# FIELD EVALUATION OF EXPANDED POLYSTYRENE MOLDS FOR SELF-CURED, ACCELERATED STRENGTH TESTING OF CONCRETE

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An accelerated-curing method that offers the possibility of forecasting the 28-day strength of concrete 48 hours after sampling was evaluated in the field. The method consists of casting and curing the concrete in styrofoam molds and has the following advantages over conventional accelerated-curing methods: (a) There is no change in the sampling and testing procedures normally used for the standard 28-day test, (b) the test is done during normal working hours, (c) no special heating or curing equipment is needed, (d) the concrete sample is protected from large curing-temperature variations that may occur during handling and transportation from the field to the laboratory, (e) the test cylinder of green concrete is protected from rough-handling damage, and (f) the technician is not exposed to injury by heat. More than 1,300 cylinders of paving and structural concrete, produced by 4 suppliers, were tested. The study showed that (a) there is a good correlation between 48-hour and 28-day test results, (b) the gain in strength at 48 hours is more than 60 percent of the 28-day strength, (c) a different 48-hour to 28-day strength regression equation was found for each concrete supplier, and (d) the reliability of the strength test results of cured samples obtained by using the expanded polystyrene mold method is of the same order as that obtained by more elaborate accelerated-curing methods.

•THE advantage of early determination of concrete strength potential has been recognized for many years. Accelerated strength tests for concrete have been used since 1920, and a considerable amount of work has been done in the 1960s (1, 2, 3, 4). In 1963, the Canadian Standards Association (CSA) and the American Society for Testing and Materials (ASTM) appointed subcommittees to study the development of accelerated strength tests for concrete. It was not until the beginning of 1970 that CSA and ASTM adopted tentative methods for making, curing, and determining the compressive strength of accelerated-cured concrete test specimens (CSA A 23.2-1973 and ASTM C 684-73T).

CSA A 23.2-1973 offers a modified boiling-water method and an autogenous curing method (CSA A 23.2.26). ASTM C 684-73T also included the warm-water method. A brief description of the three accelerated-curing procedures is given in Table 1.

Although it is evident that an early strength test, in lieu of the 28-day test, is an effective tool to improve quality control and promote early decision making, none of the standardized procedures have come into general use. The proposed methods require special equipment and curing procedures, they complicate testing, they are awkward to perform, and they increase the cost of testing significantly.

## SCOPE

The purpose of this study was to determine if a truly simple accelerated strength test method could be achieved by using a single-use expanded polystyrene mold such as the one originally developed to protect concrete test cylinders from frost or handling damage (5). The inherent insulating property of the mold is used to accelerate the curing of the concrete so that the potential 28-day compressive strength can be predicted from the 48-hour self-accelerated strength.

The study is divided into two main parts:

1. Evaluation of the self-cured accelerated strength test results, and
2. Comparison between the results of the proposed method and other accelerated strength test methods.

The evaluation was based on testing of a large number of field-sampled specimens of ready-mixed concrete, for which the sampling technicians received no special instructions. The concrete was produced for paving and structural works by four suppliers. All concretes used portland cement concrete (CSA type 10 or ASTM type 1), limestone coarse aggregates, natural or manufactured sand, and air-entraining and water-reducing admixtures (CSA type WN or ASTM type A).

## EQUIPMENT AND TEST PROCEDURES

Figure 1 shows the commercially available expanded polystyrene mold used in this experiment. It meets all CSA and ASTM requirements for single-use molds.

The main features of the mold pertinent to this study are as follows:

1. It is made of expanded polystyrene so that the heat generated by the exothermic chemical reaction during cement hydration can be partially retained within the concrete to accelerate the curing, and
2. It has tight press-fit cover to prevent heat and moisture losses.

Standard procedures are followed for molding the specimens, which are cured in their molds at room temperature [60 to 80 F (15.6 to 26.7 C)] at the job site or the central laboratory until testing. No special curing facilities are required; the insulation of the mold provides for the self-accelerated curing. Cylinders are demolded immediately before testing, and CSA or ASTM procedures are used for capping and load testing. The concrete specimens are tested at, or about, 48 hours. A correction factor may be applied for discrepancies in testing time. However, in this study, corrections based on the strength-time curve of laboratory mix concrete (see Appendix) have not indicated any substantial improvement in the accuracy of the method. A strength-time curve up to 96 hours based on the self-cured method should be established to eliminate weekend testing and to reduce testing expenses.

