WADD TECHNICAL REPORT 60-657

THE THERMAL PROPERTIES OF SOME PLASTIC PANELS

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Southern Research Institute

JANUARY 1961

WRIGHT AIR DEVELOPMENT DIVISION

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Materials Central
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WRIGHT AIR DEVELOPMENT DIVISION
AIR RESEARCH AND DEVELOPMENT COMMAND
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FOREWORD

This work was performed by Southern Research Institute under USAF Contract No. AF 33(616)-6073. The contract was initiated under Project No. 7360, "The Chemistry and Physics of Materials", Task No. 73603, "Thermodynamics and Heat Transfer", and was administered under the direction of the Materials Central, Directorate of Advanced Systems Technology, Wright Air Development Division, with Capt. Frank Zaleski and Mr. Hyman Marcus acting as project engineers.

This report covers the work conducted from March 1, 1959, to July 31, 1960.

ABSTRACT

The thermal expansion, specific heat, and thermal conductivity were measured for twelve different resin-reinforcement combinations, some of which had variations in reinforcement orientations. These properties were also determined for one foam core. The temperature range was generally from -50° F to 700° F. Rather extensive physical property data are also presented on all of the materials (including flexural strength, flexural modulus, Barcol hardness, density, and resin content). Detailed descriptions of the panels and cures are given.

The specific heats of the laminates ranged from about 0.25 Btu/lb ° F to 0.47 Btu/lb ° F with most falling between about 0.25 and 0.32 Btu/lb ° F. The nylon-reinforced material had a specific heat of 0.47 Btu/lb ° F, which is consistent with the fact that the specific heat of nylon is around 0.4 Btu/lb ° F compared to 0.2 to 0.3 Btu/lb ° F for the other reinforcements.

Expansion coefficients varied considerably. The only materials with a reasonably constant slope through the entire temperature range were materials containing silicone resin. An increased expansion coefficient was found with increased deviation from the major fiber axis from 0° to 90°. A permanent change in expansion coefficient, probably due to additional curing at elevated temperatures, was also demonstrated.

The conductivity with the heat flow normal to a continuous reinforcement was influenced primarily by the resin rather than by the reinforcement, while the reinforcement was the major parameter with parallel heat flow.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Jules I. Wittebort

J. I. WITTEBORT
Chief, Thermophysics Branch
Physics Laboratory
Materials Central

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THE THERMAL PROPERTIES OF SOME PLASTIC PANELS

INTRODUCTION

This report to Wright Air Development Division under Contract No. AF 33(616)-6073 covers the determination of the thermal conductivity, capacity, and expansion of twelve plastic-reinforced panels and one foam core. The density, Barcol hardness, flexural strength, and flexural modulus were obtained from the suppliers when available and further supplemented with measurements by Southern Research Institute. In addition, information on the fabrication and curing processes was obtained on most of the materials.

The thermal properties were determined in the general range of -50° F to 700° F.

MATERIALS

The materials for which the thermal properties were measured included eight laminates, four molded panels, and one foam core. In addition, the measurements were made with several different reinforcement orientations on three of the laminates. A complete material description is given in Table 1, which lists, among other data, fabrics, resins, and fabrication and curing processes. Table 2 presents the physical properties as reported by the manufacturers or determined by Southern Research Institute.

Since part of the materials were to be run to destruction, Table 3 is included to show the degree of destruction of each material in the conductivity runs and the maximum temperature of that exposure.

PHYSICAL PROPERTIES

The flexural strength, flexural modulus, and densities of the materials were determined by Southern Research Institute in accordance with Federal specification LP-406(b). Some supplier data is also included.

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Table 1

Materials Specifications

SRI No.	Type and Trade Name	Manufacturer	Reinforcing	Resin Type	No. of Plies	Avg. Tk. In.	% Resin and/or Fabric	Finish	Catalyst	Panel Size and Cost Total	Fabrication and Curing
1-1	Unidirectional Laminate Scotchply	Minnesota Mining and Manufacturing Company, St. Paul, Minn.	60N Roving	3MXP-175 Epoxy	20	0.125	30% ±1.5% Resin	Garan	3MXP-175	12 x 18 x 1/8 $210	Press temp. 275-280° F. Total time in press 40 min. Pressure on panel* 90-95 psi. Post cure temp. 225° F. Time in post cure 16 hrs.
1-2	Isotropic Laminate Scotchply	Same as above	60N Roving	3MXP-175 Epoxy	21	0.122	30% ±1.5% Resin	Garan	3MXP-175	12 x 18 x 1/8 $210	Press temp. 265-270° F. Total time in press 40 min. Pressure on panel* 90 psi. Post cure temp. 225° F. Time in post cure 16 hrs.
2	Molded Panel	Reinhold Engrg. and Plastics Co., Inc., Norwalk, California	181 Chopped Glass	CTL-91 LD Phenolic Resin	Molded	0.281	35% ±5% Resin	A-1100	"B" Stage Phenolic	8 x 8 x 1/4 $127.50	1 hr. at 275° F. Post cure 24 hrs. at 275° F.
3	Foam Core	Dow Corning Corporation, Midland, Mich.	--	R-7002 Silicone Foam	Foam	0.688	--	--	--	30 x 12 x 1/2 $175	† 1 hr. at 390° F. 1 hr. at 435° F. 24-48 hrs. at 480° F. 1 hr. at 435° F.) 1 hr. at 390° F.) cooling 1 hr. at 150° F.)
4	Molded Panel Fiberite 4030-190	The Fiberite Corporation, Winona, Minn.	Glass Roving No. F846	Phenolic R181	Molded	0.230	48% to 53% Resin	--	C-205	8 x 8 x 1/4 $45	Curing in hydraulic press at 2000 psi. Cured for 20 min. at 320° F.
5	Molded Panel Coast F130R	Coast Manufacturing and Supply Company, Livermore, California	Chopped Glass 1B603	Silicone 4P020, F130R DC-2106	Molded	0.273	35% ±3% Resin	--	Dow Corning XY-15	6½ x 10 x 1/4 $130	16 hrs. at 200° F. 2 hrs. at 260° F. 2 hrs. at 300° F. 2 hrs. at 350° F. 2 hrs. at 400° F. 2 hrs. at 440° F. 12 hrs. at 482° F. Cooled to 200° F before removing from oven.
6	Laminate Random Reinforcement Astrolite	H. I. Thompson Fiber Glass Company, Los Angeles, California	½" x ½" squares of 1201V cloth	Phenolic SC-1008	Molded	0.132	30% to 35% Resin Content by Wt.	None	None	6 x 16 x 1/8 $66.30	Curing 2 hrs. at 300° F.
7-1	Laminar Construction Astrolite Parallel Layup	Same as above	Refrasil 184 Weave	Phenolic SC-1008	6	0.126	30% to 35% Resin Content by Wt.	None	None	18 x 18 x 1/8 $140	Curing 2 hrs. at 300° F.
7-2	Edgewise Layup with Thickness in Warp Direction Astrolite	Same as above	Refrasil 184 Weave	Phenolic SC-1008	50/inch	0.125	30% to 35% Resin Content by Wt.	None	None	12 x 8 x 1/8 $280	Curing 1 hr. at 200° F. 1 hr. at 250° F. 2 hrs. at 300° F.

* Cured to 0.125" stops.
† From standard Dow Corning literature.

Table 1 (Continued)

Materials Specifications

SRI No.	Type and Trade Name	Manufacturer	Reinforcing	Resin Type	No. of Plies	Avg. Tk. in.	% Resin and/or Fabric	Finish	Catalyst	Panel Size and Cost Total	Fabrication and Curing
8-1	Laminar Construction Regular Layup Parallel	Cincinnati Testing and Research Laboratories, Cincinnati, Ohio	181 "E" Glass Fabric	CTL 37-9X	14	0.132	25.7% Resin	A-1100	None	18 x 18 x $\frac{1}{8}$ \$91.56	Molding cycle Type of molding - press. Part pressure - 100 psi. Curing - $\frac{1}{2}$ hr. at 280-290° F. Post cure cycle 4 days at 250° F.
8-2	Edgewise Layup with Thickness in Warp Direction	Same as above	181 "E" Glass Fabric	CTL 37-9X	91/inch	0.699	31.272% Resin	A-1100	None	$4\frac{3}{4}$ x 7 x 0.7 \$394.50	Molding cycle Type of molding - press. Part pressure - 100 psi. Curing - 4 hrs. at 280-290° F. Post cure cycle 4 days at 250° F.
8-3	Edgewise Layup with Thickness at 45° of Warp Direction	Same as above	181 "E" Glass Fabric	CTL 37-9X	--	0.708	24.312% Resin	A-1100	None	10 x 10 x 0.7 \$571.48	Molding cycle Type of molding - augmented bag. Part pressure - 100 psi. Curing - 4 hrs. at 280-290° F. Post cure cycle 4 days at 250° F.
9	Chopped Fabric Construction YN 25	U.S. Polymeric Chemicals, Inc., Santa Ana, California	SN-19 Nylon Heat Set and Scoured	CTL-91 LD Phenolic	--	0.265	42% Resin by Wt.	--	--	6" Dia. x $\frac{1}{4}$" \$180	Molding cycle 1 hr. at 275° F.
10	Laminate	Same as above	40 RPD Asbestos	DC-2106 Silicone	37	0.121	--	--	--	12 x 12 x $\frac{1}{8}$ \$50	Loaded at 330° F. 20 sec. required for loading, 20 sec. for closing press. Full pressure applied and bumped after 20 sec. Cured $1\frac{1}{4}$ hrs. at 330° F and 850 psi. Removed hot from press.
11	Laminate	WADD	Glass Type YM-31A Weave Style 181	CTL-91 LD Phenolic	--	0.116	36-40% Resin in Pre-preg. Prior to Molding. 31% by Wt. Resin	A-1100	--	16 x 16 x $\frac{1}{8}$	Pressure - 345 psi. Press cure - 20 min. at 300° F. Post cure - 24 hrs. at 300° F. 24 hrs. at 350° F. 24 hrs. at 400° F.
12	Laminate	WADD	Glass Type YM-31A Weave Style 181	Epon 1031 Epoxy	--	0.110	38-40% Resin in Pre-preg. Prior to Molding. 22% by Wt. Resin	Volan A	CL	18 x 18 x $\frac{1}{8}$	Pressure - 245 psi. Press cure - 30 min. at 340° F. Post cure - 24 hrs. at 300° F.
13	Mat	Raybestos-Manhatten, Inc., Manheim, Pa.	Asbestos R/M Style 42 RPD	R/M High Heat Resistant Phenolic	40	0.147	25-30%	--	None	18 x 18 x $\frac{1}{8}$ \$30.20	No post cure.

