

CANADIAN EXPERIENCE IN THE USE OF THE MODIFIED BOILING METHOD

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This paper briefly reviews the history of accelerated-curing techniques for quality control of concrete. In a modified boiling method that has been developed by the Mines Branch, the test specimens are standard cured for 23 to 23½ hours, then boiled for 2½ hours, and tested for compression 1½ hours after being boiled. The total elapsed time between molding and testing of cylinders does not exceed 28.5 hours. This method is finding increasing acceptance in Canada and has been adopted by the American Society for Testing and Materials and the Canadian Standards Association. The data from Hydro-Quebec, Acres-Bechtel, a ready-mix concrete company in Ottawa, and the University of Calgary, Alberta, show significant correlations between the results of the accelerated and 28-day compressive strength tests. The original regression equation reported by the Mines Branch relating the compressive strength of accelerated-cured cylinders to that of 28-day standard-cured cylinders has been compared with the equation developed at the University of Calgary, and the two regression lines are about identical. Each testing and control authority contemplating the use of the modified boiling method is urged to develop its own correlations for predicting 28-day compressive strengths and not to rely on the correlations published by others.

•RAPID advances have been made in the processing and manufacture of mineral aggregates and cements during the past 50 years. Unfortunately, little of the progress is reflected in the techniques used for quality control of concrete in the field. The concrete industry is still burdened with control tests in which cylindrical specimens are subjected to a compression test at 28 days. This waiting period is anachronistic when multistory buildings are being completed in a matter of months.

Notwithstanding the fact that the compression test has successfully served the construction industry for the past several decades, the faster pace of modern-day construction practices requires new quality control tests in which the waiting period of 28 days is eliminated or considerably reduced. This paper traces the efforts of earlier researchers to develop a rapid test to control the quality of concrete and describes, in some detail, a new modified boiling procedure that is becoming increasingly popular in Canada and several other countries.

BACKGROUND

Despite the perennial problems associated with the 28-day compression test, efforts to develop rapid tests for quality control of concrete are recent. The pioneering work in the field of accelerated-strength testing of concrete was done in the United States between 1925 and 1935. One of the earliest publications on the subject was in 1927 by Gerend (1), who showed that a rapid gain in concrete strength was achieved by subjecting 6 by 12-in. (152 by 305-mm) cylinders to a saturated steam bath at 80 to 100 lbf/in.² (552 to 689 kPa). The need of an autoclave to increase the rate of strength gain was an obvious drawback, and the procedure failed to gain acceptance.

The construction of the Hoover Dam in the 1930s caused the U.S. Bureau of

Reclamation to investigate the use of an 8-hour, boiling-water accelerated strength test (2). The boiling of 6 by 12-in. (152 by 305-mm) cylinders that had been molded in special jackets was limited to 7 hours, and 1 hour was used for cooling, capping, and testing the specimens. After several years of field trials, the test procedure was considered unsatisfactory because of the lack of precision in the predicted 28-day compressive strengths.

From the late 1930s until the early 1950s, no significant progress in the development and use of accelerated strength testing of concrete was reported anywhere in the world. At that time, a number of research papers dealing with rapid control tests originated in the United Kingdom (3, 4, 5). Then, in 1963, the Réunion International des Laboratoires d'Essais et de Recherches sur les Matériaux et les Constructions in Paris sponsored an international correspondence symposium on the theme of accelerated hardening of concrete and rapid control tests (6). In North America, Canada has been in the forefront of the development of accelerated strength tests. Since 1962, the Mines Branch of the Ottawa Department of Energy, Mines and Resources has made significant contributions in this field (7, 8, 9, 10, 11, 12).

MODIFIED BOILING METHOD

Malhotra et al. (7) adopted the modified boiling method originally proposed by Akroyd (4) for further study and development and used 6 by 12-in. (152 by 305-mm) cylinders. The salient features of this technique, which has now been accepted by the American Society for Testing and Materials (ASTM C 684-73 T) and the Canadian Standards Association (CSA A 23.2.26), are as follows:

1. Prepare two 6 by 12-in. (152 by 305-mm) test cylinders in steel molds using standard molding methods. The delay between mixing concrete and preparing the test specimens should not exceed 30 min.
2. Immediately after the cylinders are molded, close all molds tightly with steel cover plates and place them in a moist-curing room or in a box maintained at about 73 ± 3 F (23 ± 1.7 C) and 100 percent relative humidity. If suitable moist-curing facilities are not available, cover the molds with wet burlap and keep them wet for 23 hours.
3. At the end of the curing period, place the cylinders, complete with molds and covers, in boiling water. Keep the temperature of water just below the boiling point to avoid excessive evaporation.
4. After 3.5 hours of boiling, remove the cylinders from the boiling water, strip the molds, and allow the specimens to cool for about one-half hour.
5. Weigh the test cylinders, cap them, and test them in compression 1 hour later.