## FIELD EXPERIMENT

### Description

The experiment was carried out during construction of different contract sections of the Trans-Canada Highway through the city of Montreal, which includes elevated and depressed roadways and a unique multilevel underground interchange. The concrete, supplied by four producers, consisted of several classes of concrete with different strength or durability requirements based on water-cement ratios. All concrete samples were collected at the job site as a part of normal field control work. The temperature, slump, and air content of each concrete sample were obtained before molding. Five 6 by 12-in. (15 by 30-cm) cylinders were molded from each concrete sample by using standard methods. Expanded polystyrene molds were used for the two accelerated-

**Table 1. Accelerated-curing procedures.**

| Procedure | Molds | Accelerated Curing Medium | Accelerated Curing Temperature (F) | Age Accelerated Curing Begins | Duration of Accelerated Curing (hours, min) | Age at Testing (hours, min) |
|---|---|---|---|---|---|---|
| Warm-water | Reusable or single-use | Water | 95 | Immediately after casting of cylinder | 23½, ±30 | 24, ±15 |
| Boiling-water | Reusable or single-use | Water | 212 | 23 hours after casting | 3½, ±5 | 28½, ±15 |
| Autogenous | Single-use | Heat of hydration | Initial concrete temperature augmented by heat of hydration | Immediately after casting | 48, ±15 | 49, ±15 |

Note: 1 F = 1.8 (C) + 32.

**Figure 1. Commercially available expanded polystyrene mold used in test.**

**Table 2. Number of samples and cylinders tested for each contractor.**

| Supplier | No. of Samples | No. of Cylinders |
|---|---|---|
| A | 100 | 500 |
| B | 35 | 175 |
| C | 30 | 150 |
| D | 48 | 240 |
| Total | 213 | 1,065 |

cured cylinders; standard paraffin-cardboard molds were used for one normal-cured, 7-day cylinder and two normal-cured, 28-day cylinders.

All concrete samples were kept at room temperature in the field laboratory for the first 20 to 30 hours before they were transported to the central laboratory for testing. The 7-day and 28-day cylinders were cured normally; the samples cast in the expanded polystyrene molds were demolded immediately before testing at 48 (±5) hours.

The slight discrepancies between the actual and the target testing time were accepted to avoid overtime and to accommodate laboratory procedures.

The number of samples and cylinders tested for each contractor is given in Table 2.

## Analysis of Test Results

The statistical analysis of all test results obtained for each supplier is given in Table 3. The analysis includes all results from concretes of widely different strength levels, slump, and air content requirements.

A summary of the statistical analysis of strength test results of different classes of concrete from each supplier is given in Table 4. The results show that the concretes sampled in this investigation may be rated good to excellent.

The repeatability of results of the accelerated strength test and the normal 28-day compression test obtained with concrete from different suppliers is given in Table 5. The repeatability is expressed in terms of coefficient of variation, which is estimated from the mean strength of all cylinders and the mean range calculated from individual range values of companion cylinders.

From the test results, we can conclude that the within-test variation of the field control is good to excellent and that the proposed accelerated strengths have a lower standard deviation than the normal 28-day strengths; however, the coefficients of variation are approximately the same.

## Correlation Between Accelerated and Normal 28-Day Strengths

A series of linear correlations have been made to find the relationships among the accelerated strength, the 7-day strength, and the 28-day strength.

Table 6 shows the best fit lines for the uncorrected-accelerated and 28-day strengths, the corrected-accelerated and 28-day strengths, and the 7-day and 28-day strengths for each of the four suppliers. The regression equations, standard errors of estimate, and the correlation coefficients are also given.

The uncorrected value is the strength obtained at time of test (48 hours ± 5), and the corrected value is the strength results obtained at the time of test other than 48 hours, corrected to represent exactly 48 hours. The corrections are based on the data in Table 7. In relation to the data in Tables 6 and 7, the following observations can be made:

1. A different equation was used for each concrete supplier.
2. The correlation coefficient and the standard error of estimate are both improved when the 7-day strength values are used to predict the 28-day strength.
3. In general, a supplier with a good coefficient of correlation between 7-day and 28-day strengths will also have a good coefficient of correlation between the accelerated and the 28-day strengths. This also appears valid for the standard error of estimate.
4. The corrected results have little influence on the nature or the error of correlation.

