CONF-810801--53

MASTER

# TESTING PROGRAM FOR CONCRETE AT TEMPERATURES TO 894°K*

D. J. Naus, C. B. Oland and G. C. Robinson

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830 USA

MGW

ABSTRACT

A test program was conducted to define the variations in mechanical properties of a limestone aggregate concrete and a lightweight insulating concrete exposed to elevated temperatures. Four test series were conducted: (1) unconfined compression, (2) shear, (3) rebar bond, and (4) sustained loading (creep).

Unconfined compression tests were conducted on cylindrical test specimens fabricated from both standard weight and lightweight insulating concretes. Specimens were subjected to temperatures ranging from ambient to 894°K for periods of exposure of 14 days. Results obtained from the standard weight and the lightweight concrete specimens indicate that for temperature exposures up to 644°K and 533°K, respectively, the compressive strengths increased relative to 28-d room-temperature cured control specimens, but for temperatures above these values strengths decreased steadily with increasing temperature. For both types of concrete the compressive strain at ultimate load increased and the modulus of elasticity decreased as the exposure temperature increased.

S-shaped, parallelepiped specimens were used to determine the effects of elevated temperature exposure on the shear strength of limestone aggregate concrete. Specimens were subjected to thermal stabilization at temperatures up to 894°K for 14 days. Results indicate that the shear strength was inversely proportional to the exposure temperature.

Tests were conducted to determine the effect of exposure temperature on the concrete-rebar slip-load behavior. These tests were conducted using 0.30-m standard weight concrete cubes containing No. 11 reinforcing bars, which were embedded vertically. Specimens were exposed to thermal stabilization temperatures up to 894°K for 14 days prior to testing. Results indicate a decreasing trend for the bond stress at a specified slip interval as the exposure temperature increased.

Sustained load tests were conducted on limestone aggregate cylindrical specimens to determine their deformational behavior under sustained loading at elevated temperature. Specimens were loaded to either 20% or 50% of their design 28-day reference compressive strength value and exposed to thermal stabilization temperatures up to 811°K for 60 days. Total specimen length changes due to loading, thermal expansion, specimen modulus change with temperature, and moisture loss were monitored throughout the 60-day test period.

---

*Research sponsored through the CRBRP Project Office, U.S. Department of Energy, under contract W-7405-eng-76 with Union Carbide Corporation.

## 1. Introduction

Concrete temperatures in a Liquid Metal Fast Breeder Reactor (LMFBR) in excess of normal code limits can result from postulated large sodium spills in steel lined cells, both inerted and air-filled. Since elevated temperature concrete property data which may have application for providing a basis for the design and evaluation of such postulated accident conditions was limited, an interim testing program [J. P. Callahan et al., 1] was conducted to define the strength variations of a limestone aggregate concrete at temperatures from ambient to 1033°K. Results from the interim program were used as a basis for the development of the present testing program [C. B. Oland et al., 2] so that it would sufficiently define all physical (thermal) and mechanical (strength) concrete properties under prototypic thermal accident conditions. More specifically, the objective of the investigation was to define the variations in physical and mechanical properties of a limestone aggregate structural concrete and a lightweight insulating concrete exposed to temperatures ranging from ambient to 894°K. To meet this objective five test series were conducted: (1) unconfined compression, (2) shear, (3) concrete-rebar bond, (4) sustained load (creep), and (5) physical properties. Results of the first four test series are presented herein and the fifth test series is presented as another paper [H. Hirth et al., 3].

## 2. Concrete Mix Criteria and Curing

Specimens were cast from either a structural limestone aggregate concrete or an insulating lightweight concrete. Mix criteria for the two basic mixes are presented in Table I. Specimens were demolded between 24 and 48 hours after casting and submerged in galvanized steel curing tanks which contained a saturated limewater solution. Standard weight specimens remained in the curing tanks until they were removed at 28 or 60 d for control tests, or until heating was initiated when the specimens were 60 to 90 d old. Twenty-eight days after casting, the lightweight concrete specimens were removed from the curing tank and placed into an environmental chamber (297°K ± 2°K and 50 ± 10% RH) until heating was initiated when the specimens were 60 to 90 d old. During the curing period ends of cylindrical specimens were machined so that they met requirements for flatness and planeness.

## 3. Test Specimen Description

Cylindrical test specimens 0.30 m by 0.15 m diam. were used for the control, unconfined compression, and sustained load test series. S-shaped parallelepiped specimens, Fig. 1, were used for the shear tests and 0.30 m cube concrete specimens containing a No. 11 rebar embedded vertically were used for the concrete-rebar bond tests. Structural limestone aggregate specimens were used for all test series. Lightweight concrete specimens were evaluated only in the unconfined compression test series. A minimum of three specimens were tested for each test condition.

## 4. Testing Procedures

Three separate testing facilities were developed to satisfy the required testing criteria: (1) unconfined compression and shear, (2) concrete-rebar bond, and (3) sustained load. All elevated temperature specimens were heated in an open-hot condition and tested in individually controlled ovens equipped with loading platens and instrumentation assemblies.

