively. These results also are representative of the magnitude of strengths obtained using aggregate materials from the other three selected sources. In addition to providing improved strength results, test results obtained during this part of the study showed that partial replacement of cement with fly ash provided enhanced workability, reduced bleeding and reduced temperature rise of fresh concrete.

6. Final Aggregate Selection for Detailed Property Determinations

Compressive strength test results demonstrate that the target compressive strength of ≥63.4 MPa can be achieved using materials from each of the four aggregate sources selected for evaluation. In order to obtain a representative range of concrete properties that can be obtained from potential aggregate sources in the U.S., the Pennsylvania-Delaware border area and Florida City-Turkey Point, Florida materials were selected for use in the balance of the investigation. The Pennsylvania-Delaware border area aggregate was selected on the basis that it had been used in the development of 45 MPa mix designs for the previous generation PCRVs (Fulton and Summit plants) [3]. Selection of the Florida City-Turkey Point, Florida aggregate was on the basis that it produced concrete mixes having the lowest modulus of elasticity. Compressive strength, tensile strength, modulus of elasticity and Poisson's ratio values will be established from specimens which have been fabricated using materials from these sources. Tests will be conducted on both moist-cured and sealed specimens at concrete ages to 182 d. These materials will also be utilized in subsequent Phases II and III of the overall study.

7. Summary and Conclusions

An overview of a three phase program to develop and evaluate high-strength concrete (≥63.4 MPa) material systems utilizing aggregate materials selected to provide bounds on material properties is presented. Factors related to the production of high-strength concretes are discussed. Phase I results on material selection-evaluation, optimum

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cement content determinations, aggregate and fly ash evaluation testing, and final aggregate selection are presented. Test results indicate that concretes having the desired compressive strengths are easily achievable and the incorporation of fly ash into the concrete mixes imparts several benefits.

Acknowledgements

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References

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SPECIMEN FABRICATION FOR DETERMINATION OF OPTIMUM CEMENT CONTENT USING 38 mm MSA HAS BEEN COMPLETED