The total elapsed time between molding and testing of the test cylinders is 28.5 hours.

FIELD USE OF MODIFIED BOILING METHOD

Since publication of the results of the original investigation by Malhotra et al. (7), the modified boiling method has been adopted by a number of organizations in Canada and elsewhere for routine quality control of concrete (9, 10, 11, 12, 13). The method is probably widely accepted because it is simple and the curing cycle can be controlled easily.

Test data from a cross section of organizations that have used this method are shown in Figures 1 (9), 2 (10), 3 (9), 4 (11), and 5 (12). The regression equations are also shown where they were available. The test results for lightweight concrete are shown in Figure 6 (13).

Figure 1. Field data for accelerated versus 28-day compressive strength for nine jobs from coast to coast in Canada using normal portland cement concrete.

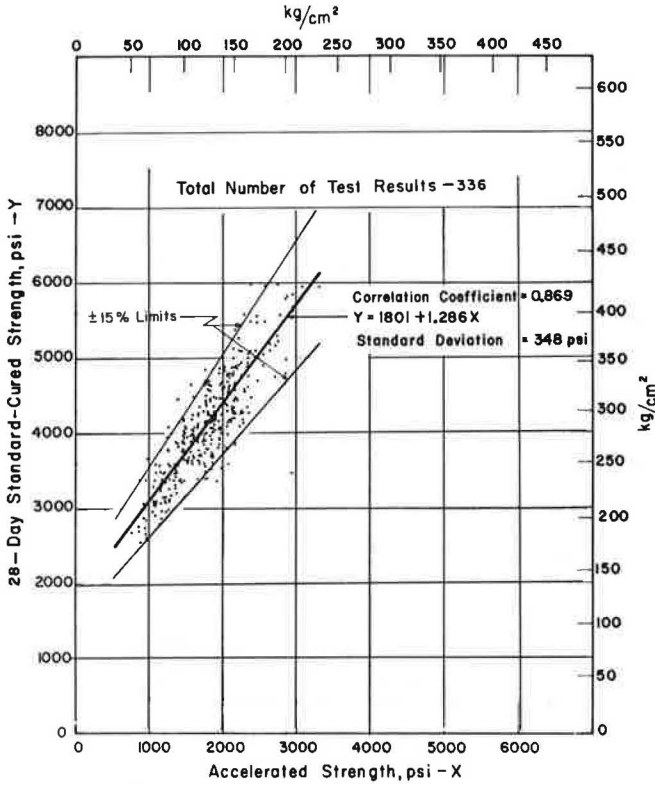


Figure 2. Accelerated versus 91-day compressive strength of concrete for Outardes-3 dam project.

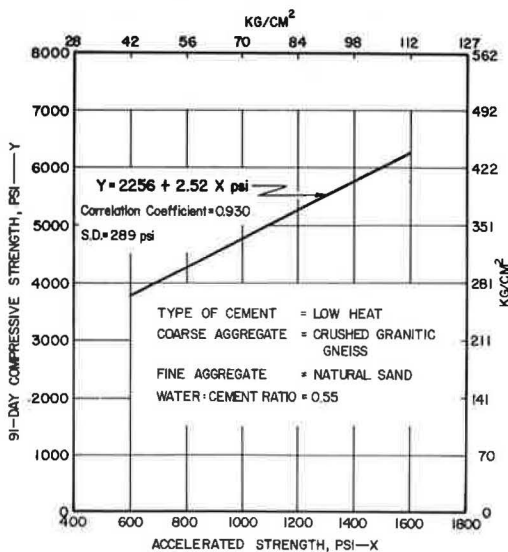


Figure 3. Accelerated versus 28-day compressive strength of concrete for Churchill Falls project.

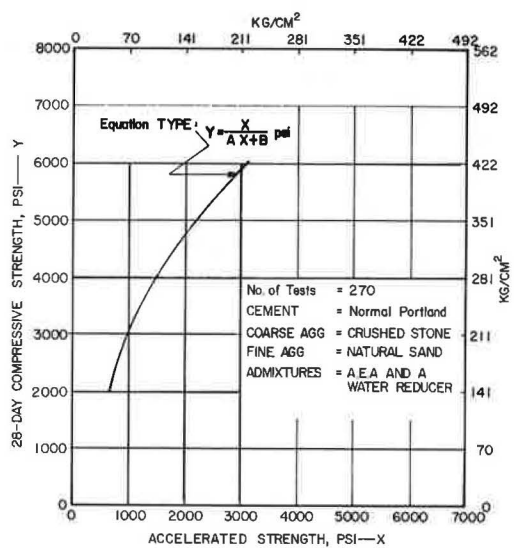


Figure 4. Accelerated versus 28-day compressive strength of ready-mix concrete.

