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Progress Report

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THERMAL EXPANSION OF DENTURE BASE RESINS

by

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Abstract

Thermal expansion measurements were made on eleven denture base materials and one sample of commercial Lucite rod. Measurements were made over a temperature range from approximately 20°C to 70°C (68° - 158°F) using the fused-quartz tube apparatus. The materials were run dry and then after having been stored in water at either 37°C (98.6°F) or 68°C (154.4°F) for several days, they were run wet. The dimensions of the molded specimens were approximately 8 inches by 7/16 inch by 7/16 inch. The results show that coefficients of thermal expansion of the methyl methacrylate denture base resins over the 20°C (68°F) to 70°C (158°F) range averaged near the approximately 90×10^{-6} per °C obtained for commercial Lucite rod. The coefficients for vinyl copolymer, epoxy, and styrene denture resins were approximately 10, 15 and 25 percent respectively below the average for the methyl methacrylate materials. Methyl methacrylate resins containing large

amounts of glass fiber had cofficients over 50 percent lower than the average of those of the other methyl methacrylate resins. Soaking in water at elevated temperatures for several days raised the coefficients of methacrylate materials by approximately 10 to 20 percent.

1. INTRODUCTION

In the field of dentistry, where dimensional accuracy is essential, thermal expansion is a very important property. In spite of this, little information has been published on the expansion of dental materials, particularly those which have been developed during the past ten years.

Some data are available on the expansion of the basic components of the various denture base resins [1]; that is, on methyl methacrylate, acrylics, styrenes, vinyls, epoxys, and various copolymers but little has been done to relate these values to dental materials as they appear on the market. A search of the information provided with the denture base materials studied disclosed that only one listed thermal expansion among the physical properties for which data were given.

This study was undertaken to obtain data on the

linear thermal expansion of denture base resins between room temperature and approximately 70°C (158°F).

2. MATERIALS AND EQUIPMENT

Included in the group of denture base materials studied (Table 1) were self-curing and heat-curing methyl methacrylates, filled methyl methacrylate, vinyl-acrylic copolymer, styrene, and epoxy resins. Measurements were also made on one specimen of commercial Lucite rod. The recommended methods of processing the denture base materials included injection and compression molding, "dry" and "wet" curing, and short and long curing cycles.

The fused quartz expansion apparatus (Figure 1) was essentially that described by Hidnert and Sweeney [2] and later modified by Hidnert [3]. A water jacket surrounding the fused quartz tube was used to control the temperature of the specimens. Water at temperatures from room temperature to 70°C was passed through the jacket by means of a Precision Scientific Company circulating water bath. Temperatures below room temperature were obtained by passing tap water through cooling coils in an ice bath and then through the water jacket.

3. PROCEDURE

Most of the thermal expansion specimens were made by mixing and curing the material according to the

manufacturers' directions. One "unit" of material was sufficient to mold a bar specimen 8 inches x 7/16 inch x 7/16 inch in the brass mold shown in Figure 2. The mold, with overall dimensions of 9 1/2 inches x 3 1/2 inches x 7/16 inch, was filled with resin, placed in a Carver Press under a load of 5,000 pounds, and held there for the length of time recommended to effect a cure. In those cases where heat was needed, the press platens were heated to the recommended temperature before the mold was placed in position and then the whole assembly was held at this temperature for the proper length of time, usually 6 to 8 hours, after which the heat was turned off and the specimen allowed to cool in the press over night. The specimen was then removed from the mold, the edges smoothed, and the length of the specimen measured.

The specimen of commercial rod was as received except for length, and the specimen of Vernonite Gel was cut from a block which had been cast at the Vernon-Benshoff Company in 1948. The specimen of Jectron was obtained from a local supply house and turned down to the proper diameter, but it was approximately 2 inches shorter than the rest of the specimens. Specimens were conditioned at a temperature of 23° ± 1°C (73.4 ± 1.8°F) and relative

humidity of 50 ± 4 percent for at least 2 or 3 days prior to being run in the thermal expansion apparatus.