The percentage ratios of the accelerated and 28-day strengths and the 7-day and 28-day strengths (strength gained) obtained for concretes produced by different suppliers are given below.

**Table 3. Statistical analysis of strength test results.**

| Supplier | Value | Compressive Strength (psi) Accelerated Curing No Time Correction | Accelerated Curing Time Correction | Normal Curing 7-Day | Normal Curing 28-Day | Slump (in.) | Air Content (percent) | Concrete Temperature (F) |
|---|---|---|---|---|---|---|---|---|
| A | Mean | 2,910 | 2,910 | 3,900 | 4,745 | 3.31 | 5.47 | 69.3 |
| | Minimum | 1,310 | 1,370 | 2,120 | 2,615 | 1.25 | 1.50 | 58.0 |
| | Maximum | 4,425 | 4,410 | 5,300 | 6,065 | 8.00 | 8.00 | 78.0 |
| | Range | 3,115 | 3,040 | 3,180 | 3,450 | 6.75 | 6.50 | 20.0 |
| | Standard deviation | 596 | 581 | 571 | 608 | 1.00 | 1.30 | 3.5 |
| B | Mean | 3,505 | 3,530 | 4,245 | 5,055 | 3.12 | 5.70 | 72.4 |
| | Minimum | 2,795 | 2,780 | 3,710 | 4,385 | 2.50 | 4.40 | 60.0 |
| | Maximum | 4,370 | 4,430 | 4,920 | 5,625 | 4.25 | 7.30 | 82.0 |
| | Range | 1,575 | 1,650 | 1,210 | 1,240 | 1.75 | 2.90 | 22.0 |
| | Standard deviation | 355 | 370 | 282 | 339 | 0.48 | 0.75 | 5.7 |
| C | Mean | 3,045 | 3,075 | 3,920 | 4,740 | 3.54 | 5.54 | 70.2 |
| | Minimum | 1,890 | 1,950 | 2,550 | 3,080 | 2.00 | 2.40 | 52.0 |
| | Maximum | 3,920 | 4,000 | 4,880 | 5,605 | 4.50 | 7.90 | 80.0 |
| | Range | 2,030 | 2,050 | 2,330 | 2,525 | 2.50 | 5.50 | 28.0 |
| | Standard deviation | 405 | 400 | 430 | 476 | 0.59 | 1.14 | 7.18 |
| D | Mean | 2,780 | 2,780 | 3,625 | 4,400 | 3.17 | 4.72 | 68.9 |
| | Minimum | 1,630 | 1,620 | 2,510 | 3,415 | 1.75 | 1.00 | 60.0 |
| | Maximum | 3,505 | 3,565 | 4,420 | 5,440 | 7.00 | 7.80 | 80.0 |
| | Range | 1,875 | 1,945 | 1,910 | 2,025 | 5.25 | 6.20 | 20.0 |
| | Standard deviation | 505 | 506 | 483 | 495 | 0.79 | 1.35 | 4.9 |
| All data | Mean | 2,980 | 2,990 | 3,880 | 4,695 | 3.31 | 5.47 | 69.3 |
| | Minimum | 1,310 | 1,370 | 2,120 | 2,615 | 1.25 | 1.50 | 58.0 |
| | Maximum | 4,425 | 4,430 | 5,300 | 6,065 | 8.00 | 8.00 | 78.0 |
| | Range | 3,115 | 3,060 | 3,180 | 3,450 | 6.75 | 6.50 | 20.0 |
| | Standard deviation | 559 | 557 | 522 | 561 | 1.004 | 1.29 | 3.5 |

Note: 1 psi = 6.9 kPa. 1 in. = 2.5 cm. 1 F = 1.8 (C) + 32.