Table 2

Physical Properties

SRI No.	Material	Density lbs/ft³	Barcol Hardness on Panel Face	Flexural Strength at Room Temperature psi	Flexural Modulus at Room Temperature psi x 10^6
1-1	Unidirectional Laminate	114.9	62	129,000	5.39
1-2	Isotropic Laminate	114.9	69	74,000	2.61
2	Molded Panel	114.2	69	15,210	1.76
3	Foam Core	11.60	Compressive Strength = 200 psi		
4	Molded Panel Fiberite 4030-190	107.9	60	20,000	3.00
5	Molded Panel Coast F-130	106 to 109.7	53	41,800	2.90
6	Laminate Random Reinforcement	90.0	54	5,000	1.00
7-1	Laminar Construction Parallel Layup	90.0	60	25,000	3.00
7-2	Edgewise Layup with Thickness in Warp Direction	90.0	33	[1] 21,020 [2] 3,300	[1] 2.15 [2] 0.85
8-1	Laminar Construction Regular Layup (Parallel)	116.5	78	Warp - 24,000 Fill - 13,200	Warp - 2.50 Fill - 1.80
8-2	Edgewise Layup with Thickness in Warp Direction	111.0	64	41,900	3.03
8-3	Edgewise Layup with Thickness at 45° of Warp Direction	111.7	62	See 8-1 and 8-2	See 8-1 and 8-2
9	Chopped Fabric Construction	72.0	16	10,750	0.397
10	Laminate	113.6	61	Warp - 27,200 Fill - 19,600	Warp - 3.89 Fill - 1.97
11	Laminate	131.0	86	Warp - 59,300 Fill - 54,800	Warp - 4.88 Fill - 3.86
12	Laminate	137.5	76	Warp - 84,000 Fill - 80,100	Warp - 5.43 Fill - 5.18
13	Mat	117.0	74	Warp - 47,600 Fill - 36,400	Warp - 2.68 Fill - 2.37

[1] Fill lengthwise (see Figure 1).
[2] Fill across length.

Table 3

Physical Appearance of Materials

Material SRI No.	Before Conductivity Measurements	Top Temp., ° F	After Conductivity Measurements
1-1 and 1-2	Light green	527	Black and brown areas with some delamination
2	Medium brown	593	Black with resin completely burned out around edges
3	Light tan	704	Medium brown to black, crushed somewhat and cracked all over
4	Dark brown	780	Black with resin completely burned out in spots around edges and beneath getters
5	Mottled red	633	Mottled white and brown
6	Mottled medium brown and tan	725	Black
7-1	Tan	730	Black with resin completely burned out around edges
7-2	Tan	733	Black and delaminated in several places
8-1 8-2 8-3	Dark brown	730 701 702	Black with resin completely burned out in spots
9	Brownish yellow	732	Black; completely burned up; in small pieces
10	Grey	721	Light grey
11	Chocolate brown	586	Black resin completely burned out around edges
12	Amber	599	Black, resin completely burned out around edges
13	Black	706	Black, with large white areas where resin was completely burned out

Flexural Strength and Modulus

All flexural tests were made on a Tinius Olsen Universal Testing Machine at a crosshead speed of approximately 0.25 in./min and with a loading arrangement as shown in Figure 1, only modified to the reinforcement orientation as required for the different panels. See Table 2 for the strength and modulus values.

The ultimate flexural strength was calculated from the formula:

$$S = \frac{3PL}{2bd^2}$$

where

S = maximum fiber stress, psi
P = maximum load, pounds
L = distance between points of support, inches
b = width of beam as tested, inches
d = depth of beam as tested, inches

As might be expected, the laminates with either a roving or woven continuous reinforcement across the planes of principal stress had a higher flexural strength than the panels with a chopped and randomly oriented reinforcement. As seen in Table 2, one exception to this was material No. SRI 5 with a strength of 41,800 psi, which was higher than materials No. SRI 7-1 (25,000 psi), No. SRI 8-1 (warp 24,000, fill 13,200), and No. SRI 10 (warp 27,200, fill 19,600). Material No. SRI 5 had rather large flakes of glass cloth that overlapped and probably provided an interlock and continuous reinforcement.

Although material No. SRI 2 failed initially in tension, there was some indication that shear may have initiated the failure as the break was not at the loading point, but within $\frac{3}{4}$ inch of one support. The rest of the materials failed in either tension or a combination of tension and compression.

The flexural modulus was calculated from the formula:

$$E_B = \frac{L^3}{4bd^3}\left(\frac{P}{y}\right)$$

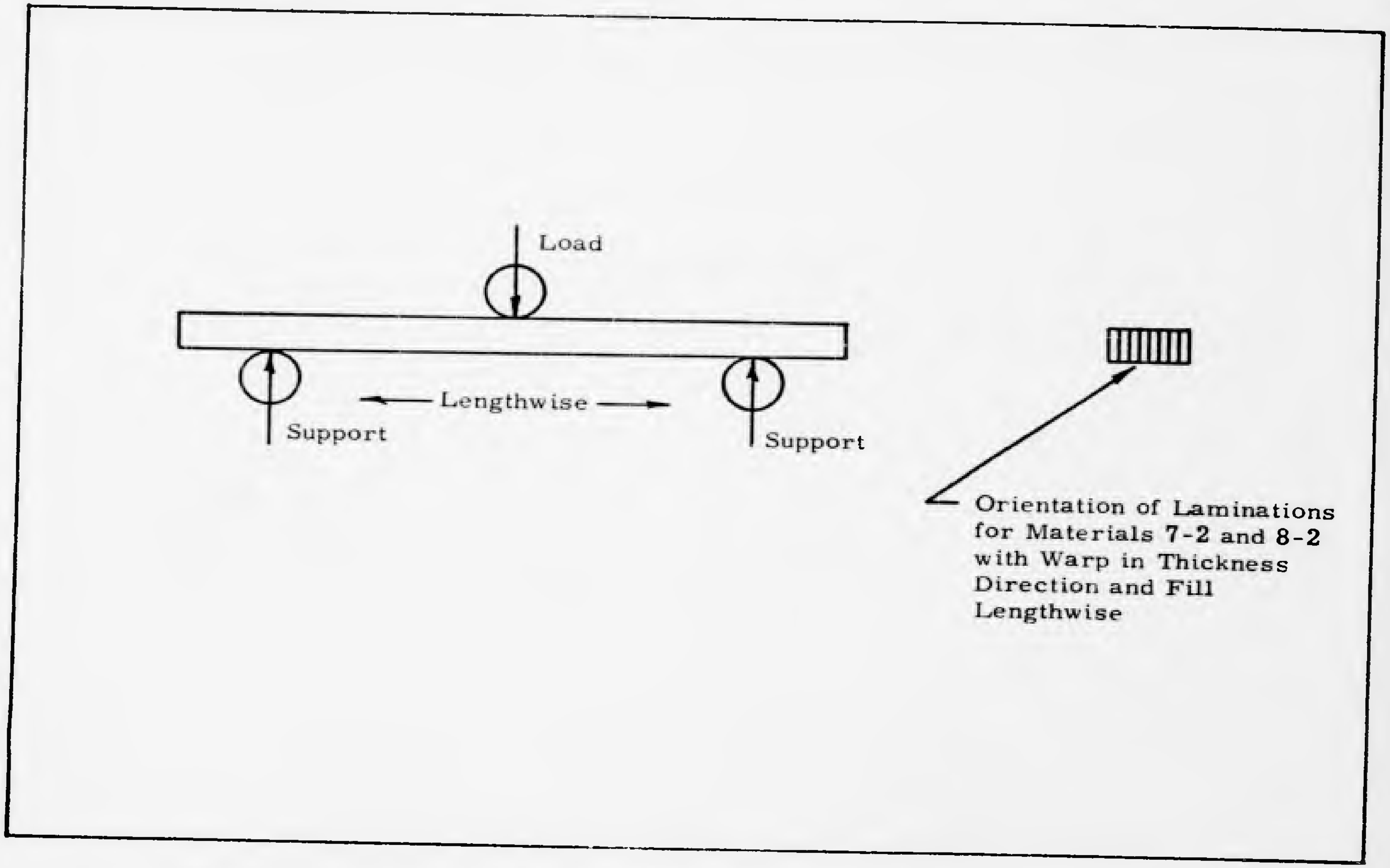

Figure 1. Orientation of Materials for Flexural Strength Determination.

where

E_B = modulus of elasticity in bending, psi
L = distance between points of support, inches
b = width of beam as tested, inches
d = depth of beam as tested, inches
$\frac{P}{y}$ = slope of straight line portion of load deflection curve in pounds per inch

Generally, the moduli of the materials fell within the range of 2×10^6 to 5×10^6 psi. A few materials exhibited values a little higher or lower. A correlation appeared to exist between continuous and discontinuous reinforcement across the principal plane of stress with those materials having a discontinuous reinforcement having a low modulus and those materials having a continuous reinforcement having a high modulus. Also, the modulus was generally greater when the warp was lengthwise with the beam or across the principal plane of stress. Other conditions being similar, glass reinforcement resulted in a higher modulus than asbestos, and nylon fell in between.