Unconfined compression tests were performed using the test setup shown in Fig. 2. The testing procedure consisted of placing the cylindrical test specimen into the appropriate compression test furnace-platen assembly, installing thermocouples, heating the specimen at a rate of 17°K/hr to the scheduled thermal stabilization temperature [339, 380, 450, 533, 644, 755 or 894°K (894°K not considered for lightweight concrete specimens)], maintaining the thermal stabilization temperature for 14-d, transferring the test furnace-platen assembly to the testing machine, calibrating the instrumentation, and loading the specimen while at temperature to failure at a rate of 0.34 MPa/s or less. Cylinder length and diameter changes were continuously monitored as a function of load. This procedure was repeated for each specimen in the test series. Compressive strength, modulus of elasticity, stress-strain, and Poisson's ratio (not determined for lightweight concrete specimens) data were determined for each specimen.

Specimen preparation, heatup, and thermal stabilization procedures for the shear test series were similar to those used for the unconfined compression tests. After a thermal stabilization period of 14-d the test furnace-platen assembly was transferred to the testing machine and the test specimen while at temperature was loaded in compression at a rate of 6.67 kN/s or less, until the maximum load was reached, and the load started to decrease. The shear strength was then evaluated by dividing the maximum load by the area of the predesignated shear plane, Fig. 1.

The concrete-rebar bond test setup is shown in Fig. 3. The test procedure consisted of placing the cubical concrete specimen containing a rebar and several thermocouples in the test furnace-platen assembly, heating the specimen at a rate of 17°K/hr to the thermal stabilization temperature (same as preceeding series)[@], maintaining the temperature for 14-d, calibrating the instrumentation, and applying load at a rate of 0.35 MPa/s or less to the rebar while the concrete cube was restrained. Loading was terminated when either the rebar yielded, the concrete failed, or a load of 445 kN was reached. A continuous record of load vs concrete-rebar displacement was obtained during each test.

Sustained load tests were conducted using the test setup shown in Fig. 4. The testing procedure consisted of placing the cylindrical test specimen containing thermocouples in the test furnace-platen assembly, loading the specimen to either 20% (533 and 811°K) or 50% (339, 380 and 450°K) of its 28-d design reference compressive strength (31.7 MPa), heating the specimen at a rate of 17°K/hr to its scheduled thermal stabilization temperature (339, 380, 533 or 811°K), and maintaining the thermal stabilization temperature for 60 days followed by permitting the specimen to slowly cool to ambient. Specimen load, length change and temperature were continuously monitored throughout the heat-up, thermal stabilization, and cool-down periods.

## 5. Results

Table II presents a summary of results obtained from the linestone aggregate standard weight (structural) concrete and the lightweight concrete unconfined compressive strength tests. Results obtained from the standard weight concrete tests indicate that for tem-

---

[@] For thermal stabilization temperatures in excess of 450°K there was a 6 h thermal stabilization period at 450°K to permit excess moisture to be driven from the test article. This was followed by continued heating at 17°K/h to the test temperature.

perature exposures up to 644°K the compressive strength generally increased relative to 28-d room-temperature moist cured specimens, however, for temperatures above this value the strengths decreased steadily with increasing exposure temperature. For the lightweight insulating concrete a similar trend was observed relative to 28-d reference values with strength increases, or only slight strength decreases, observed up to 533°K followed by a steady decrease in strength with increasing exposure temperature. The compressive strain at ultimate load increased and the modulus of elasticity steadily decreased with increasing exposure temperature for both types of concrete investigated.

Figure 5 presents the effect of thermal stabilization temperature on the shear strength of the standard weight concrete. Results indicate that the shear strength relative to 28-d reference values was inversely proportional to the exposure temperature.

Table III presents the effect of thermal stabilization temperature on the concrete-rebar bond stress at specified slip intervals. Results indicate a trend for the bond stress at a specified slip interval to decrease as the exposure temperature increased.

Figure 6 presents sustained load test results for the standard weight concrete specimens subjected to sustained loads of 50% of the 28-d design reference compressive load and a thermal stabilization temperature of 811°K. Other results obtained in the test series were similar except that the plots were translated either up or down depending on the combination of load and thermal stabilization temperature imposed on the test specimen. Specimen length changes resulted from loadings, thermal expansion, modulus change with temperature, and moisture loss. Specimen behavior within each concrete batch was consistent, but specimen behavior from batch to batch for the same loadings conditions exhibited somewhat differing displacement histories. No specimen failures occurred under the combinations of load and temperature investigated.

## REFERENCES

[1] J. P. Callahan, G. C. Robinson, and R. C. Burrow, "Uniaxial Compressive Strength of Concrete for Temperatures Reaching 1033°K," Nuclear Engineering and Design, Vol. 45, Issue 2, pp. 439-448 (1978).

[2] C. B. Oland, G. C. Robinson, J. R. Dougan, and J. P. Callahan, "Plan for the Determination of Mechanical and Thermal Properties of Concrete to Temperatures of 621°C (1150°F)," ORNL/TM-6234, Oak Ridge National Laboratory (September 1978).

