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THERMAL EXPANSION OF CERTAIN ILLINOIS LIMESTONES

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ABSTRACT

The thermal expansion of 16 samples of Illinois limestones, representing the principal commercial limestone formations of the state, was observed through a range of -4° to 140° F by means of a dilatometer. This temperature range includes the usual extremes to which Illinois limestones might be exposed during a normal year.

The mean linear coefficient of thermal expansion perpendicular to the bedding of the stone throughout this temperature interval was most commonly 2.2×10^{-6} (.0000022) per degree F, but several coarse-grained limestones had coefficients that ranged as high as 3.9×10^{-6} (.0000039) per degree F. These values, respectively, are equivalent to an expansion of 0.000026 and 0.000047 inches for each foot of limestone per degree F change in temperature.

The expansion of the fine-grained limestones proceeded at a nearly constant rate throughout the test, but the coarse-grained limestones expanded more rapidly as the temperature increased.

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INTRODUCTION

Limestones exposed to the weather are subject to daily variations in temperature that may range from relatively few degrees to more than 50 degrees. During a year in Illinois, a piece of limestone exposed to air temperatures may experience temperatures ranging from -26° F to more than 100° F, a total change of over 126 degrees.

Thermal expansion and contraction is an important consideration in the design of large buildings constructed of limestone, and also may affect the long-time durability of such crushed stone products as concrete aggregates and some sewage filter stone.

The present investigation was made to obtain data on the thermal expansion of Illinois limestones in the temperature range occurring in Illinois and to determine possible relations between their texture and thermal expansion.

The thermal expansion of a solid material is usually expressed in terms of its mean linear expansion coefficient, hereafter termed expansivity, which is the mean or average amount of change in length (expansion) for each unit of length (e.g., an inch) for each degree of change in temperature.

Expansion = expansivity x original length x degrees of temperature change.

Thus the changes in length of a piece of limestone due to changes in temperature can be determined if the expansivity of the stone is known. If a limestone bar 12 inches long has an expansivity of $3 \times 10^{-6}/^\circ$ F at 40° F, when it is heated to 90° F its length will increase an amount equal to $3 \times 10^{-6} \times 12$ inches x 50 degrees, which equals 1800.0×10^{-6} inches, or 0.0018 of an inch.

Expansion of a bar of limestone 10 feet (120 inches) long whose expansivity is 3.0×10^{-6} when the temperature is raised 36° F is:

$$120 \times 3 \times 10^{-6} \times 36 = .013 \text{ inch, or nearly } 1/64 \text{ of an inch.}$$

The expansivity, or rate of expansion, of limestone is, however, rarely a constant value and usually increases slightly as the temperature increases.

PREVIOUS STUDIES

The reports of Callan (1952) and Mather et al. (1953) contain data on thermal expansion of three Illinois limestone deposits. Both list the average expansivities of samples from the same deposits in the range

35° to 135° F as follows: 2.4×10^{-6} for dense, oolitic, and fine-grained limestone from Alton, 2.6×10^{-6} for fine- to medium-grained fossiliferous limestone from Falling Spring (near Dupo), and 2.3×10^{-6} for dense, fine- to medium-grained limestone from Krause (near Columbia). Cherty specimens from Krause gave similar results, but clayey limestones gave expansivities up to 5.4×10^{-6}.

SAMPLES

The limestones selected for study represent most of the major limestone formations quarried in Illinois, although it was not possible to include all textural varieties of stone in each formation. However, a sufficient range in texture is thought to be included among the samples to reveal any major relations between texture and thermal expansion. The samples are listed in table 1.

All samples tested contained more than 90 percent calcite except samples 24 (Kinkaid Limestone) and 27 (Girardeau), both of which had a mineral content of 73 to 78 percent calcite, 5 percent quartz, 7 percent clay, and 10 to 15 percent dolomite.

Test specimens were cores drilled from large limestone blocks and were 1 inch in diameter and 4 inches long. Two cores were taken parallel to the bedding of the stone and two perpendicular to the bedding.