To obtain thermal expansion data the specimen of resin was placed in the fused-quartz tube and the quartz plunger was placed on top of it. This assembly was then inserted into the water jacket and the dial indicator adjusted on the top of the quartz plunger. When the temperature in the water jacket and the specimen had reached the minimum desired (usually about 15°C), initial readings of the gauge and the thermometer were taken. From this point, the temperature was raised in approximately 10°C (18°F) intervals to 49°C (120°F) and in approximately 5°C (9°F) intervals from 49°C to 70°C (120° - 158°F). It was found that about 45 minutes was a sufficient time to reach equilibrium at each temperature as evidenced by cessation of movement of the indicator. Readings of the dial indicator and the thermometer in the water jacket were recorded at equilibrium, the temperature was raised to the next equilibrium point and the process was continued until the top temperature was reached. Temperature rise was controlled by a thermoregulator in the circulating water bath.

After being heated the specimens were allowed to cool down overnight in the apparatus and were run again.

This was repeated at least once more. After the runs described above had been completed, the specimens were removed from the apparatus and allowed to remain in air at a temperature of 23° ± 1°C (73.4 ± 1.8°F) and a relative humidity of 50 ± 4 percent. Some time later one specimen of each material (with one exception) was conditioned in water at 37°C (98.6°F) or 68°C (154.4°F) for at least one week and then placed in water in the quartz tube and the procedure described above repeated. In addition to the above procedure the specimen of Lucite was dried in an oven after being run wet and was then re-run in the dry condition. This specimen was weighed before and after conditioning treatments in order to determine the change in water content.

Curves of the form $y = a + bx + cx^2 + dx^3$ were fitted to the data by the method of least squares using an IBM 704 computer. Figure 3 shows the calculated curves and experimental points for three runs (dry) of Lucite. The computer provided values of y corresponding to the selected values of x = 20, 27, 37, and 70°C (68, 80.6, 98.6 and 158°F) from these curves. From these values, coefficients of linear

thermal expansion from either 20°C (68°F) or 27°C (80.6°F) to 37°C (98.6°F), from 37°C (98.6°F) to 70°C (158°F) and from either 20° or 27° to 70°C were calculated for each run. Average coefficients for each specimen were then obtained by averaging the values for two or more runs.

4. RESULTS AND DISCUSSION

Average coefficients for all of the materials in both "dry" and "wet" condition, are given in Table 2. The curves shown in Figure 4 also show average "dry" expansion of all resins included in this study. These curves were obtained by averaging, for each material, the ordinates of the calculated curves for the individual runs and converting the averages to percent change in length.

Reproducibility of the results for repeated runs of the same specimen is indicated by the standard deviations given in Table 2. In some instances, results obtained on the first run differed greatly from those obtained on later runs. Such erratic results, which may be caused by slight changes in position of the specimen during the first heating in the apparatus, were eliminated from the averages reported.

In comparison with other denture base materials, the methyl methacrylates show slight higher average coefficients.

The coefficients for vinyl-acrylic, epoxy, and styrene resins were approximately 10, 15 and 25 percent lower, respectively, than the average of the methyl methacrylate values. Methyl methacrylate resins containing large amounts of glass fiber as filler had coefficients 50 percent or more lower than those of the other methacrylate materials.

Comparison of the thermal expansion values below and above 37°C (98.6°F) shows that all of the materials, with the exception of the glass-filled resins, have higher coefficients of expansion at the higher temperatures. Apparently, the effectiveness of the glass fibers in restraining the expansion of the resin increases with increasing temperature.

Soaking in water at elevated temperatures for several days raised the coefficient of methyl methacrylate resin by approximately 16 percent on the average. Coefficients of the other denture base resins were increased to a lesser extent by the absorption of water. Table 3 shows the change in coefficient of thermal expansion of the Lucite specimen as a result of change in water content. Sufficient data have not been obtained to determine whether or not the magnitude of the change in coefficient can be related to the amount of water absorbed. Absorption of water while the thermal expansion measurements

were being made would produce an apparent increase in the coefficient of thermal expansion. However, the amount of water absorbed by the Lucite specimen as shown in Table 3 is too small to account for the increased change in length during heating according to data published by Sweeney [4] which indicates that absorption of 1 percent by weight of water results in an increase in linear dimension of 0.23 percent. It is also evident that the increase in coefficient is considerably greater than would be expected if the resin specimen and the absorbed water expanded independently as a mixture of materials. The average linear coefficient of expansion of water over the range 20°C to 70°C (68°F to 158°F) is 140×10^{-6} per °C. [5]. One percent by weight of water in a specimen of resin with a coefficient of 90×10^{-6} could be expected to increase the coefficient of the mixture by approximately 0.6×10^{-6} per °C above the expansion of the resin. The values in Table 3 show that the increase in coefficient is much greater than this. Water thus appears to increase the expansion of the resin by some means other than the thermal expansion of the water.