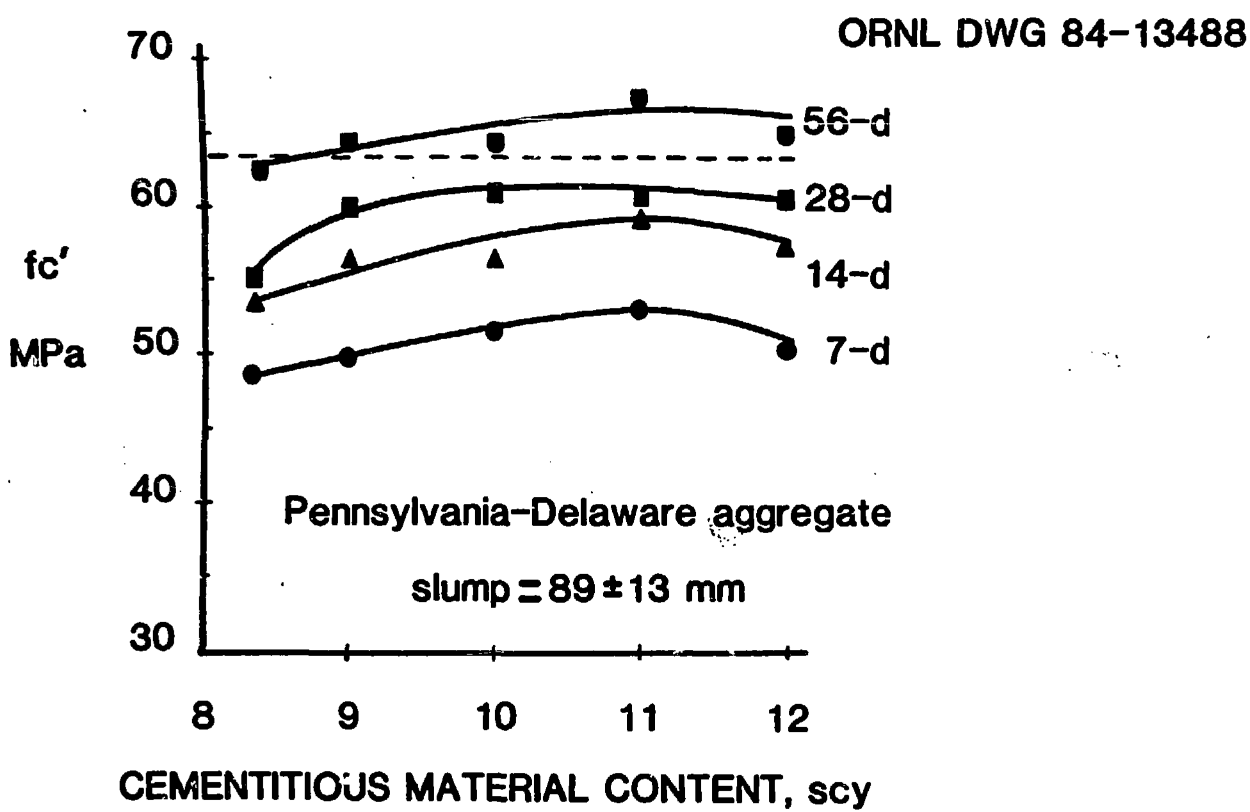

Fig. 1

SPECIMEN FABRICATION FOR DETERMINATION OF OPTIMUM CEMENT CONTENT

USING 9.5 mm MSA HAS BEEN COMPLETED

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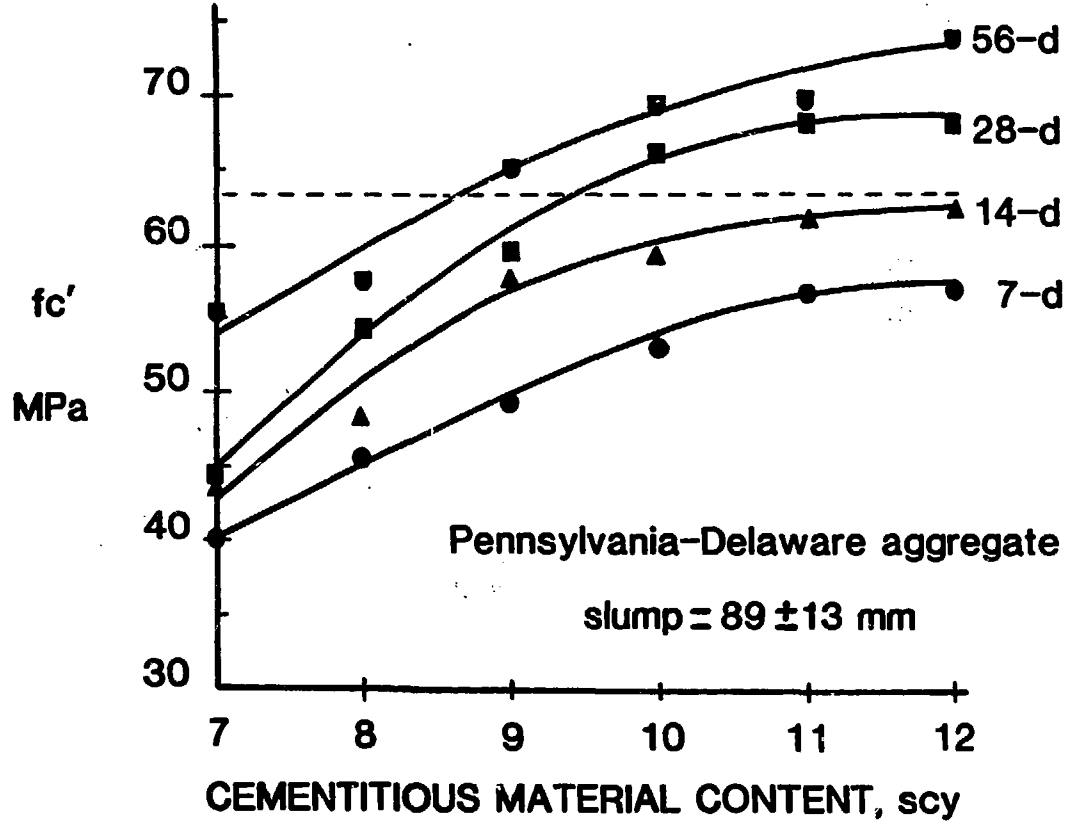

Fig 2.