Barcol Hardness

The hardness of the surface finish was determined with a Barcol Impressor No. GYZJ 934-1. A curve for converting values obtained with this tester to other hardness scales is given in Figure 2.

The Barcol hardness obtained for each material is shown in Table 2 and is an average of three readings taken from each sample. The hardness values varied from a low of 16 for material No. SRI 9 to a high of 86 for material No. SRI 11. This low value for material No. SRI 9 is probably due to the short molding cycle, which did not allow time for the resin to cure sufficiently. Material No. SRI 11, which also had a 91-LD phenolic resin, was cured extensively. Most of the materials, however, fell into a range between 50 and 70.

SPECIFIC HEAT

Apparatus and Procedure

Specific heat determinations for these panels were made by means of a drop-type adiabatic calorimeter consisting of a covered

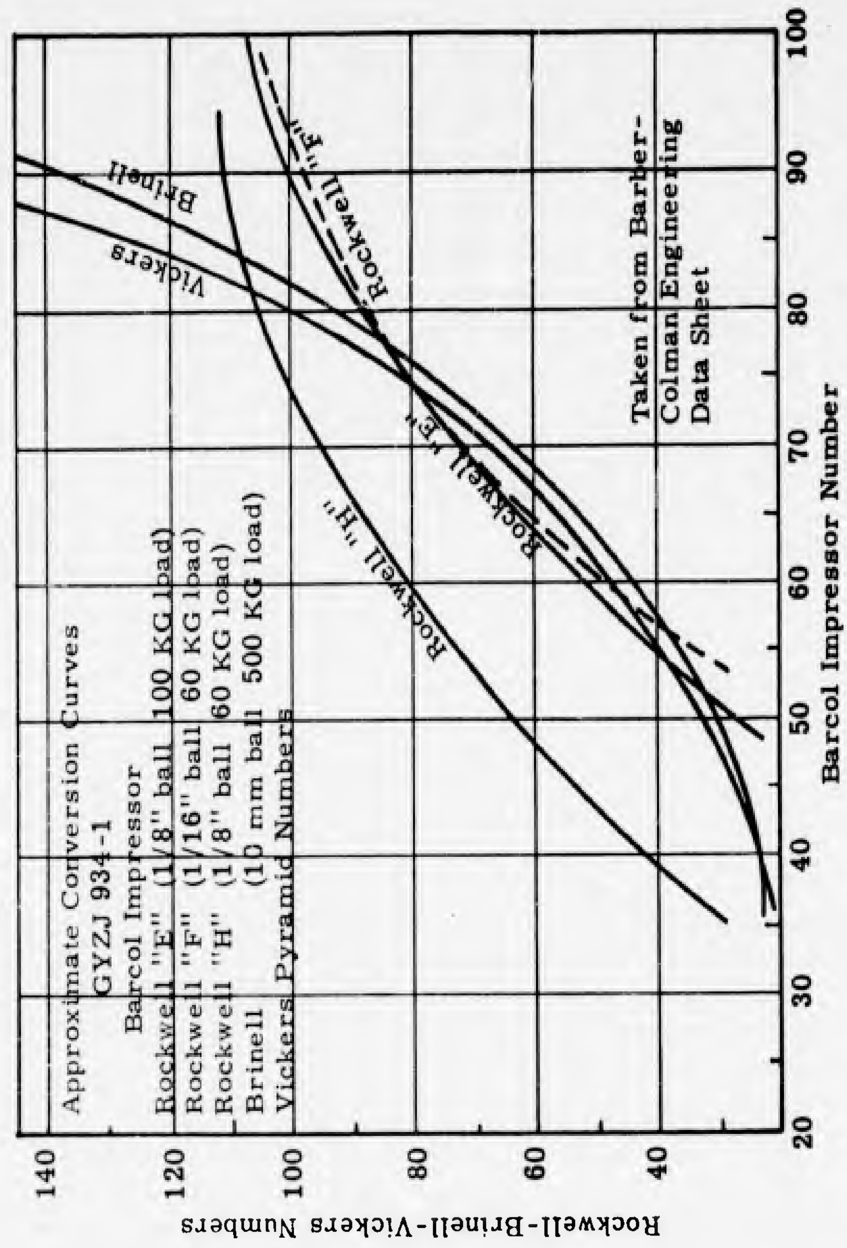

Figure 2. Barcol Hardness Conversion Table.

brass cup approximately $2\frac{1}{2}$ inches in diameter by 2 inches deep. Three thermocouple wells were located in the bottom wall of the cup. The cup was mounted on cork supports, which rested in a silver-plated copper jacket, the jacket being immersed in a bath of ethylene glycol. The temperature of the bath was maintained at the temperature of the cup by means of a 1000-watt nichrome wire heater and a copper cooling coil immersed in the liquid. Chilled trichloroethylene was pumped through the cooling coil to cool the bath. A double-bladed stirrer maintained uniform bath temperature.

A tubular furnace and a cold box were used to bring the specimens to temperature. When this equipment was pivoted on a common post near the calorimeter, the samples could be transferred to a position directly over the calorimeter cup. At this position the specimen was released from a suspension assembly, which was externally triggered. Thermocouples located near the specimen indicated specimen temperature.

Elevated specimen temperatures were maintained by a manual setting of a variable voltage transformer, which controlled the voltage of the furnace. Cold sample temperatures were obtained by filling the cold box with dry ice. A fan inside the box circulated the air to insure temperature uniformity. The cold box consisted of two concentric cylinders enclosed in an insulated plywood box. The smaller cylinder (3 inches in diameter by 16 inches high) was constructed of $\frac{1}{4}$-inch mesh hardware cloth. The larger cylinder was made of galvanized sheet metal (15 inches in diameter and 16 inches high). The annulus was partially filled with dry ice.

Three copper-constantan thermocouples, differentially connected between calorimeter cup and jacket, indicated temperature differences between cup and bath. The three thermocouples enabled a difference of 0.03° F to be detected. During the test runs, this difference was maintained to within 0.15° F. Absolute temperature measurements of the cup were determined by means of three thermocouple junctions, connected in series in the bottom of the calorimeter cup. All of the thermocouple readings were taken on a Leeds and Northrup K-2 potentiometer in conjunction with a galvanometer of 0.43 microvolts per mm deflection sensitivity. This setup permitted temperature measurements within 0.01° F. This apparatus is shown in Figure 3.

Specimens of the test materials were heated or cooled to the desired temperature and, following a stabilization period, were dropped

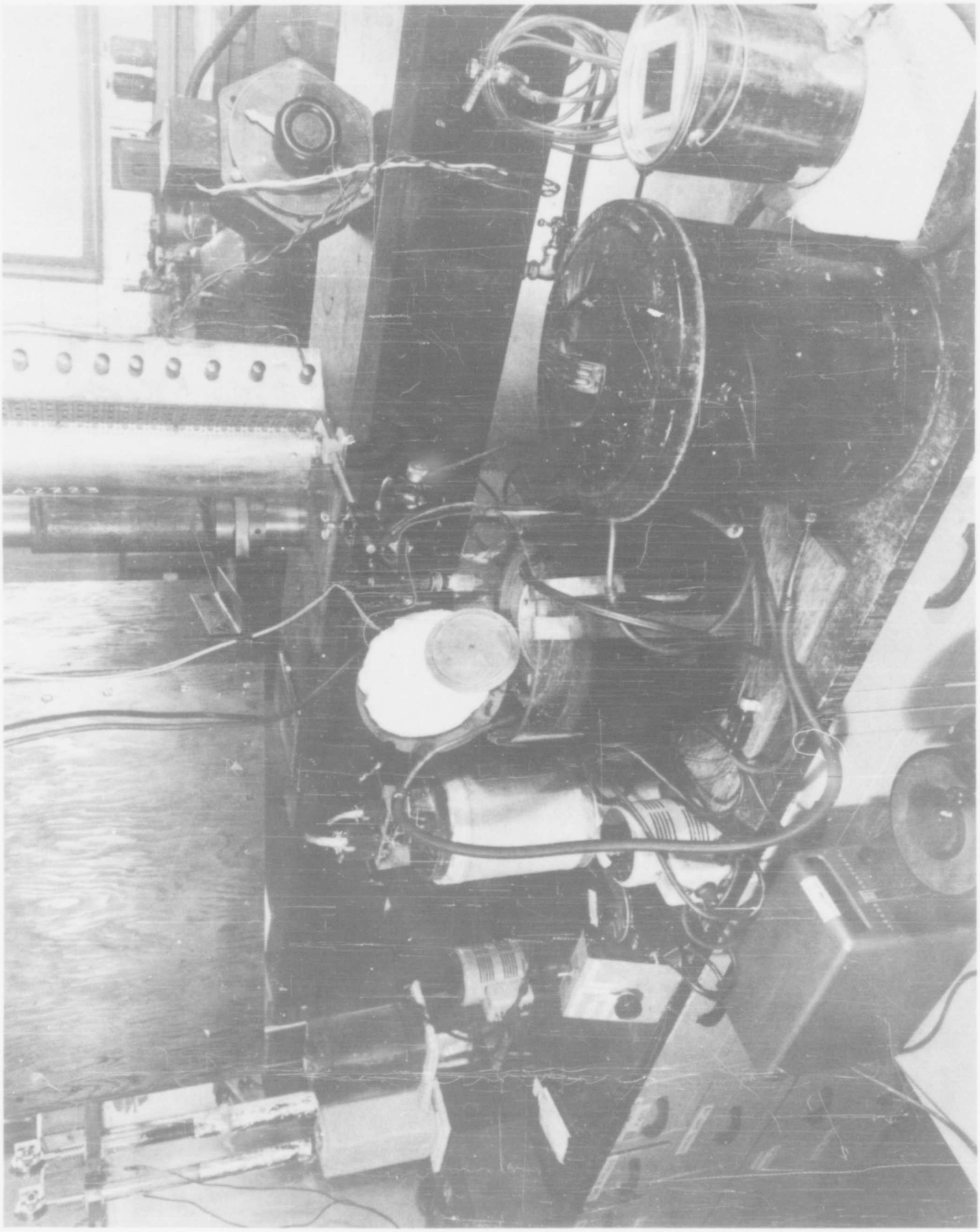

Figure 3. Specific Heat Apparatus.