5. SUMMARY

The coefficient of linear thermal expansion of methyl methacrylate denture base resins, over the range

20°C to 70°C (68° - 158°F) was approximately 86 x 10^{-6} per °C when conditioned at 50 percent relative humidity. Coefficients for vinyl-acrylic, epoxy, and styrene resins were approximately 10, 15 and 25 percent, respectively, below the value for methyl methacrylate resins. Glass fiber-filled methyl methacrylate resins had coefficients approximately 50 percent below unfilled resins. Absorption of water caused increased in the thermal expansion coefficients of methyl methacrylate resins of approximately 10 to 20 percent and smaller increases in the coefficients of the other denture base resins.

REFERENCES

1. Plastic Properties Chart. Modern Plastic Encyclopedia. 1960 Edition. Plastics Catalogue Corp., New York, New York. Sept. (1959).

2. Hidnert, P. and Sweeney, W. T. Thermal expansion of magnesium and some of its alloys. BS J. Research 1:771 (1928).

3. Hidnert, P. Thermal expansion of magnesium and some of its alloys. BS J. Research 14:523 (1935).

4. Vernonite Workbench. Vol. 6, No. 3 March (1947).

5. Smithsonian Physical Tables Ninth Revised Edition. The Smithsonian Institution. Washington, D. C. (1954).

TABLE 1

MATERIALS

MATERIAL	TYPE OF RESIN	MANUFACTURER OR DISTRIBUTOR
Acralite-88	Methacrylate	Acralite Co., Inc.
Duraflow	Methacrylate	Product Research Laboratory, Inc.
Hydro-Cast	Methacrylate	Kay-See Dental Mfg. Co.
Vernonite Gel	Methacrylate	Vernon-Benshoff Co.
Vernonite P.L.	Methacrylate	Vernon-benshoff Co.
Tilon	Methacrylate	Ticonium Div. of Consolidated Metal Products Corp.
Lucite	Methacrylate	E.I. duPont deNemours and Co.
Miracle 50	Methacrylate 14% glass filled	American Consolidated Manufacturing Co.
Mystic 100	Methacrylate 20-21% glass filled	
Luxene-44	Vinyl-acrylic	Luxene, Inc.
Jectron	Styrene	Jectron Co.
Epoxolon	Epoxy	Surgident, Ltd.

TABLE 2

AVERAGE COEFFICIENTS OF LINEAR THERMAL EXPANSION per °C

	DRY						WET					
MATERIAL	20-37°C	S.D	37-70°C	S.D	20-70°C	S.D	20-37°C	S.D.	37-70°C	S.D.	20-70°C	S.D
	$x10^{-6}$		$x10^{-6}$		$x10^{-6}$		$x10^{-6}$		$x10^{-6}$		$x10^{-6}$	
Acralite-88	83.7	0.9	96.4	1.5	91.9	0.8	94.9	0.8	116.7	1.8	109.3	1.4
Duraflow	81.8	0.4	91.1	1.5	87.9	1.0	86.8	1.3	100.9	1.7	96.1	1.0
Hydro-Cast	77.2	0.3	84.1	3.8	81.8	2.6	88.0	1.6	100.2	1.3	96.0	1.3
Vernonite Gel	73.5	0.4	81.4	0.4	78.7	0.1	86.0	0.2	93.2	0.5	90.8	0.4
Vernonite P.L.	87.3	0.9	95.4	3.4	92.7	2.2	98.3	1.6	110.5	0.9	106.3	1.2
Tilon	79.0	0.7	85.4	1.6	83.2	1.6	82.5	4.0	94.9	2.6	90.7	1.8
Lucite	82.6	0.4	93.1	0.8	89.3	0.8	92.3	0.6	111.9	1.6	105.3	1.2
Miracle 50	45.5	2.7	39.8	2.6	41.7	1.2	48.3	1.2	39.2	1.8	42.3	0.9
Mystic 100	42.5	0.1	35.2	4.1	37.2	2.9	42.7*	1.3	37.1	0.8	38.4*	0.4
Luxene-44	65.4	0.6	82.4	1.0	76.6	0.6	69.2	4.6	82.2	1.0	77.8	1.0
Jectron	61.0	2.5	66.8	1.8	64.7	0.5	67.3	1.3	72.9	1.3	71.0	0.5
Epoxolon	69.2	1.8	74.0	3.1	72.8	3.1	73.0	1.2	75.3	1.3	74.5	2.9

NOTE: Correction of 0.4×10^{-6} per °C for thermal expansion of fused quartz included.