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PARTIAL CEMENT REPLACEMENT WITH FLY ASH PROVIDES STRENGTH BENEFITS

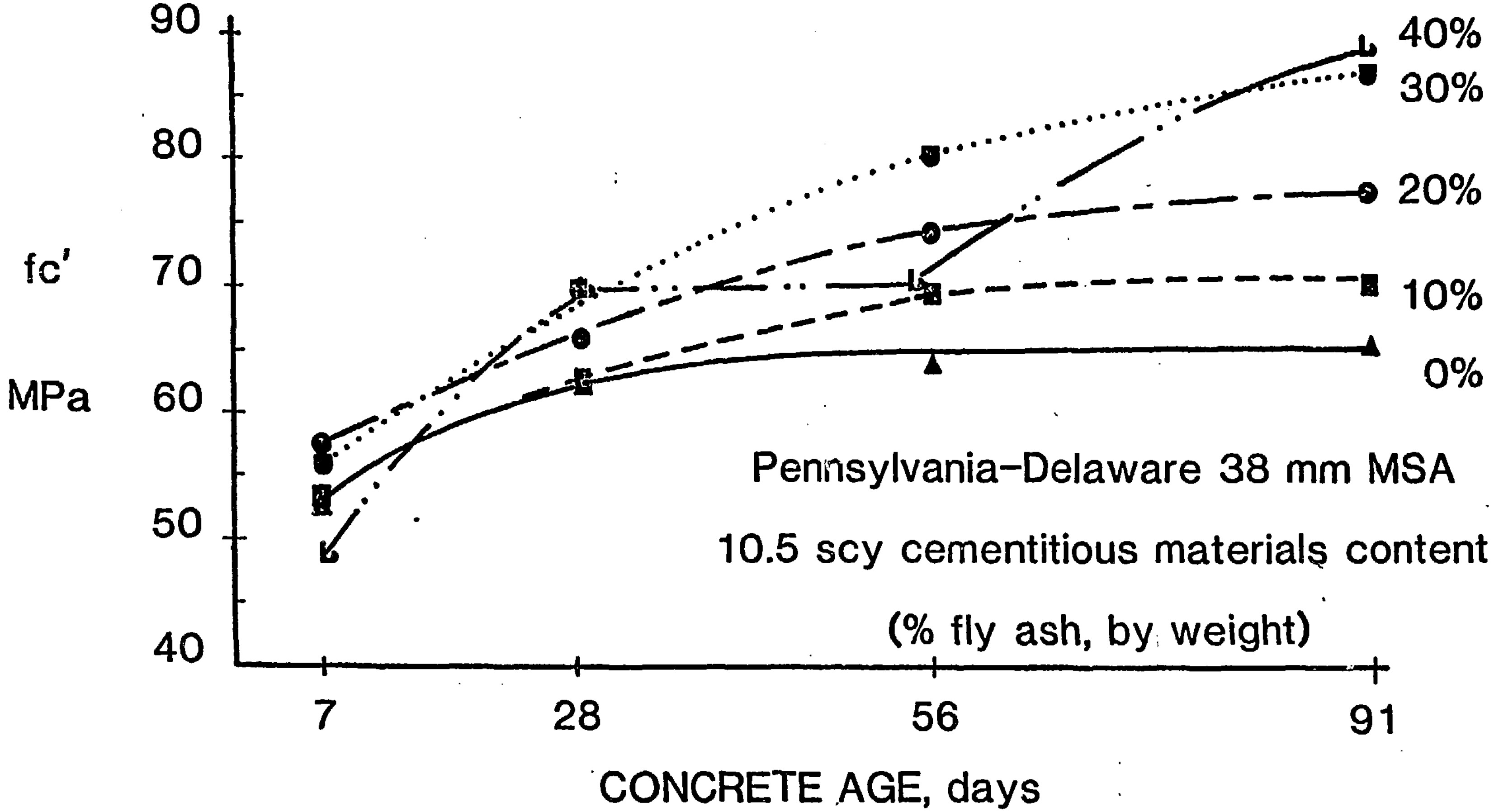