into the calorimeter cup. Adiabatic conditions were maintained during each test by manually adjusting the temperature of the bath guarding the cup.

The foam core had such a small specific gravity that the specimens were made so that they would just fit into the cup in order to obtain the largest mass possible. Considerable difficulty was encountered in getting the specimen to drop into the cup, as it would fit in only one direction.

The foam samples were formed into cylinders, about $1\frac{3}{8}$ inches in diameter x $1\frac{3}{4}$ inches long, out of two halves that were held together by a few drops of Sauereisen DW-30 cement. These samples were then baked overnight at 215° F to remove any moisture.

The remainder of the samples were made by forming cubes approximately 1 inch x 1 inch x $\frac{1}{2}$ inch out of several thicknesses, which were pinned together using pins of the same material. Layers of material No. SRI 11 and No. SRI 12 were not pinned together because no adequate means of turning the pins out of the beryllium containing materials were available.

Data and Results

A calorimeter constant of 0.2654 Btu/° F, which was previously determined by using an electrolytic copper specimen of known specific heat, was used in the calculations.

Determination of the specific heats consisted of measuring the enthalpy of the specimens as a function of the initial specimen temperature. A reference temperature of 85° F for the enthalpy determinations was used, and all enthalpy values were referred to this 85° F base.

The enthalpy of the specimen at any initial temperature is given by this formula:

$$h = \frac{K}{W_S}(t_2 - t_1)$$

where

K = calorimeter constant, 0.2654 Btu/° F
W_S = sample weight, lbs
t_1 = initial cup temperature, ° F
t_2 = final cup temperature, ° F

The enthalpy was referred to the common base temperature of 85° F by:

$$h_{85} = h \left[1 + \frac{(t_2 - 85)}{(t_3 - t_2)} \right]$$

where

h_{85} = enthalpy above the reference temperature of 85° F, Btu/lb
t_3 = initial sample temperature, ° F

The specific heat is determined as the slope of the heat content curve in the temperature range for which the specific heat is desired. In the special case when the heat content curve is a straight line, the specific heat is a constant.

Because all values are calculated using a reference temperature of 85° F, the enthalpy at 85° F is zero by definition. For this reason, all heat content curves were drawn through 85° F and zero enthalpy and a best fit of the cold and hot data points.

The calibration of the apparatus was confirmed by running a copper specimen of known specific heat. The data obtained on this specimen is shown in Table 6, and the curve plotted from this data is shown in Figure 4. The specific heat, which was the slope of the enthalpy-temperature curve, was 0.093 Btu/lb ° F between 200° F and 520° F. A comparison of specific heat values obtained by others in this temperature range is shown in Table 4 and indicates general agreement. For further calibration, a specimen consisting of sapphire enclosed in a stainless steel cup was run. The specific heat of the sapphire alone was compared to several known values as shown in Table 5. The results of this comparison again indicated general agreement.

The specific heats ranged from 0.25 Btu/lb ° F for material No. SRI 5 to 0.47 Btu/lb ° F for material No. SRI 9, but most of the materials had a specific heat between 0.25 Btu/lb ° F and 0.32 Btu/lb ° F.

Upon comparing the physical make-up and properties of the materials, a correlation between the specific heats and the types of

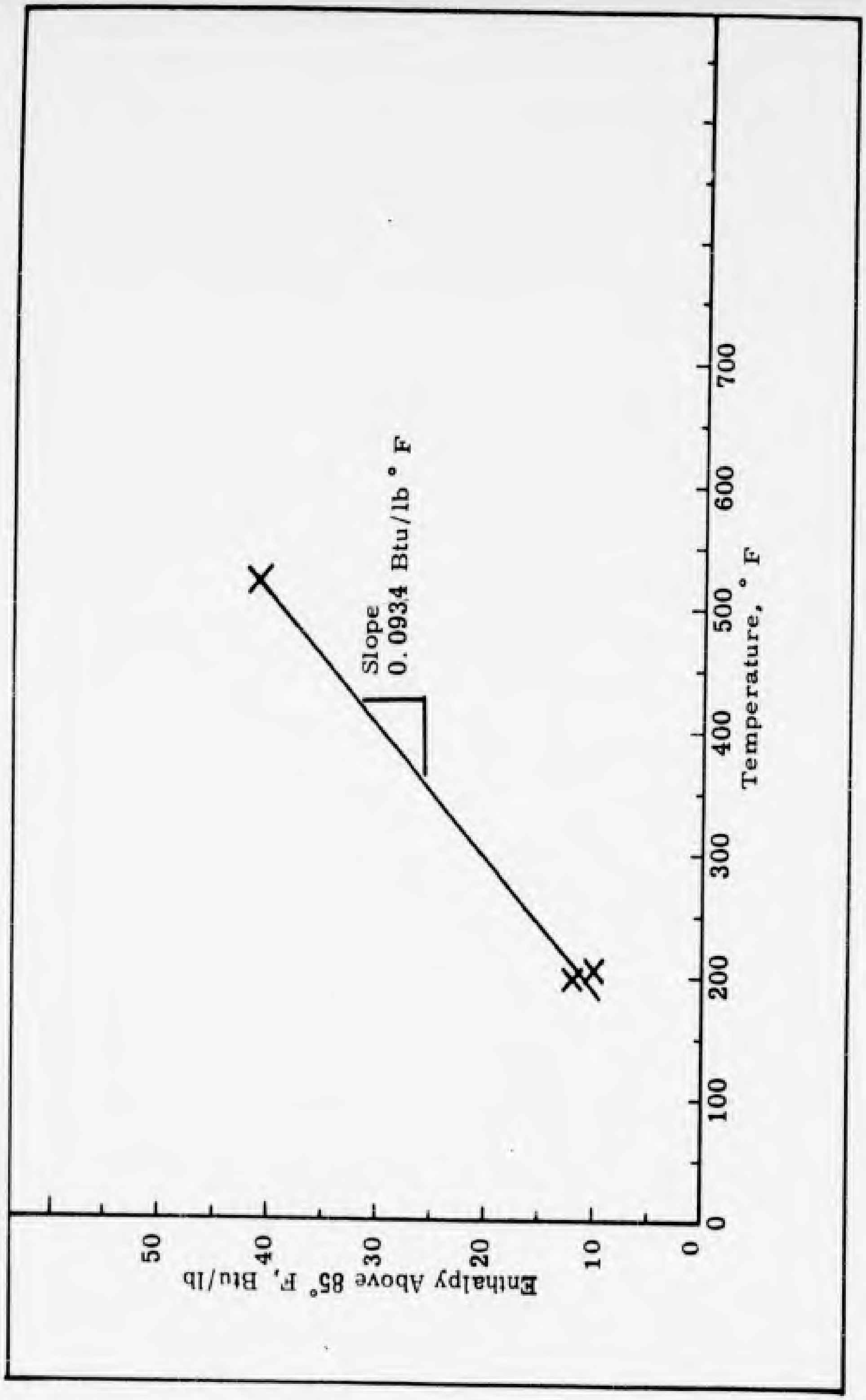

Figure 4. Heat Content Curve for Copper Calibration Specimen.

Table 4

Comparison of Specific Heat Values for Copper

Source	* DoeRinckel, F. and M. Werner		* Richards Voille		Richards White		* Schubel		SRI
Temperature ° F	232	450	212	572	212	577	212	572	200 to 520
Specific Heat Btu/lb ° F	0.0929 ±0.0010	0.0960 ±0.0007	0.0957	0.0990	0.0913	0.0947	0.0928	0.0954	0.0934

* From WADD TR 56-423, page 169.

Table 5

Comparison of the Specific Heat of Sapphire Obtained by the Adiabatic Calorimeter to That of Several Other Sources

SRI Adiabatic Calorimeter		SRI Ice Calorimeter		Armour Research Foundation		Linde Company		International Critical Tables	
Temp., ° F	Specific Heat Btu/lb ° F	Temp., ° F	Specific Heat Btu/lb ° F	Approx. Temp., ° F	Specific Heat Btu/lb ° F	Approx. Temp., ° F	Specific Heat Btu/lb ° F	Temp., ° F	Specific Heat Btu/lb ° F
490	0.223	497	0.210	500	0.263	500	0.2125		
996	0.240	1008	0.241	1000	0.280	1000	0.2265	922	0.239

reinforcement was suggested. Generally speaking, the glass-reinforced materials had the lowest specific heats, while the asbestos-reinforced materials were next, with the one nylon-reinforced material exhibiting the highest value. The foam core material had a specific heat slightly higher than the asbestos-reinforced materials.