* These values were calculated from 27°C: also, this specimen was conditioned in water for only one day.

S.D. Standard Deviation.

TABLE 3

EFFECT OF WATER SORPTION ON THE COEFFICIENT OF THERMAL EXPANSION OF A SPECIMEN OF LUCITE

Conditioning of Specimen	Specimen Weight Conditioned	Cumulative Weight Change	Coefficient (20-70°C)
	grams	%	x 10^{-6}
In evacuated dessicator with Drierite for 5 mos.	47.322	----	----
In air during 4 runs	47.328	0.01	89.6
In water at 65°C for 11 days	47.932	1.29	----
In water during 3 runs	47.947	1.32	105.3
In oven at approximately 70°C for 10 days	47.401	0.17	----
In air during 3 runs	------	----	89.0
In air at 23°C and 50% R.H. for 11 mos.	47.416	0.20	----

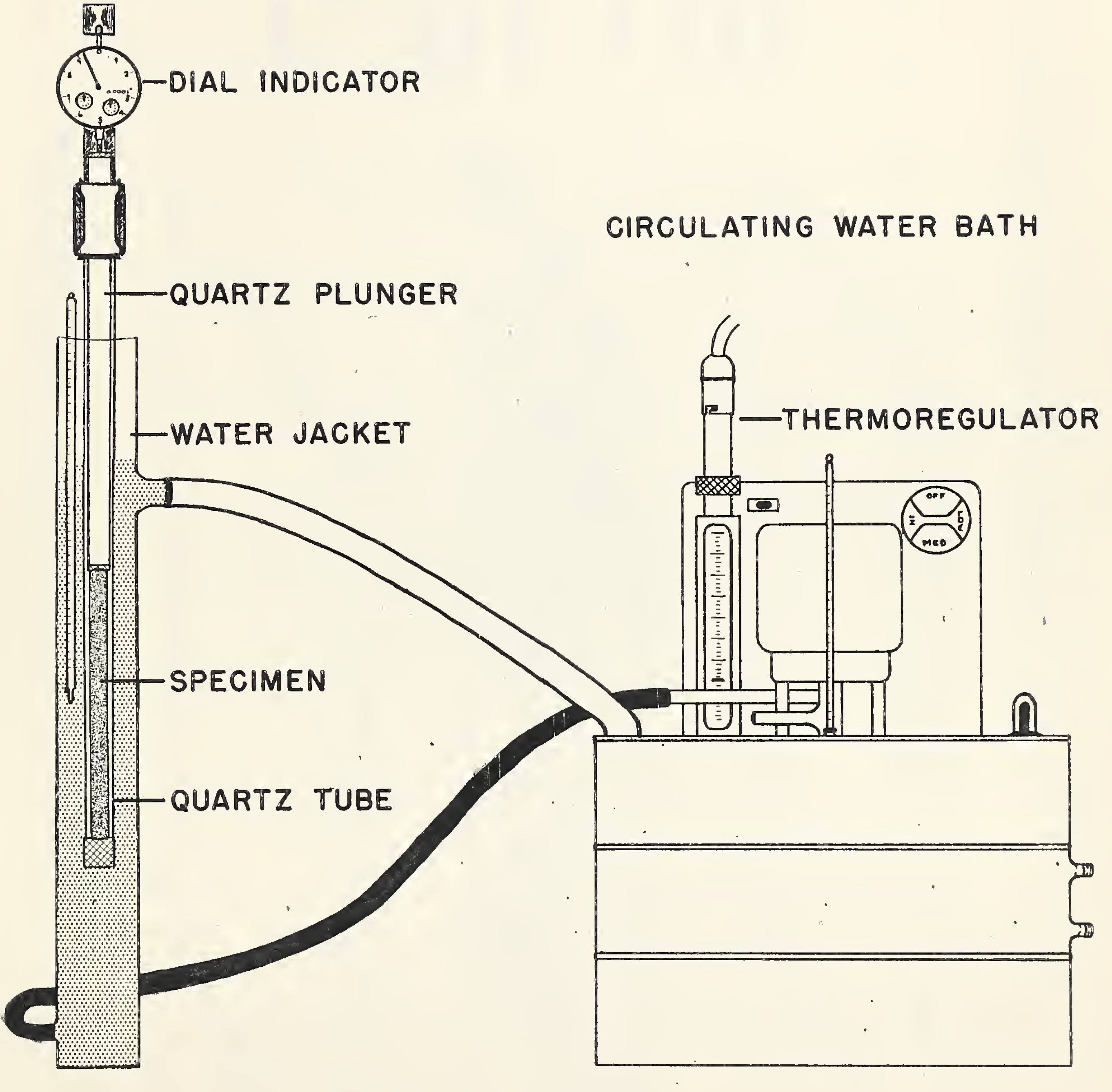
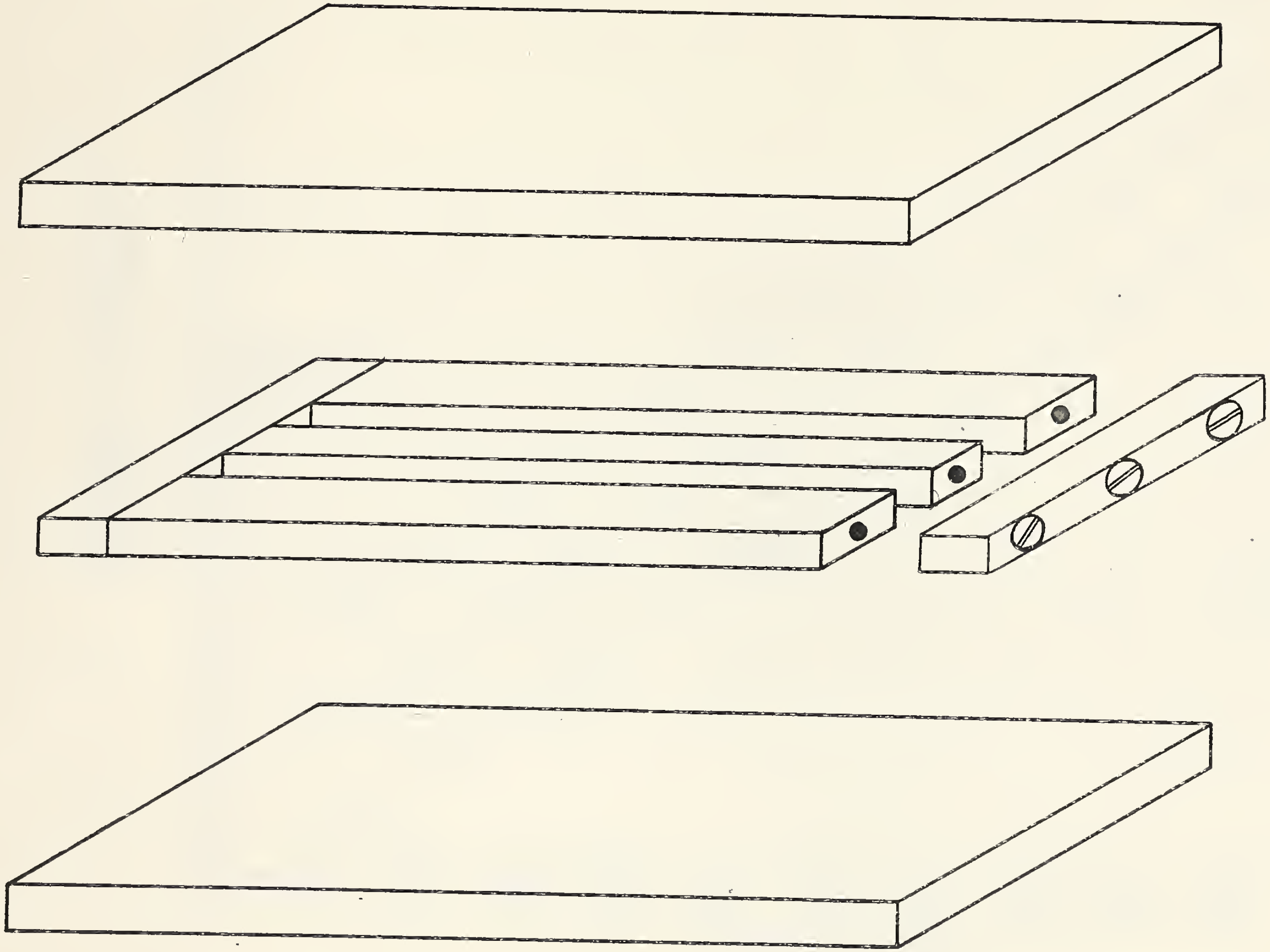


Figure 1. Fused quartz thermal expansion apparatus and circulating water bath.