Fig. 3

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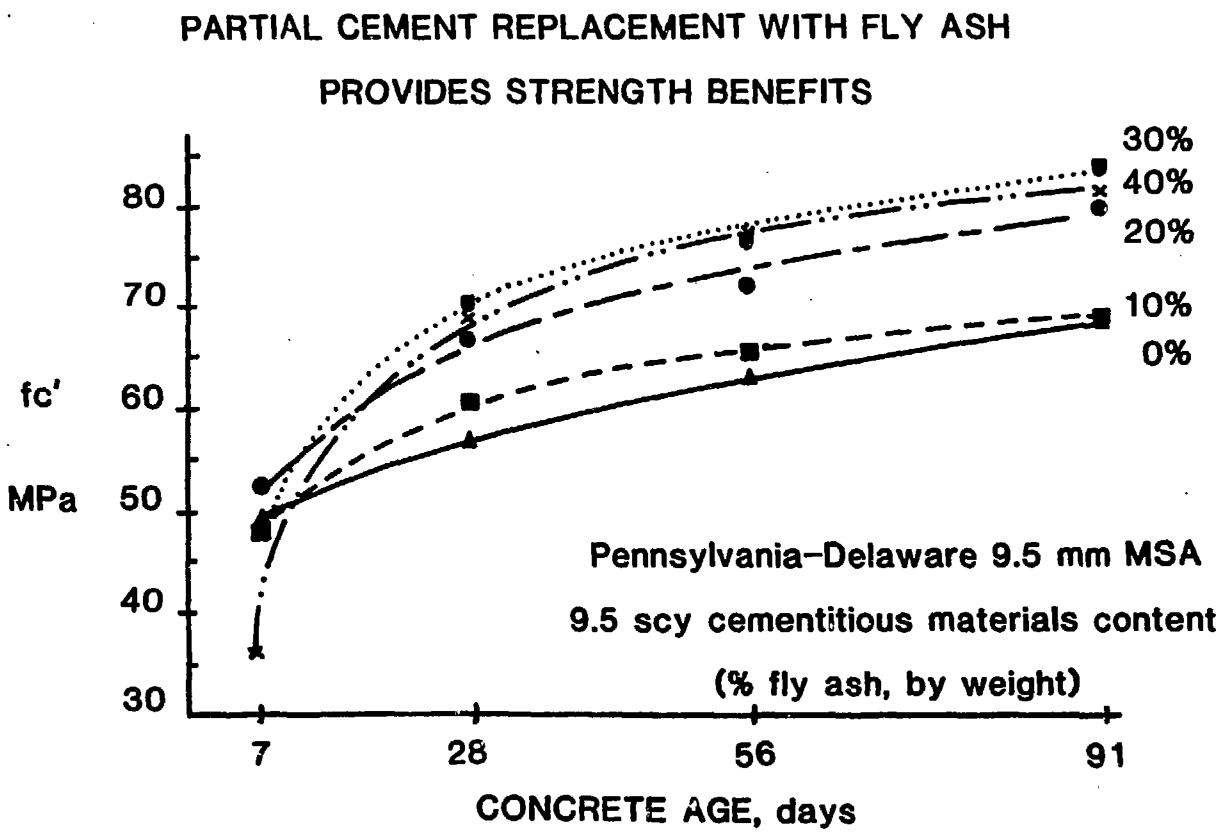

Fig. 4

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