**Table 4. Concrete quality.**

| Supplier | Water-Cement Ratio | Mean Strength, 28-Day (psi) | Standard Deviation (psi) | Coefficient of Variation (percent) | Rating of Concrete Control[a] |
|---|---|---|---|---|---|
| A | 0.49 | 5,025 | 331 | 6.6 | Excellent |
| A | 0.53 | 4,900 | 407 | 8.3 | Excellent |
| A | 0.70 | 3,775 | 498 | 13.2 | Good |
| B | 0.49 | 5,020 | 328 | 6.5 | Excellent |
| C | 0.47 | 4,820 | 344 | 7.1 | Excellent |
| D | 0.47 | 4,525 | 264 | 5.8 | Excellent |
| D | 0.63 | 4,020 | 533 | 13.3 | Good |

Note: 1 psi = 6.9 kPa.

[a]ACI 214.

**Table 5. Repeatability of results of accelerated and normal strength tests.**

| | Accelerated Curing | | | Normal 28-Day Curing | | |
|---|---|---|---|---|---|---|
| Supplier | Mean Range (psi) | Standard Deviation (psi) | Coefficient of Variation (percent) | Mean Range (psi) | Standard Deviation (psi) | Coefficient of Variation (percent) |
| A | 157 | 139 | 4.69 | 203 | 180 | 3.78 |
| B | 125 | 111 | 3.30 | 201 | 178 | 3.60 |
| C | 171 | 152 | 4.91 | 236 | 209 | 4.43 |
| D | 135 | 120 | 4.27 | 195 | 173 | 3.98 |
| Avg | 145 | 129 | 4.32 | 217 | 192 | 4.11 |

Note: 1 psi = 6.9 kPa.

**Table 6. Relationships of uncorrected-accelerated and 28-day strengths, corrected-accelerated and 28-day strengths, and 7-day and 28-day strengths.**

| | | | Regression Equation | | | |
|---|---|---|---|---|---|---|
| Strength | Supplier | Number of Samples | Constant | Slope | Standard Error of Estimate (psi) | Correlation Coefficient |
| Uncorrected-accelerated and 28-day[a] | A | 100 | 2,190 | 0.88 | 310 | 0.86 |
| | B | 35 | 3,040 | 0.57 | 275 | 0.60 |
| | C | 30 | 2,134 | 0.86 | 333 | 0.73 |
| | D | 48 | 2,405 | 0.72 | 339 | 0.73 |
| | All data | 213 | 2,284 | 0.80 | 333 | 0.80 |
| Corrected-accelerated and 28-day[a] | A | 100 | 2,118 | 0.90 | 309 | 0.86 |
| | B | 35 | 3,024 | 0.57 | 268 | 0.63 |
| | C | 30 | 2,238 | 0.81 | 355 | 0.68 |
| | D | 48 | 2,381 | 0.72 | 335 | 0.74 |
| | All data | 213 | 2,263 | 0.81 | 333 | 0.80 |
| Seven- and 28-day[b] | A | 100 | 1,027 | 0.95 | 272 | 0.90 |
| | B | 35 | 1,758 | 0.78 | 263 | 0.65 |
| | C | 30 | 1,145 | 0.92 | 272 | 0.83 |
| | D | 48 | 1,322 | 0.85 | 279 | 0.83 |
| | All data | 213 | 1,030 | 0.94 | 269 | 0.87 |

Note: 1 psi = 6.9 kPa.

[a]Regression equation for 28-day strength = constant + slope X (accelerated strength).

[b]Regression equation for 28-day strength = constant + slope X (7-day strength).

**Table 7. Correction factors for discrepancies in testing time.**

| Age at Test (hours) | Correction Factor (psi) | Age at Test (hours) | Correction Factor (psi) |
|---|---|---|---|
| 36 | 275 | 49 | -17 |
| 37 | 250 | 50 | -34 |
| 38 | 225 | 51 | -50 |
| 39 | 200 | 52 | -67 |
| 40 | 175 | 53 | -84 |
| 41 | 150 | 54 | -100 |
| 42 | 125 | 55 | -112 |
| 43 | 100 | 56 | -125 |
| 44 | 80 | 57 | -137 |
| 45 | 60 | 58 | -150 |
| 46 | 40 | 59 | -167 |
| 47 | 20 | 60 | -185 |
| 48 | 0 | | |

Note: 1 psi = 6.9 kPa.

| Supplier | Accelerated/28-Day | 7-Day/28-Day |
|---|---|---|
| A | 61 | 81 |
| B | 69 | 84 |
| C | 64 | 83 |
| D | 63 | 82 |
| All data | 63 | 83 |

The 7-day strengths slightly exceed 80 percent of the 28-day strengths, and the accelerated tests vary from 60 to 68 percent.