It is not surprising that the specific heat value for the nylon-reinforced material was high in comparison to the glass-reinforced materials, because nylon itself has a specific heat which is about twice that of glass. When there is little or no chemical interaction, the specific heat of a composite is anticipated to be the weighted average of the separate materials.

The specific heat data is shown in Tables 6 through 19 of the Appendix, and the specific heat curves are presented in Figures 15 through 27 of the Appendix.

THERMAL EXPANSION

Apparatus and Procedure

Thermal expansion measurements were made utilizing two quartz tube dilatometers of the Bureau of Standards design. The tubes and dial gages were mounted on a single arm to facilitate the testing of two samples simultaneously. The dial gages (B. C. Ames Co., Model 212, shockless) were graduated in 0.0001-inch divisions with a total range of 0.100 inch for specimens with low coefficients and 0.500 inch for the specimens with a higher coefficient. The manufacturer's stated mechanical accuracy for any given reading is ± 0.0001 inch at any point in the range.

The quartz dilatometers were wrapped with a layer of $\frac{1}{16}$-inch asbestos sheet next to the tube and with alternating layers of asbestos sheet and aluminum foil until a total of three layers of each were around the tubes. This was done to minimize the temperature gradient through the samples.

The extensions from the dial, which were made of aluminum, were finned to facilitate cooling and reduce the possibility of a different expansion between the dial-gage mount and the extension; see Figure 5.

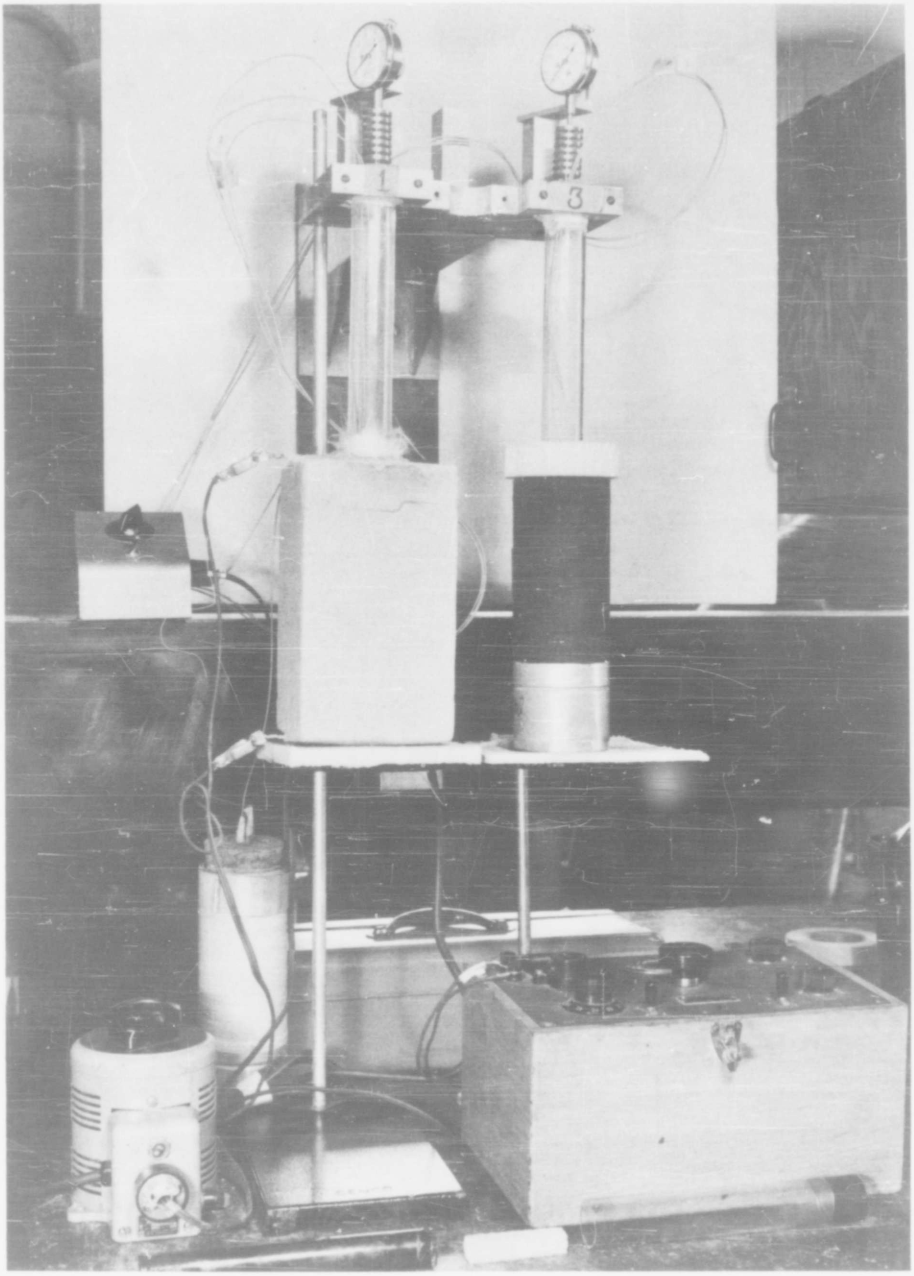

Figure 5. Thermal Expansion Apparatus.

For temperatures above room temperature, each dilatometer was heated by an individual heater. The temperature of the heater was maintained by a manual setting of a variable voltage transformer.

Cold specimen temperatures were obtained by use of a Dewar flask filled with dry ice and trichloroethylene. The flask was placed up on the dilatometer tubes to a height covering the specimens. Iron-constantan thermocouples were placed at each end and the center of the specimens to monitor the temperature throughout. This apparatus is shown in Figure 5. The specimens were 3 inches in length with the ends rounded on a 3-inch diameter. The ends of the foam core specimen were washed with Sauereisen DW-30 cement to prevent crushing.

Data and Results

The accuracy of the apparatus was checked by running a graphite and a nickel sample. The graphite was used to check the apparatus for running a material with a low coefficient of expansion. By calculation, using an equation from Kent's Mechanical Engineers Handbook, the coefficient for graphite between 70° F and 600° F is 1.19 microinches/in. °F. This is relatively close to quartz—compared to plastics—and, as shown by Figure 6 and Table 20, the dilatometers indicated practically no motion. A curve showing the theoretical value for quartz is also included on the graphite curve. The indication of zero motion for the graphite was a good check that no severe thermal gradients existed in the tubes. Several reruns were made on the graphite to develop the heating technique that would reduce thermal gradients in the specimen. The data from these reruns is also shown in Table 20.

The nickel was used to check the apparatus for running materials with a fairly high coefficient of expansion. The data for the nickel specimen when plotted produced a curve with a slope of 7.69 microinches/in.; see Figure 6 and Table 21. This value compares favorably with the value for nickel of 7.6 microinches/in. given in the literature.

The actual data points for each run were plotted on the curves shown in Figures 28 through 53. No correction for the expansion of quartz was applied to the data because the correction would have been such a small percent of the total expansion that it would have been negligible anyway. A curve showing the expansion of quartz is given in Figure 7. For those cases requiring extreme accuracy, the expansion of quartz may be added to the expansion of the desired material in the range under consideration.