[3] H. Hirth, M. Polivka, and D. Pirtz, "Thermal Properties of Concrete at Temperatures to 894°K," Section H, Sixth International Conference on Structural Mechanics in Reactor Technology (August 1981).

*Research sponsored through the CRBRP Project Office, U. S. Department of Energy, under contract W-7-05-eng-26 with Union Carbide Corporation.

Table I

Concrete Mix Criteria

| Material | Standard Weight Concrete [$\text{kg/m}^3$] | Lightweight Insulating Concrete [$\text{kg/m}^3$] |
|---|---|---|
| Cement, Type II | 242.1 | 400.5 |
| Flyash | 80.7 | — |
| Perlite | — | 112.1 |
| Aggregate, retained (oven-dry weights) | | |
| 9.5 mm (3/8 in.) | 626.5 | — |
| No. 4 | 326.9 | — |
| No. 8 | 119.2 | 52.9 |
| No. 16 | 221.3 | 97.7 |
| No. 30 | 173.2 | 102.5 |
| No. 50 | 188.1 | 83.3 |
| No. 100 | 93.1 | 41.6 |
| Pan | 52.2 | 22.4 |
| Water | 177.4 | 292.5 |
| Air-entraining agent | 950 ml | 1150 ml |
| Water reducer | Manufacturer's recommendations | |
| Required Properties | | |
| Slump, mm | 25-76 | 51-127 |
| Air content, % | 4-8 | 10 plus |
| Unit weight, $\text{kg/m}^3$ | | |
| Wet | 2343 ± 48 | 1249 ± 64 |
| Air dry | — | 1073 ± 32 |
| Compressive strength (28 days), MPa | 31.70 minimum | 6.89 minimum |

Table II

Unconfined Compression Test Result Summary

| Mix Designation | | Thermal Stabil. Temp., °K | Comp. Strength, MPa | Residual Strength, % 28-d | Comp. Modulus of Elasticity, GPa | Residual Modulus, % 28-d | Comp. Strain at Ultimate Strength, με | Poisson's Ratio, ν |
|---|---|---|---|---|---|---|---|---|
| Batch 1 | Std.Wt. | 339 | 41.6 | 144.1 | 28.6 | 96.5 | 2060 | 0.17 |
| | | 380 | 34.9 | 120.7 | 24.8 | 83.7 | 1590 | 0.21 |
| | | 450 | 36.5 | 126.3 | 22.2 | 74.9 | 2050 | 0.19 |
| | | 533 | 38.0 | 131.6 | 22.0 | 74.2 | 2720 | 0.22 |
| | | 644 | 28.3 | 98.0 | 11.2 | 37.8 | 3560 | 0.20 |
| | | 755 | 26.5 | 91.6 | 10.8 | 36.4 | 5270 | 0.17 |
| | | 894 | 16.1 | 55.8 | 4.8 | 16.2 | 6870 | 0.23 |
| Batch 3 | Std.Wt. | 339 | 40.5 | 152.9 | 26.8 | 99.7 | 2270 | 0.17 |
| | | 380 | 37.4 | 141.4 | 26.4 | 98.2 | 1990 | 0.23 |
| | | 450 | 38.2 | 144.4 | 22.6 | 84.0 | 2350 | 0.24 |
| | | 533 | 34.4 | 130.0 | 17.4 | 64.7 | 3100 | 0.21 |
| | | 644 | 28.5 | 107.7 | 12.4 | 46.1 | 4150 | 0.19 |
| | | 755 | 24.2 | 91.3 | 11.6 | 43.1 | 4460 | 0.17 |
| | | 894 | 15.8 | 59.5 | 5.2 | 19.3 | 7520 | 0.22 |
| Batch 5 | Std.Wt. | 339 | 47.3 | 127.0 | 33.8 | 101.8 | 2070 | 0.23 |
| | | 380 | 42.3 | 113.6 | 38.6 | 116.2 | 1280 | 0.32 |
| | | 450 | 45.0 | 120.8 | 34.6 | 104.2 | 1850 | 0.30 |
| | | 533 | 42.6 | 114.4 | 21.6 | 65.0 | 2970 | 0.21 |
| | | 644 | 32.6 | 87.6 | 13.6 | 40.9 | 4070 | 0.20 |
| | | 755 | 29.4 | 79.0 | 11.0 | 33.1 | 5120 | 0.20 |
| | | 894 | 19.3 | 51.9 | 5.6 | 16.9 | 7240 | 0.23 |
| Batch 11 | Lt.Wt. | 339 | 9.7 | 107.5 | 5.0 | 92.6 | 2390 | - |
| | | 380 | 9.5 | 105.3 | 3.6 | 66.7 | 3110 | - |
| | | 450 | 8.8 | 97.5 | 3.6 | 66.7 | 2820 | - |
| | | 533 | 9.2 | 101.4 | 2.8 | 51.9 | 4100 | - |
| | | 644 | 7.3 | 80.9 | 2.6 | 48.2 | 3970 | - |
| | | 755 | 6.9 | 75.9 | 2.0 | 37.0 | 4100 | - |
| Batch 14 | Lt.Wt. | 339 | 9.3 | 103.0 | 4.2 | 74.6 | 2550 | - |
| | | 380 | 8.9 | 99.1 | 3.4 | 60.4 | 2990 | - |
| | | 450 | 8.9 | 98.6 | 3.6 | 63.9 | 3100 | - |
| | | 533 | 8.1 | 89.7 | 2.8 | 49.7 | 3550 | - |
| | | 644 | 6.8 | 75.2 | 2.0 | 35.5 | 4170 | - |
| | | 755 | 6.9 | 76.9 | 1.8 | 32.0 | 5000 | - |
| Batch 17 | Lt.Wt. | 339 | 11.7 | 99.8 | 5.8 | 80.3 | 2260 | - |
| | | 380 | 11.8 | 101.1 | 4.6 | 63.7 | 2920 | - |
| | | 450 | 11.7 | 99.8 | 4.2 | 58.1 | 3300 | - |
| | | 533 | 10.2 | 87.4 | 3.2 | 44.3 | 4030 | - |
| | | 644 | 8.9 | 75.8 | 2.8 | 38.7 | 4430 | - |
| | | 755 | 8.6 | 73.2 | 2.4 | 33.2 | 4480 | - |