Figures 2 and 3 show the combined data for tests of accelerated versus 28-day strengths and 7-day versus 28-day strengths.

## ACCELERATED STRENGTH TESTS VERSUS METHOD USING EXPANDED POLYSTYRENE MOLD

The results of field evaluation of accelerated strength tests reported by Smith and Tiede (2), Malhotra and Zoldners (3), and Rodway and Ward (4) are compared with those of the present investigation. The method used and the correlations obtained by different investigations are given in Table 8. Although the slopes and the constant of the regression equation are quite different, the correlation coefficients are all between 0.8 and 0.9, and the standard error of the correlation in all three cases is in the range of 300 to 350 psi (2068 to 2413 kPa). The slightly lower correlation coefficient obtained in this study (0.8) may be attributable to the narrow range in results of 28-day compressive tests of the concrete used to establish the relationship (i.e., maximum/minimum value).

The relationships between accelerated and 28-day tests, from different studies, are shown in Figure 4. Although there is a general agreement in the trend, the origins [at 1,000 psi (6895 kPa)] or the slopes of the lines are quite different. This is not surprising since the procedures of the accelerated-curing methods used are different and the cement and concrete characteristics vary with localities.

## CONCLUSIONS

Expanded polystyrene molds, such as those used to protect concrete cylinders against frost and jarring damage, can be used for field evaluation of self-cured, accelerated strengths of concrete specimens in routine quality control of concrete. Under the conditions in this study, the field evaluation indicated that the method is simple, practical, and reliable because

1. It makes use of expanded polystyrene molds of normal dimensions and involves no special equipment and procedures,
2. The complete test can be done during normal working hours,
3. The repeatability of test is equal to or better than the presently accepted standard 28-day strength test, and
4. The reliability of this method compares favorably with that of other accelerated test methods in predicting the 28-day strength.

This study indicates that an accelerated testing procedure using expanded polystyrene molds shows considerable promise and that further study should be made to investigate the effects of special environmental conditions and concrete mixes.