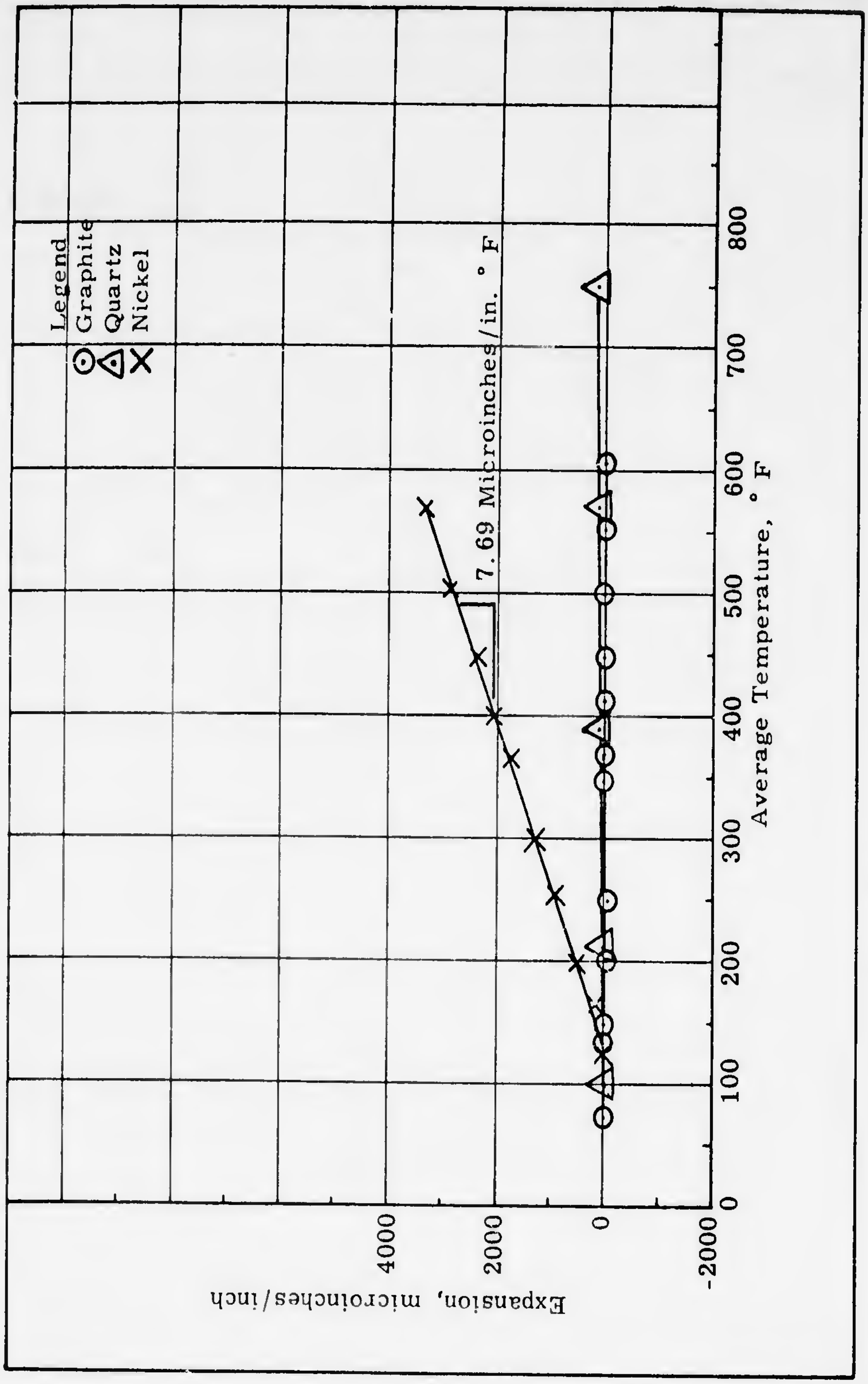

Figure 6. Expansion of Calibration Specimens.

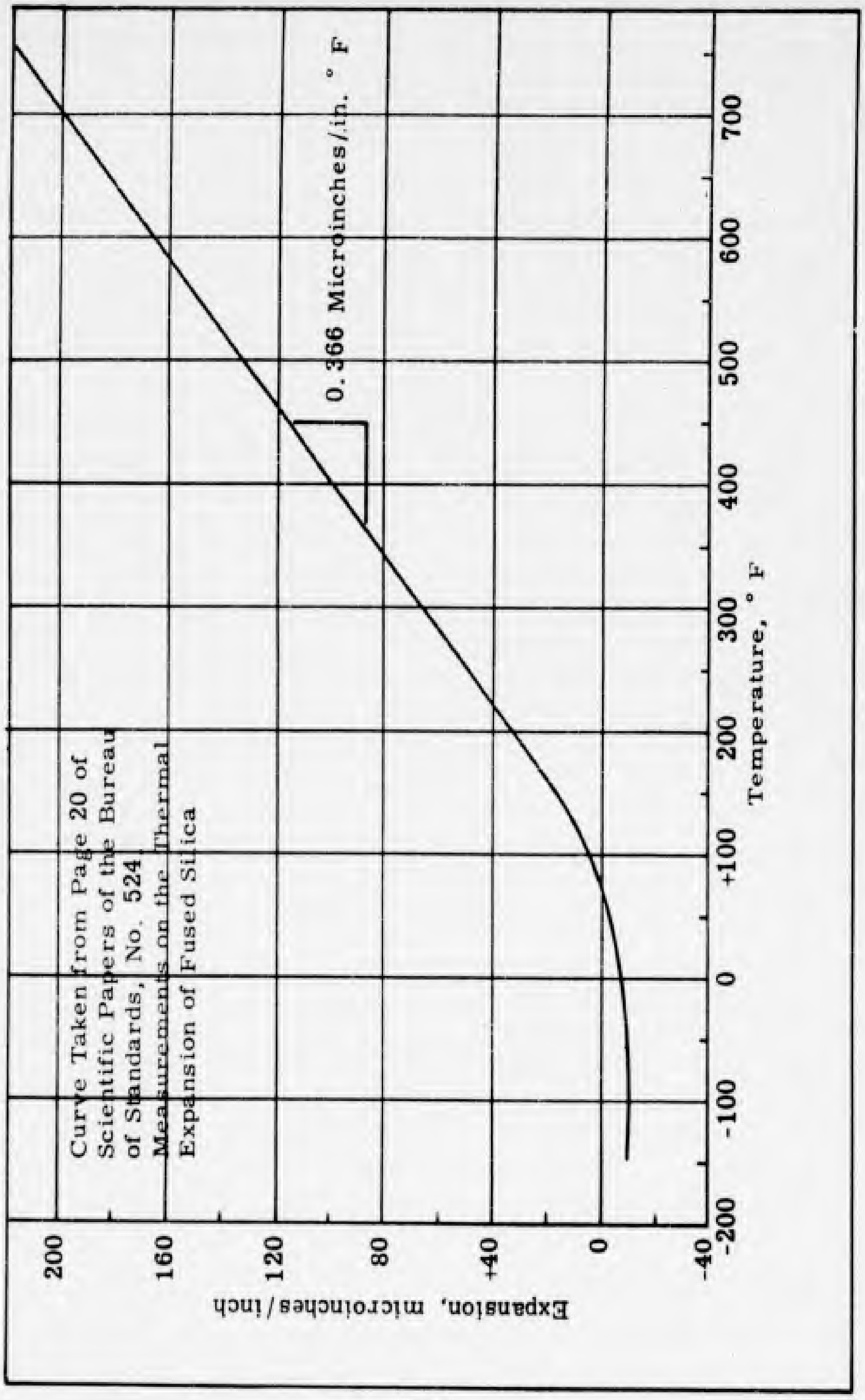

Figure 7. Expansion of Quartz.

The expansion coefficient is the slope of the expansion curve over a temperature increment. This slope is shown on those curves having a straight line portion over a reasonable temperature increment. This slope has been corrected in those cases when the expansion of quartz exceeded 5 percent of the specimen expansion.

Figure 8 shows the curves of the expansion parallel to the panel for all of the materials run in this direction. It can be seen from this figure that most of these materials had a reasonably constant expansion from -100° F to 200° F. After passing 200° F, however, the curves exhibited very little similarity. Material No. SRI 1-1, No. SRI 7-1, No. SRI 11, and No. SRI 12, all with continuous reinforcements, expanded until they reached a maximum at some temperature, and then began to contract. Material No. SRI 1-1 and No. SRI 7-1, an epoxy and a phenolic with a relatively light cure, reached this maximum at a fairly low temperature, while material No. SRI 11 and No. SRI 12, a phenolic and an epoxy with a hard cure, continued to expand to around 600° F. Material No. SRI 2 and No. SRI 10 had a plateau preceding their maximum expansions, and material No. SRI 2, after reaching its maximum and declining, began to expand again. Material No. SRI 4 and No. SRI 6, with a discontinuous reinforcement, while not exhibiting this plateau before the maximum expansion was reached, did show the re-expansion after a previous increase and decrease. Material No. SRI 5 and No. SRI 13, silicones with a hard and light cure respectively, had a reasonably constant expansion to 700° F. This is typical of materials with silicone resins probably because this resin remains more stable at higher temperatures regardless of cure.

An interesting comparison of the same material expanding in different orientations is shown in Figure 9. The curves of this figure indicate an increase in expansion for the material from a minimum, oriented at 0° to the major axis of the fibers, and parallel to the plane of the reinforcement, to a maximum at 90° to the major axis of the fibers, and parallel to the plane of reinforcement. The curve for the expansion of the isotropic laminate is also included for comparison. The expansion of the isotropic laminate was somewhat greater than the minimum expansion, but closer to it than either of the other curves. This difference in expansion rates for various reinforcement configurations is an indication of the importance of the orientation in design considerations of the expansion of plastic laminates. However, this material had a roving reinforcement that caused a greater difference in expansion at different orientations than would have been exhibited for a woven reinforcement.