TESTING METHOD

The testing apparatus consisted of a closed end, quartz glass tube, which was surrounded by a liquid whose temperature could be varied from -4° F to over 140° F. The test core was placed within the tube and the temperature of the liquid lowered to -4° F overnight. The following morning the temperature was gradually raised above 140° F. As the specimen was inside the tube, it remained dry. The expansion of the core was indicated continuously by a sensitive dial indicator mounted on the tube. The indicator was actuated by a quartz glass push rod inside the tube which rested on the specimen. The temperature of the specimen was measured with a thermocouple on the top of the specimen core. The expansion and the temperature of the specimen were recorded every 1 to 1½ hours. The rate at which the temperature was increased was 0.35° to 0.40° F per minute for all samples.

RESULTS OF TESTS

Test results of thermal expansion measured perpendicular to the bedding of the limestones are given in table 1. The expansivity values, calculated from measured expansion of the specimen between -4° and 140° F, fall within the range reported for limestones occurring in other states (Johnson and Parsons, 1944; Callan, 1952; Dunn, 1963, and others).

Eleven of the 16 samples listed in table 1 had expansivities near $2.2 \times 10^{-6}/^{\circ}$ F. The Kimmswick samples, one of the Burlington samples, and one of the Kinkaid samples had expansivities near 3.5×10^{-6}. Sample 24,

TABLE 1. THERMAL EXPANSION OF ILLINOIS LIMESTONE SAMPLES PERPENDICULAR TO BEDDING

Sample no.	Geologic unit	Near	Average expansivity per degree between -4° and 140° F ($\times 10^{-6}$)	Average expansion of 10-foot bar of limestone per degree F rise in temperature (inches)
42A	Kimmswick	Thebes	3.5	.0004
42	Kimmswick	Valmeyer	3.9	.0005
41	Kimmswick	Valmeyer	3.2	.0004
26	Burlington (Quincy Bed)	Quincy	2.4	.0003
32	Burlington	Monmouth	3.1	.0004
25	Harrodsburg (Formerly Warsaw-Salem)	Mill Creek	2.2	.0003
24M	Kinkaid	Buncombe	2.5	.0003
24	Kinkaid	Buncombe	3.5	.0004
39	Rocher (Salem Fm.)	Prairie du Rocher	2.2	.0003
40	Kidd (Salem Fm.)	Prairie du Rocher	2.2	.0003
22	Fredonia (Ste. Genevieve Fm.)	Anna	1.9	.0002
J12	Omega (Mattoon Fm.)	Brubaker	2.2	.0003
12	St. Clair	Gale	2.3	.0003
27	Girardeau	Thebes	2.3	.0003
K14	St. Louis	Alton	2.3	.0003
33	Wapsipinicon	Milan	2.0	.0002