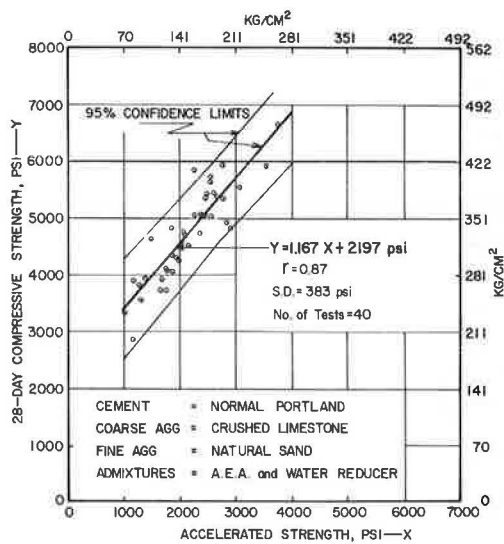


Figure 5. Accelerated versus 28-day compressive strength of concrete for a project in Calgary.

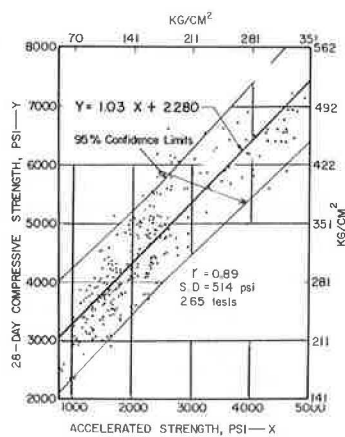


Figure 6. Accelerated versus 28-day compressive strength for lightweight concrete.

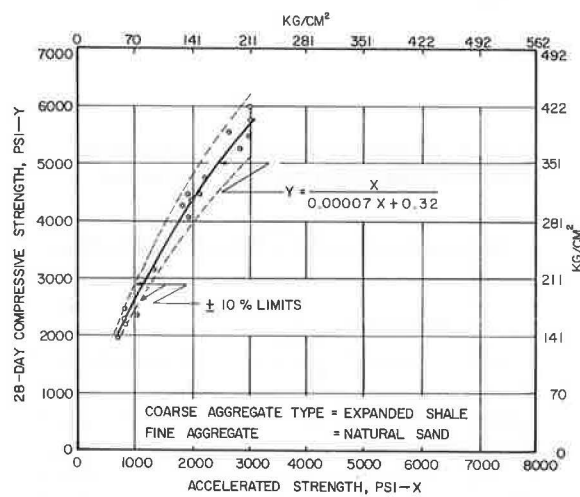
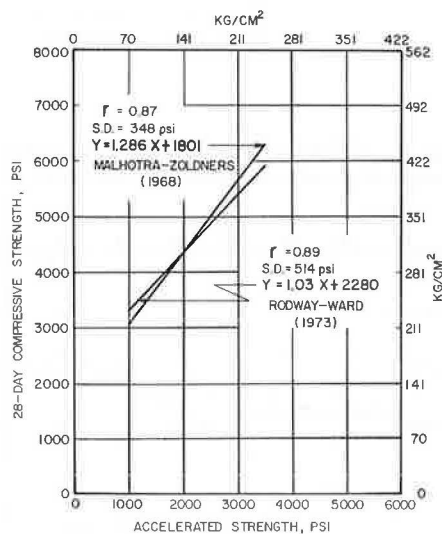


Figure 7. Accelerated versus 28-day compressive strength of concrete from different research projects.



GENERAL COMMENTS ON FIELD USE OF MODIFIED BOILING METHOD

To date, the modified boiling method has primarily been used for trouble shooting and quality control testing rather than for acceptance testing. The plots of test data (Figures 1, 2, 3, 4, 5, and 6) indicate that the modified boiling method can satisfactorily predict the 28-day compressive strength of concrete. The available correlation coefficients are greater than 0.86, indicating that correlations are significant. The test method is equally applicable to normal and to lightweight concretes. The degree of correlation does not appear to be affected by the use of high-early-strength and low-heat cements.

The original regression equation by Malhotra and Zoldners (9), relating the compressive strength of accelerated-cured cylinders to that of 28-day standard-cured cylinders, has been compared with the equation developed by Rodway and Ward (Figure 7). It is gratifying to note that the two regression lines are about identical.

Despite the high degree of correlation, however, each testing and control authority contemplating the use of the modified boiling method is urged to develop its own correlations for predicting 28-day compressive strengths and not to rely on the correlations published by others.

CONCLUDING REMARKS

The steadily increasing pace of modern construction demands the use of rapid evaluation techniques to control the quality of concrete in construction. ASTM and CSA have now published standard accelerated strength tests. Unfortunately, these tests, including the modified boiling method, are still not rapid enough because they require a waiting period of 24 to 48 hours; however, they are a vast improvement over the previous waiting period of 7 or 28 days. It is hoped that accelerated tests, instead of the 28-day test, will soon form the basis of design and the acceptance criterion and that researchers will ultimately find a method for determining the potential strength of concrete immediately after it has been mixed.

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