## Table III

### Bond Stress vs Slip Data Summary

| Slip Interval* mm | Bond Stress [MPa] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Thermal Stabilization Temperature [°K] | | | | | | | |
| | 295 | 339 | 380 | 450 | 533 | 644 | 755 | 894 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.025 | 2.05 | 1.90 | 1.90 | 2.08 | 1.62 | 0.61 | 0.52 | 0.39 |
| 0.051 | 2.99 | 2.93 | 3.05 | 3.12 | 2.65 | 1.16 | 1.04 | 0.74 |
| 0.076 | 3.89 | 3.87 | 4.00 | 3.90 | 3.48 | 1.66 | 1.57 | 1.07 |
| 0.102 | 4.80 | 4.78 | 4.83 | 4.57 | 4.23 | 2.13 | 2.10 | 1.39 |
| 0.127 | 5.76 | 5.67 | 5.61 | 5.24 | 4.96 | 2.61 | 2.61 | 1.69 |
| 0.152 | 6.76 | 6.55 | 6.36 | 5.91 | 5.68 | 3.11 | 3.12 | 2.00 |
| 0.178 | 7.73 | 7.40 | 7.08 | 6.63 | 6.39 | 3.62 | 3.63 | 2.30 |
| 0.203 | 8.66 | 8.25 | 7.79 | 7.43 | 7.08 | 4.17 | 4.11 | 2.59 |
| 0.229 | 9.52 | 9.11 | 8.52 | 8.29 | 7.75 | 4.75 | 4.61 | 2.89 |
| 0.254 | 10.29 | 9.94 | 9.24 | 9.29 | 8.41 | 5.35 | 5.10 | 3.19 |

*In accordance with ANSI/ASTM C 234-71 "Standard Test Method for Comparing Concretes on the Basis of Bond Developed with Reinforcing Steel," Part 14, Annual Book of ASTM Standards (1979).

# Figures

Fig. 1 S-shaped parallelepiped shear test specimen.

Fig. 2 Unconfined compression test setup.

Fig. 3 Concrete-rebar bond test setup.

Fig. 4 Sustained load test setup.

Fig. 5 Effect of thermal stabilization temperature on shear strength.

Fig. 6 Sustained load microstrain vs time test result.