MOLD FOR THERMAL EXPANSION SPECIMENS



DIMENSIONS

MOLD

Length: 9-1/2 in.
Width: 3-1/2 in.
Height: 7/16 in.

SPECIMEN

Length: 8 in.
Width: 7/16 in.
Height: 7/16 in.

Figure 2. Brass mold in which thermal expansion specimens were made.

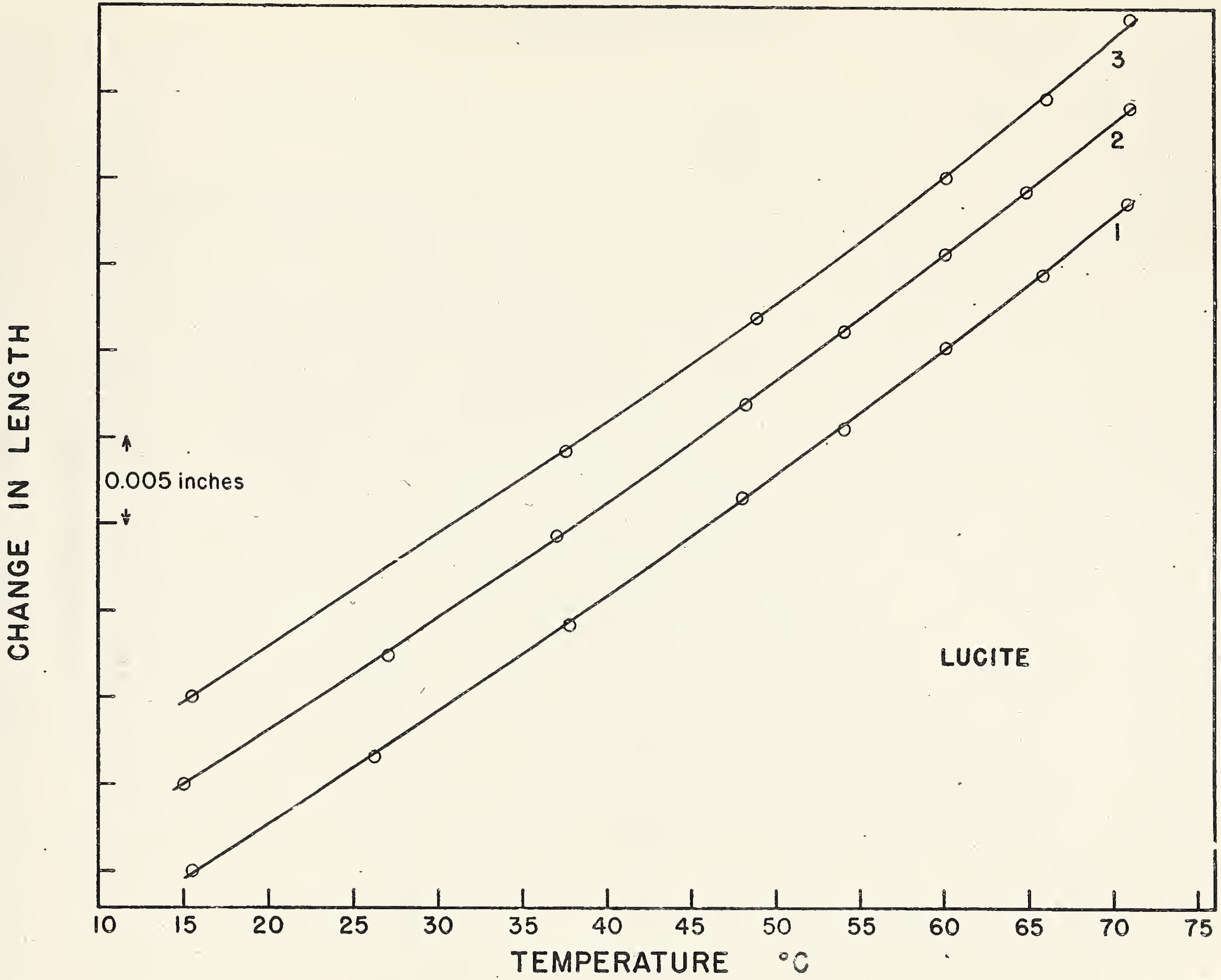


Figure 3. Calculated thermal expansion curves and experimental points for three runs of a Lucite specimen after drying in oven at 70°C for 10 days (see Table 3). The curves have been plotted from different initial points to avoid overlapping.