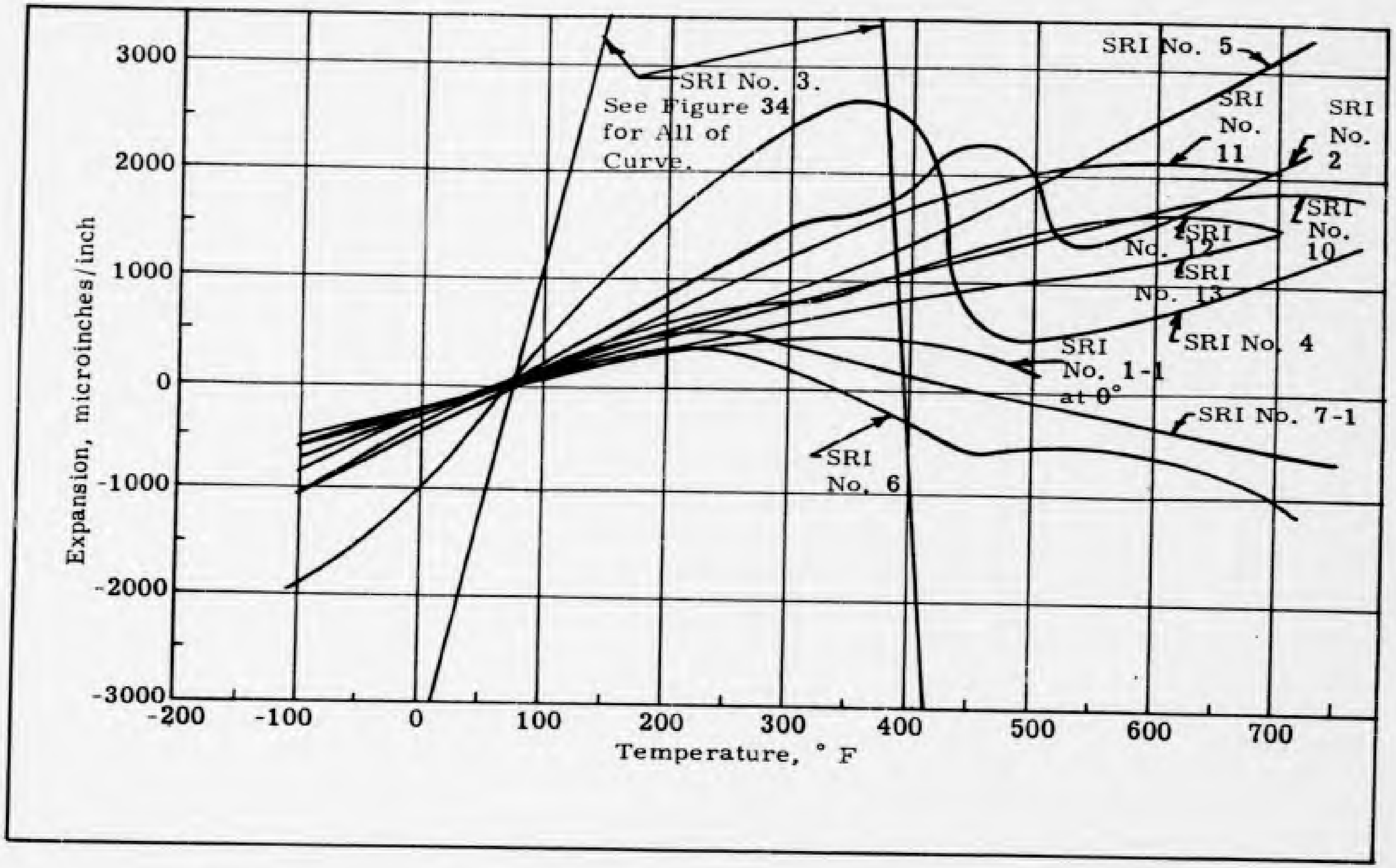

Figure 8. Composite of Expansion Parallel to Panel of All Materials Run.

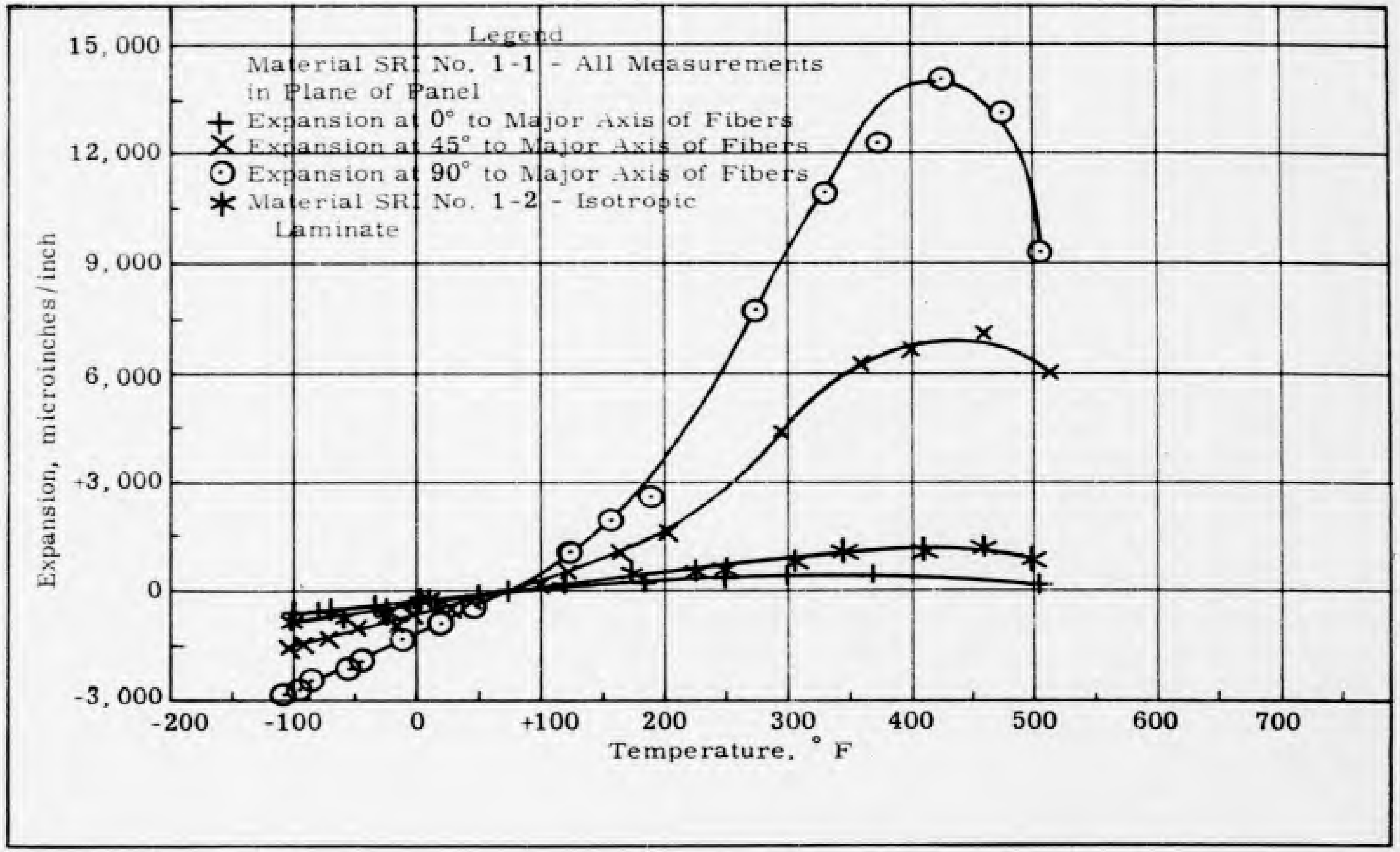

Figure 9. Curve Showing the Expansion in Different Orientations of Material SRI No. 1.

An interesting comparison that shows, in part, the influence the resin has on the over-all expansion of a plastic laminate is shown in Figure 37 of the Appendix. The curves in this figure were produced by running one specimen of material No. SRI 4 to 518° F, allowing it to cool, and then exposing it to 735° F; a second specimen was then run to 774° F. The curves made by the first runs of each specimen show a similar characteristic that is inherent in many laminates with either continuous or discontinuous reinforcements and is probably caused by the resin. The material will expand to some point, level off, and then contract to a point where it levels off and begins to re-expand. This characteristic re-expansion is probably due to additional curing of the resin at the elevated temperature. When the first specimen was run a second time, there was a decrease in expansion coefficient and the characteristic hill and valley inflections were replaced by a smooth curve to the maximum expansion. This curve indicates that the chemical change was permanent and produced a permanent change in expansion properties.

THERMAL CONDUCTIVITY

Apparatus and Procedure

Thermal conductivity measurements were made with a guarded hot plate, which is a slight modification of the standard ASTM C177-45 design.

The heat for the apparatus was supplied by a central heater plate surrounded by a guard heater; each separately controlled. The guard ring was maintained at the same temperature as the central heater so that all of the heat flow from the central heater was normal to the test surfaces. The temperature difference between the guard and central sections was measured by means of 8 differential-thermocouple junctions connected in series. Moving out from the top and the bottom of the heater, the complete assembly, shown in Figure 10, was made up in the following order. Next to the heater was the assembly for measuring the temperature on the hot side of the specimen. To insure no air film between the specimen and the thermocouple as well as between the specimen and the hot plate, the ends of the thermocouples were soldered to 1 inch x 1 inch squares of brass shim stock. Also, the leads to the thermocouples were sandwiched between sheets of thin asbestos paper. Five of these thermocouples were placed at each hot face. Next to this assembly were the test panels. The cold face measuring assemblies followed next and consisted of 14-inch square copper plates through which