ORNL-DWG 78-6175

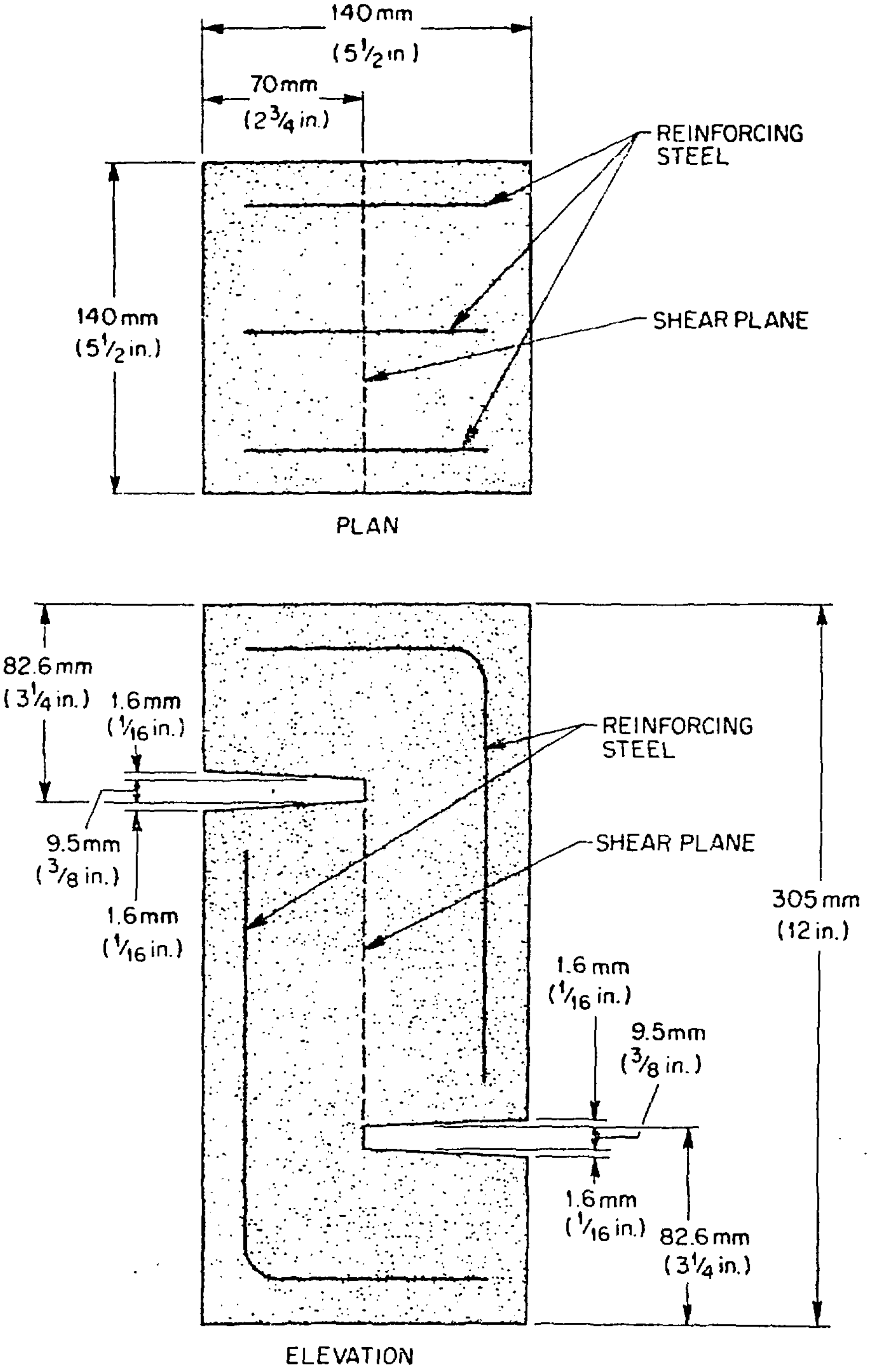

Fig. 1 S-shaped parallelepiped shear test specimen.