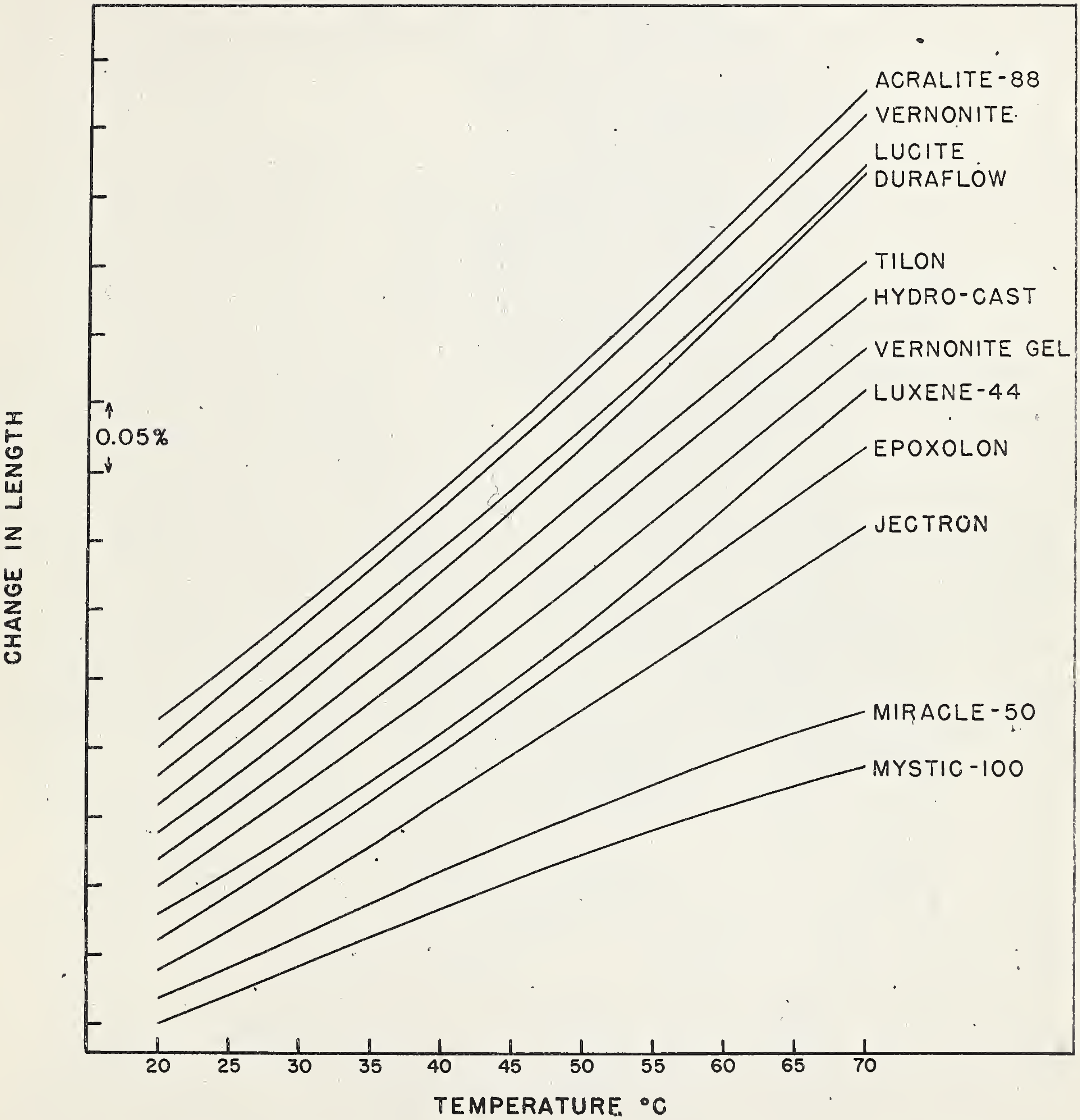


Figure 4. Average thermal expansion curves for all materials in "dry" condition.