**Figure 2. Two-day uncorrected-accelerated versus 28-day strength results.**

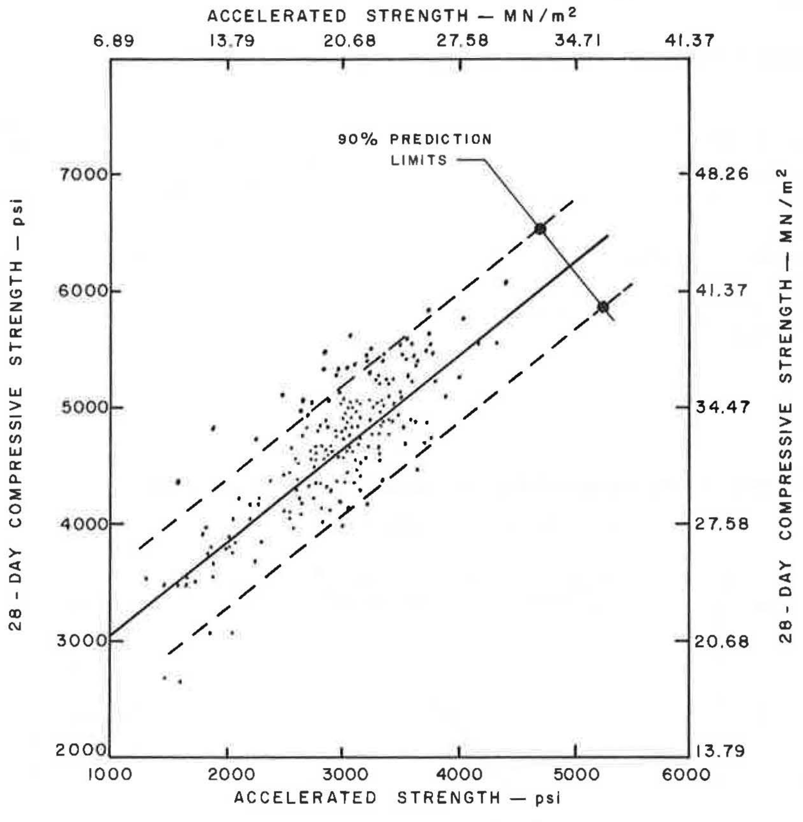



**Figure 3. Seven-day versus 28-day strength results.**

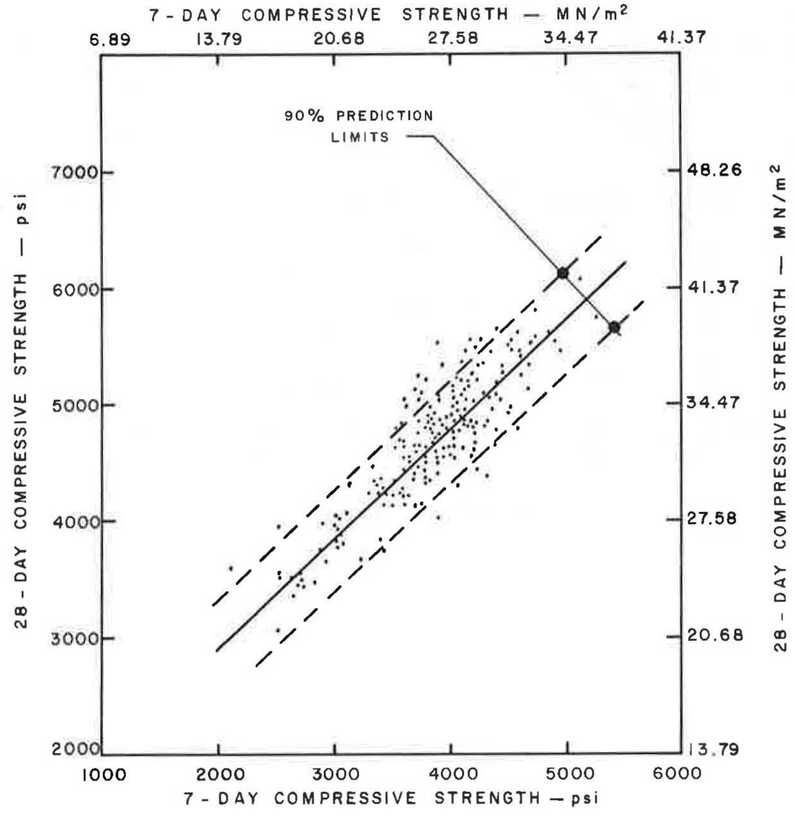


**Table 8. Results of various field evaluations of accelerated strength.**

| Investigators | Method Used | Sample Size | Regression Equation | Correlation Coefficient | Standard Deviation (psi) |
|---|---|---|---|---|---|
| Smith and Tiede | Autogenous | — | $R_{28} = 1.35\ R_a + 1{,}180$ psi | — | 301 |
| Rodway and Ward | Modified boiling method | 265 | $R_{28} = 1.03\ R_a + 2{,}280$ psi | 0.89 | 514 |
| Malhotra and Zoldners | Modified boiling method | 9 | $R_{28} = 1.29\ R_a + 1{,}801$ psi | 0.87 | 348 |
| Bisaillon, Fréchette, and Keyser | Expanded polystyrene mold | 213 | $R_{28} = 0.81\ R_a + 2{,}263$ psi | 0.80 | 333 |

Note: 1 psi = 6.9 kPa.