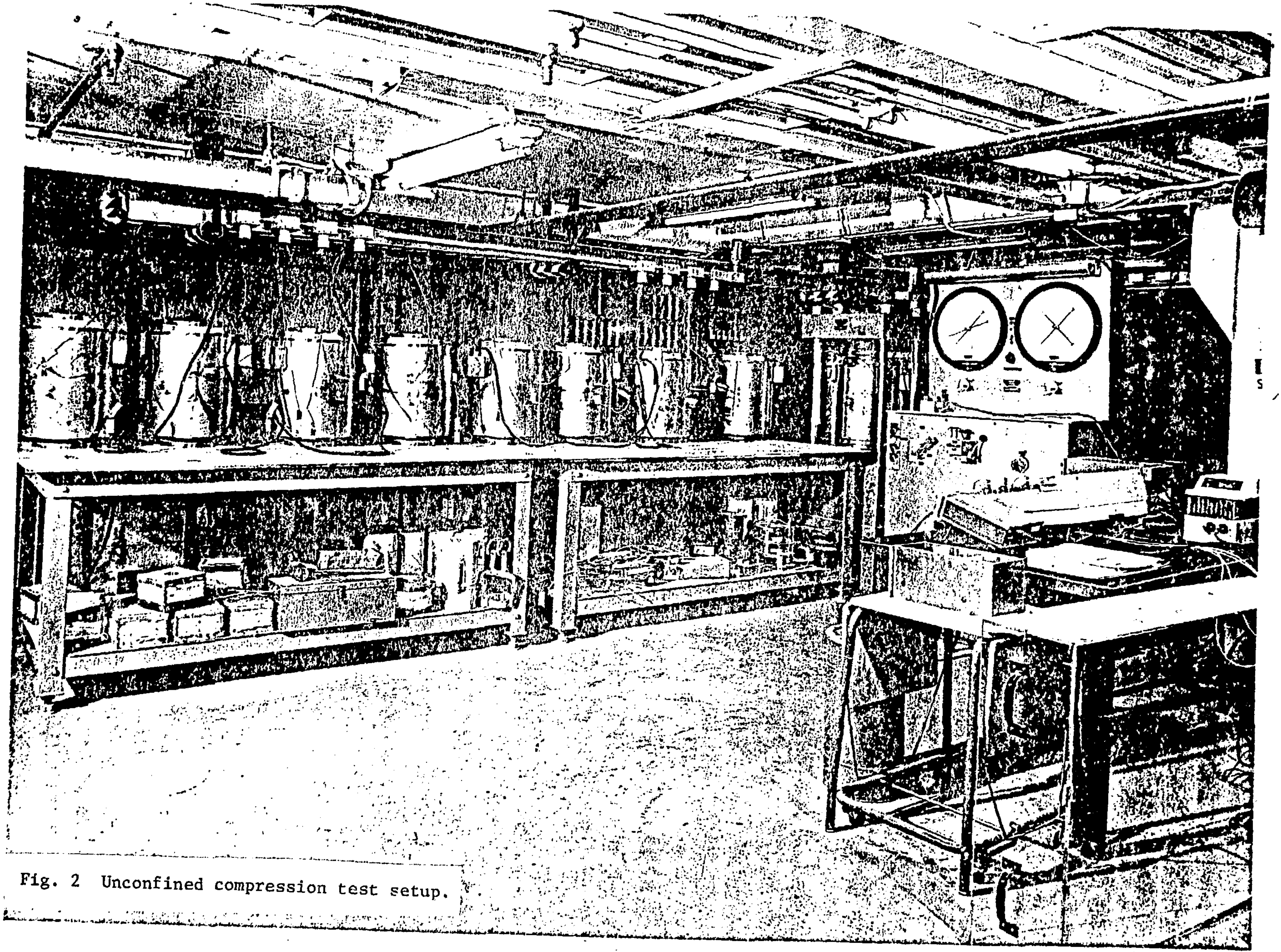

Fig. 2 Unconfined compression test setup.

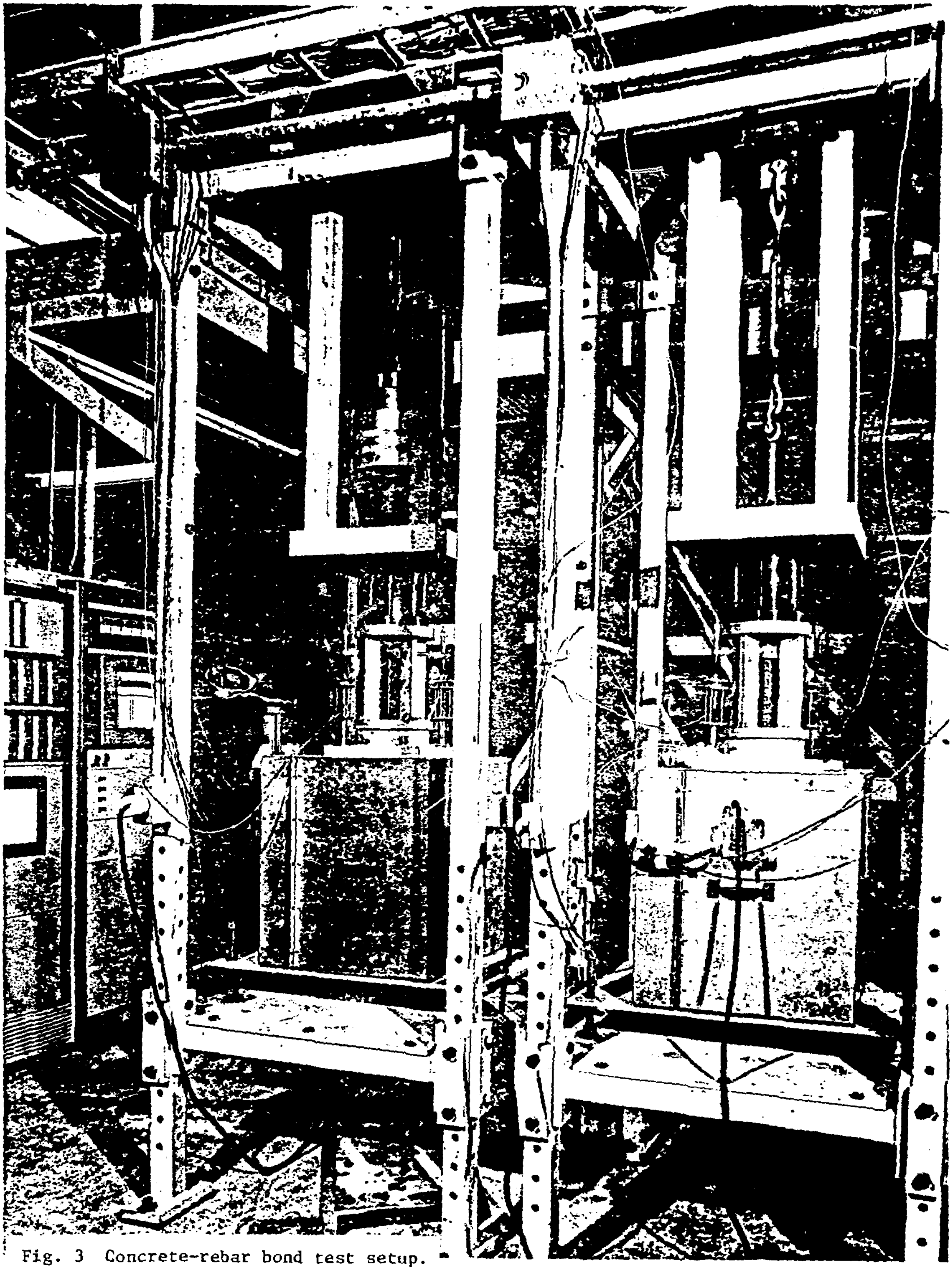

Fig. 3 Concrete-rebar bond test setup.