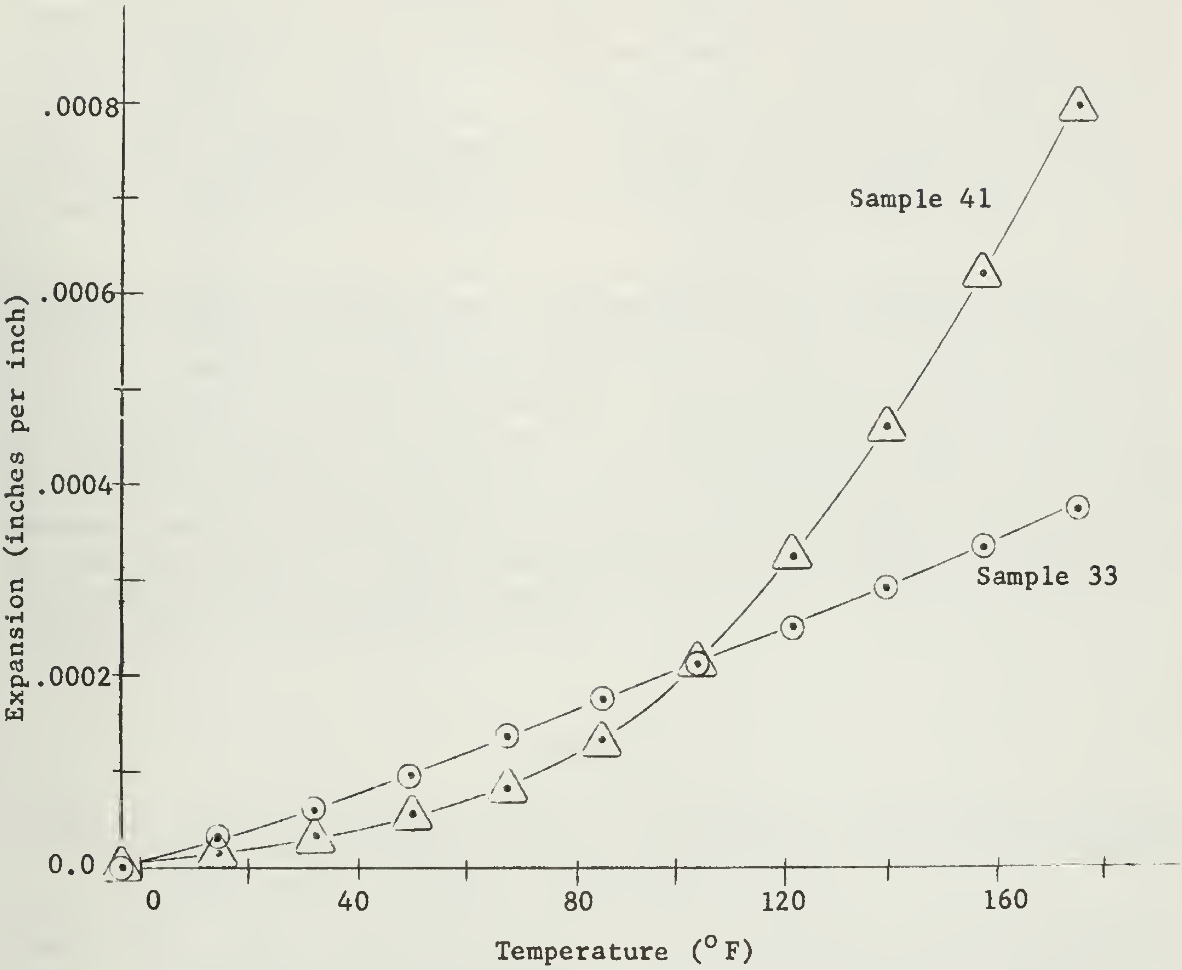

Fig. 1 - Thermal expansion curves of a fine-grained limestone (sample 33) and a coarse-grained limestone (sample 41).

the most expansive of the Kinkaid samples, contained 12 percent quartz plus clay and about 10 percent dolomite mineral grains. As each of these minerals has a greater expansivity than the mineral calcite, they tend to produce a more expansive rock. Sample 24M was not so fine grained, was essentially pure calcitic limestone, and had a lower expansivity than sample 24. Sample 42A also was a pure calcitic limestone, but it had a high expansivity, possibly related to the size and packing of the calcite particles.

Other tests on cores cut parallel to the bedding of the stone showed the fine-grained limestones generally expanded slightly more parallel to the bedding than perpendicular, whereas the coarse-grained limestones expanded slightly more perpendicular to the bedding than parallel. The rocks of intermediate grain size exhibit no consistent expansion pattern.

The temperature and expansion measurements were plotted on a graph to show the rate of expansion of the test specimens. All of the limestones showed a more or less increasing expansivity value with increasing temperature, depending on the texture of the limestone. The graph for the fine-grained sample 33 and the coarse-grained sample 41 (fig. 1) illustrate the apparent effect of grain size on expansion. The curve for sample 41 shows that, as the stone was heated, it at first expanded slowly, but as the temperature increased the limestone expanded at an increasing rate. By contrast, the curve for sample 33 is a more nearly straight line, indicating a nearly constant rate of expansion within the temperature range.

Nine specimens were heated twice or more, and their expansivities determined after reheating were compared with those obtained after first heating. The second expansivity differed from the first in each case, although, generally, by less than 10 percent. However, sample 25 expanded 22 percent more on the second heating than on the first and only 4 to 5 percent more than the first expansion on subsequent heating cycles. Sample 26 expanded 13 percent less on the second heating than it did on the first, but on the third heating cycle it expanded only 6 percent less. Most notable, however, was the fact that each time the temperature was reduced from 140° F to room temperature or below, the specimens did not contract to their original length. This apparently permanent expansion was approximately .005 percent in each case after 24 hours.

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