**Figure 4. Accelerated and 28-day strength results from different studies.**

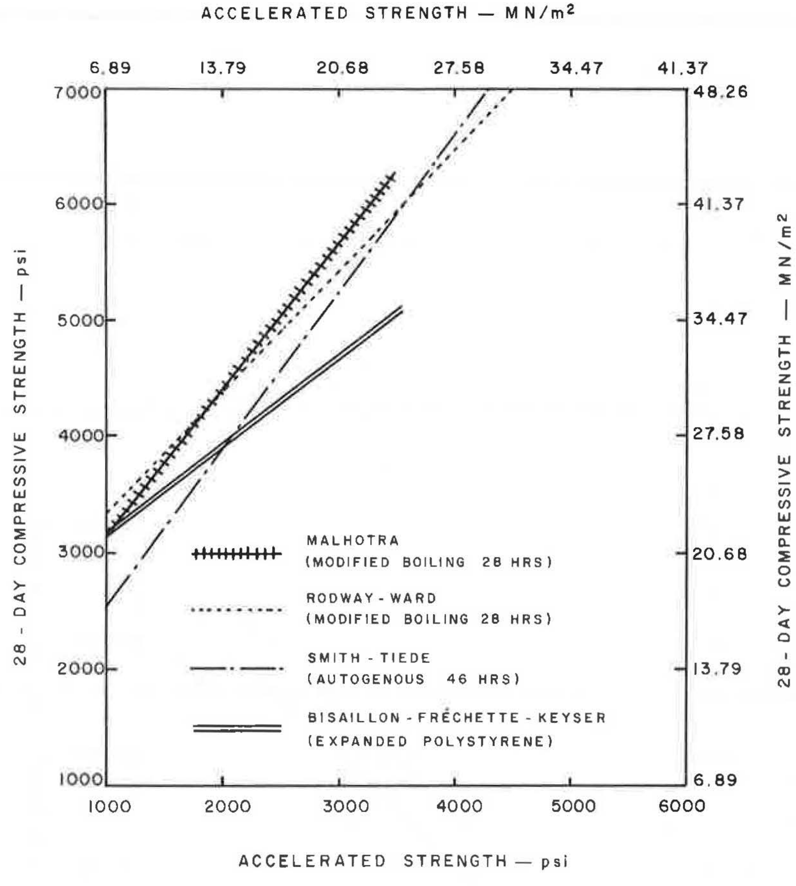
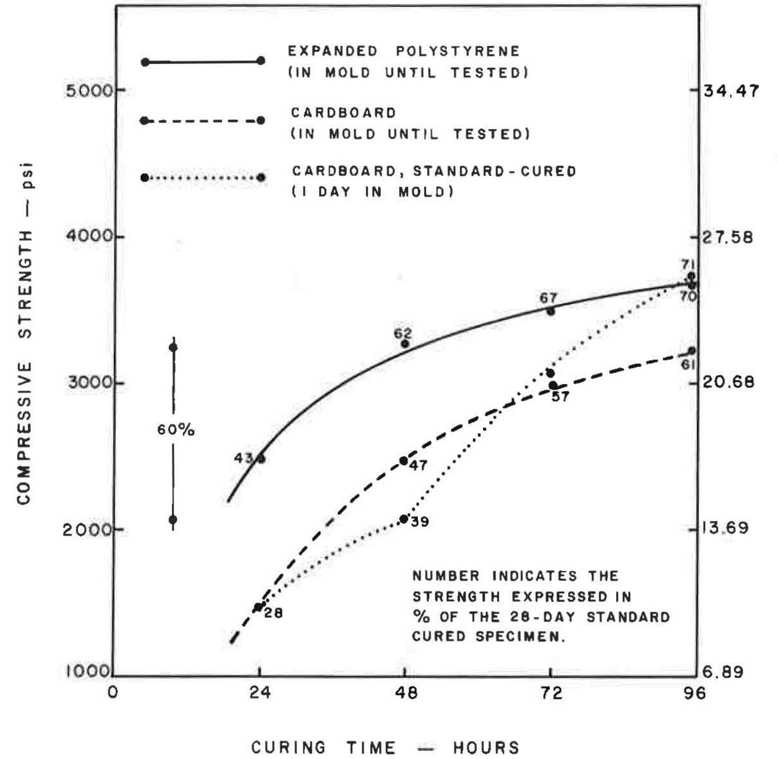


**Table 9. Test variables investigated.**

| Series of Test | Mold Type | Curing Time (hours) In Mold at Room Temperature | In Curing Room |
|---|---|---|---|
| 1 | Cardboard | 24 | 24 |
| 2 | Cardboard | Until tested | Nil |
| 3 | Expanded polystyrene | Until tested | Nil |

**Figure 5. Curing time versus strength for three curing conditions.**



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# APPENDIX

## STRENGTH GAIN OF CONCRETE CURED IN EXPANDED POLYSTYRENE VERSUS CARDBOARD MOLDS

Three series of concrete cylinders were molded and tested at 24, 48, 72, and 96 hours and at 28 days. The test variables investigated are given in Table 9.

The results of curing time and various compressive strengths are shown in Figure 5. Each point represents the average of six tests. The effect of self-cured accelerating action of the expanded polystyrene mold on the compressive strength of concrete at very early ages (less than 2 days) is clearly shown.