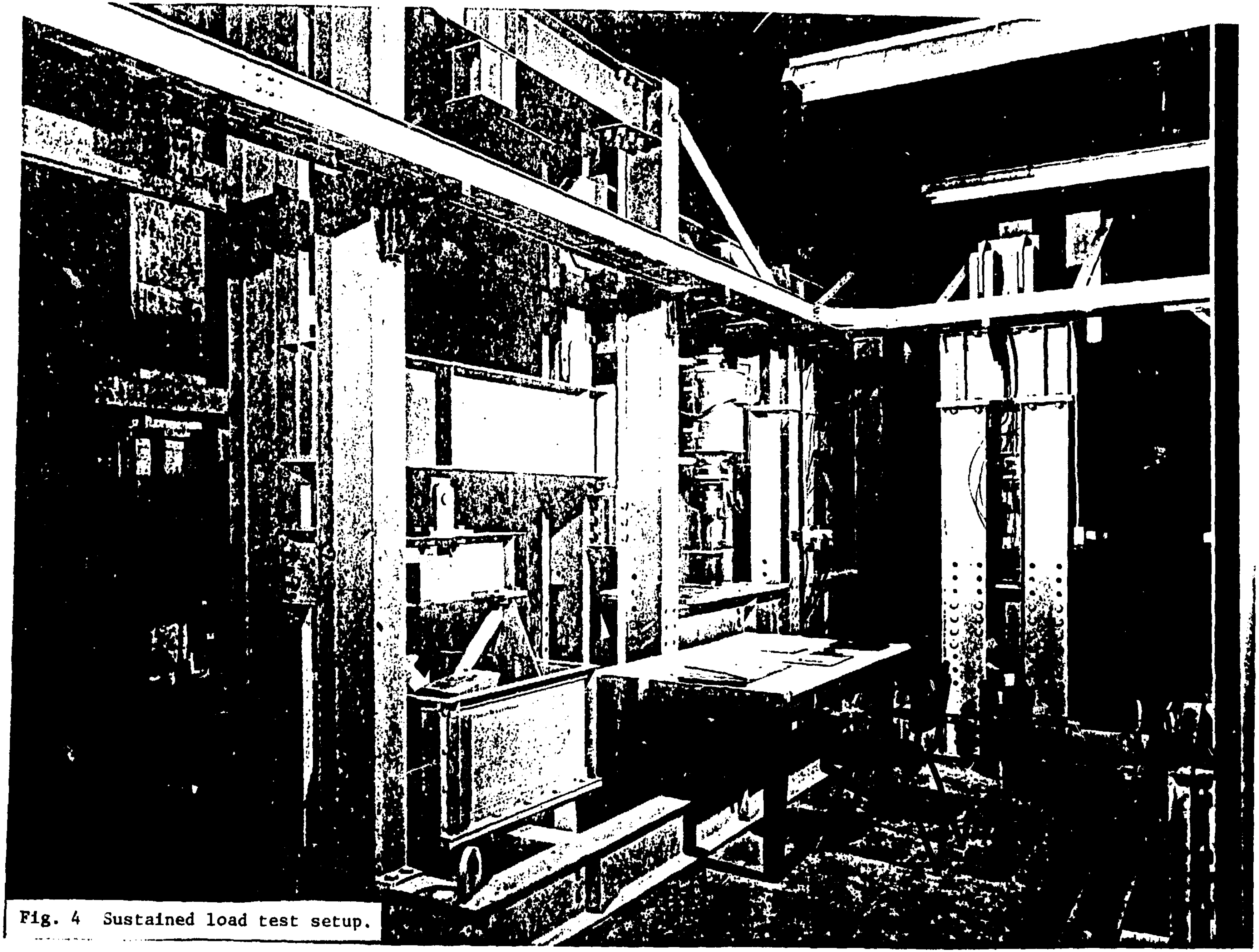

Fig. 4 Sustained load test setup.

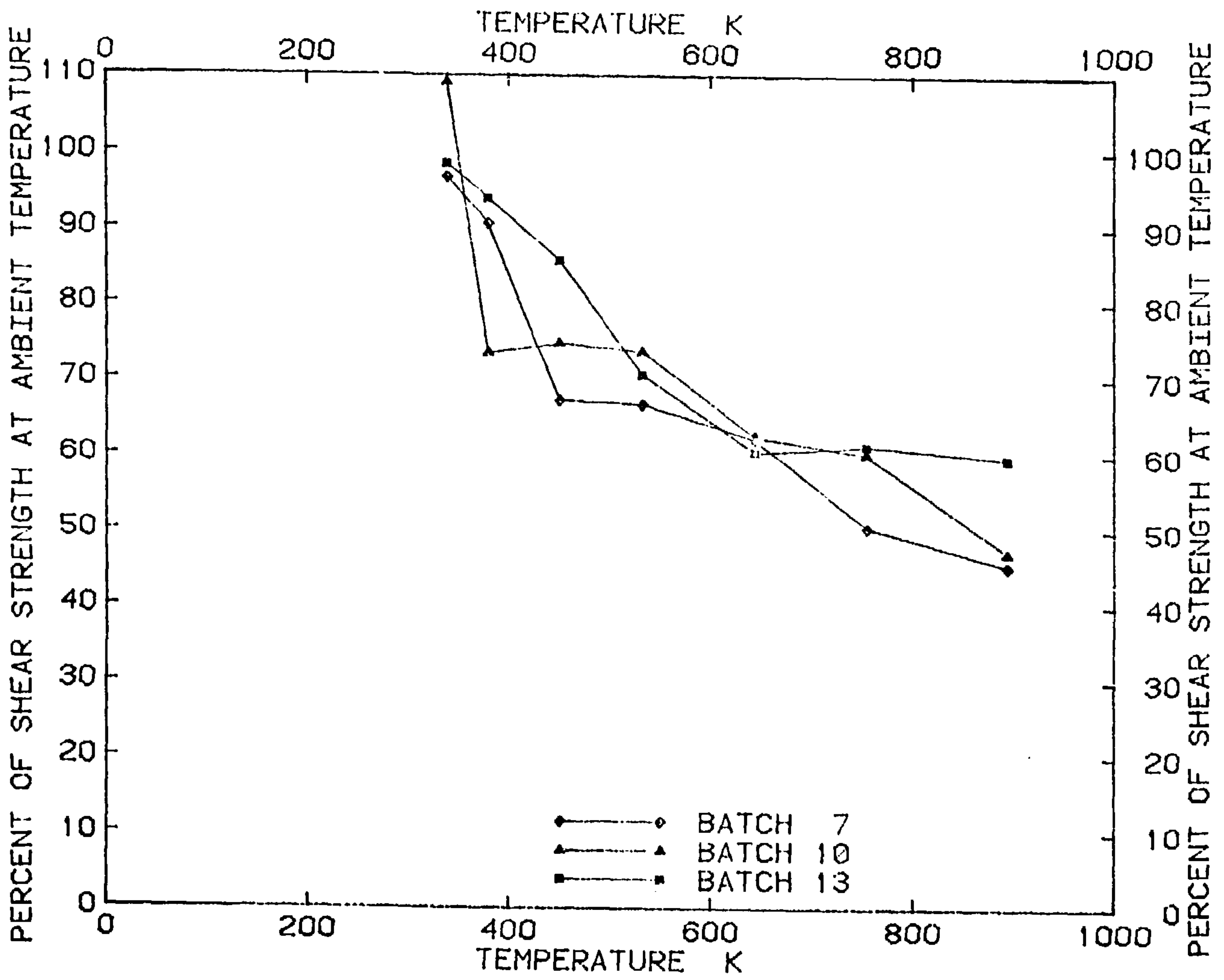

Fig. 5 Effect of thermal stabilization temperature on shear strength.

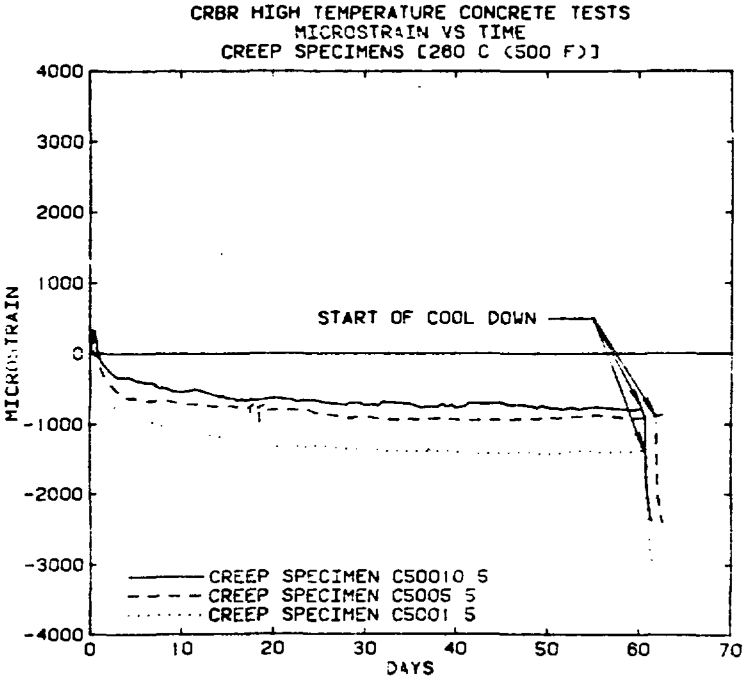

Fig. 6 Sustained load microstrain vs time test result.