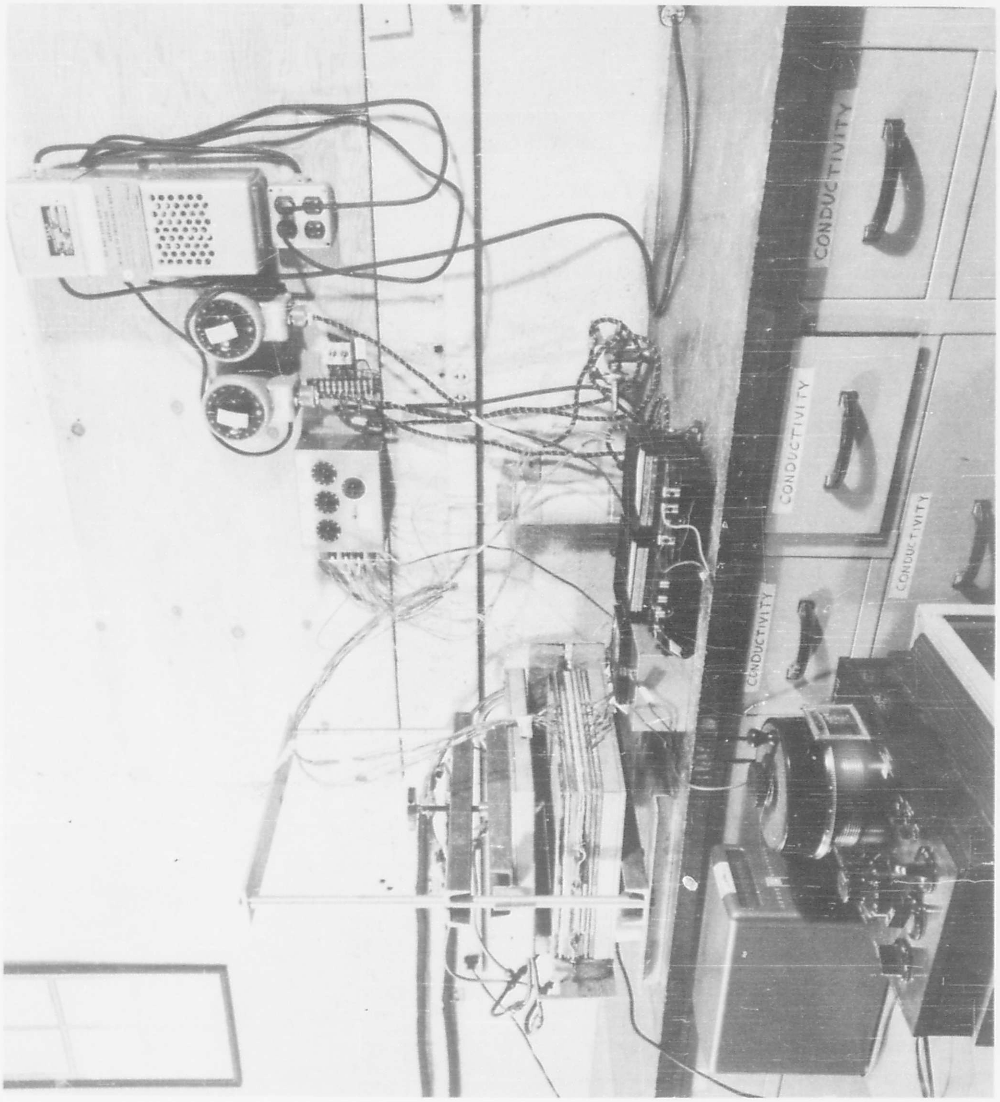

Figure 10. Thermal Conductivity Apparatus.

five thermocouples projected. The thermocouples were held in place by pieces of insulation bolted to the back of the copper plates. To protect them from high temperature corrosion, the copper plates were plated with nickel. Following next, to dissipate the heat was a cold source consisting of a copper coil enclosed in an aluminum box. To obtain mean sample temperatures above room temperature, water was circulated through the copper tubing of the cold plates. For mean sample temperatures below room temperature, cold trichloroethylene was pumped through the copper tubing. This coolant was chilled by circulating it through copper coils in a trichloroethylene dry-ice bath. Equilibrium conditions were verified before readings were taken.

To maintain good contact pressure, a screw loading device held the entire sandwich assembly pressed firmly together.

The assembly was arranged to operate with the specimen placed in the apparatus horizontally, as shown by Figure 10. The assembly was insulated around the edges by glass batting which can be seen on the far side of the apparatus in Figure 10.

A constant voltage transformer was used in conjunction with the variable control transformers, to assure a constant power supply at each setting. The central heater and guard heater were controlled individually by the variable control transformers.

Voltage and current to the central heater were monitored by means of a voltmeter and an ammeter which were switched out of the circuit except when actually being read. The voltage to the guard heater was monitored constantly by a voltmeter and an ammeter was switched in occasionally to confirm that the guard heater was operating.

All of the thermocouple readings were taken on a Leeds and Northrup K-2 potentiometer used in conjunction with a galvanometer of 0.43 microvolts per mm deflection sensitivity.

Due to the high cost of materials and the fact that larger dies were not available, some of the panels were less than the 14 inches x 14 inches required for this apparatus. Most of the undersized panels were 8 inches x 8 inches, although there were several panels in between the 8 inch x 8 inch and the 14 inch x 14 inch sizes.

To permit the undersized specimens to fit fully across the central and guard heaters these specimens were placed in a square hole cut to their size in the center of a piece of asbestos board 14 inches x 14 inches and the same thickness as the specimen. This assembly then provided a specimen the same size as the normal 14 inch x 14 inch pieces and well guarded by the asbestos periphery.

Data and Results

Coefficients of thermal conductivity were calculated from the expression:

$$K = \frac{QX}{A\Delta t}$$

where

Q = total heat flow, Btu/hr
X = average thickness of specimens, inches
A = area of central heater section, square feet
Δt = sum of temperature drops across each sample, $^\circ$F

Theoretically, Q, the heat input, should split, with exactly half of the input flowing through each sample. The temperature drops indicate that this condition rarely exists. Instead, there is a slight unbalance in the heat flow. The above formula then permits a calculation of the arithmetic average K for the two test panels.

The apparatus was calibrated against a calibration reference specimen used in previous work.

Figure 11 shows the curve established previously along with several data points obtained using (1) the same material but smaller specimens, (2) a modified periphery insulation, and (3) an improved temperature measuring technique. From this curve it can be seen that this preliminary data had considerable scatter. In spite of this scatter, sufficient information was obtained to establish operation procedure and techniques and to confirm the validity of using smaller specimens.

A more accurate calibration curve was subsequently established and is shown in Figure 12. From these data, it was determined that the best operating procedure was to measure the face temperature with five thermocouples mounted on small brass "getters" and held

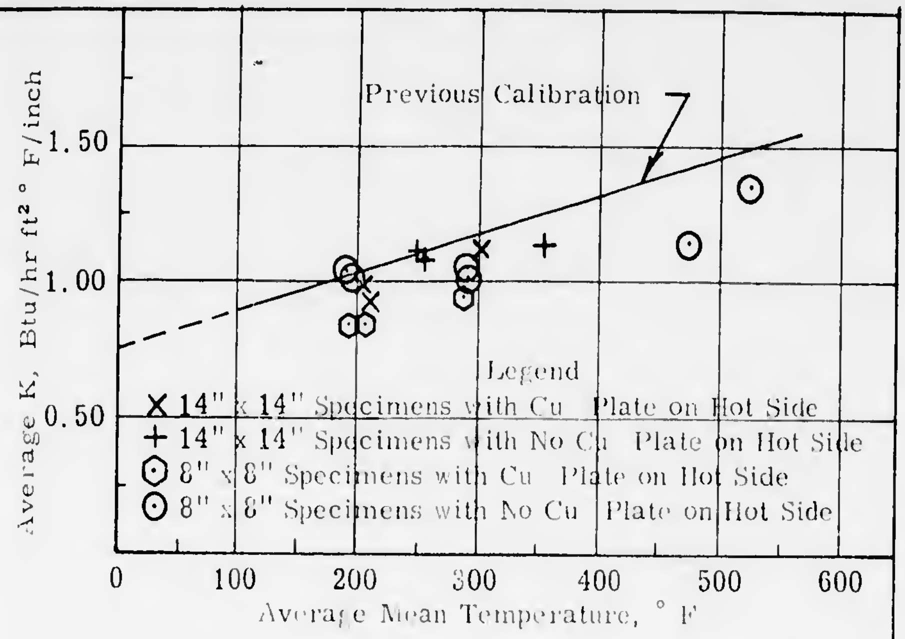

Figure 11. Conductivity Original Calibration Curve.

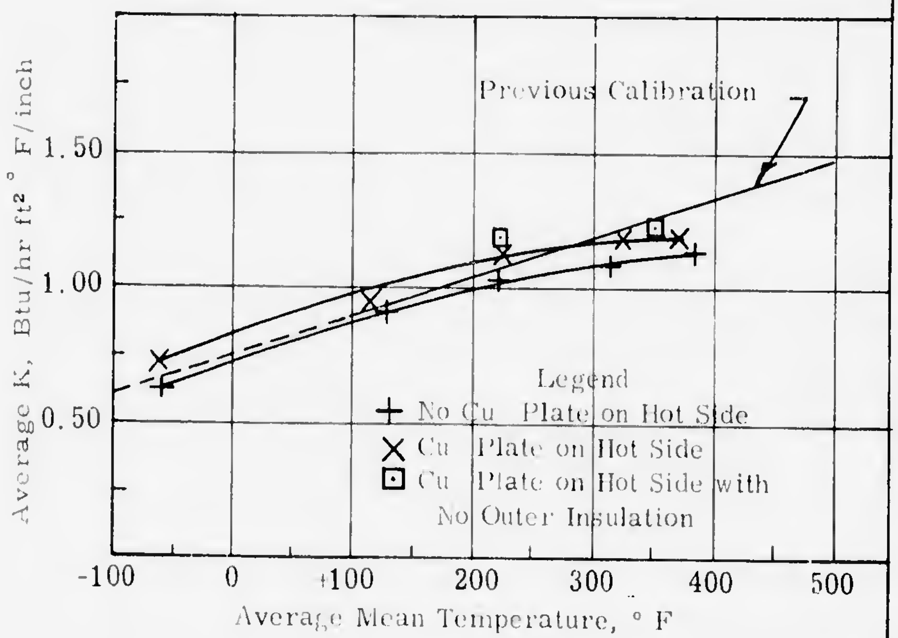

Figure 12. Conductivity Final Calibration Curve.

against the specimen by a thin sheet of asbestos paper. Also, the copper plates on the hot side were eliminated. The results from these procedures indicated close agreement with both the previous calibrations on 14-inch specimens with 6 inches of vermiculite insulation around the apparatus, and the ASTM technique of simply laying the couples between the hot plate and the specimen. This latter technique is good for deformable materials but not advisable for rather rigid structures such as some of the molded panels. With copper plates on the hot side, the conductivity obtained was higher, indicating a radial heat loss out through the copper plates on the heater side of the specimens.

Conductivity curves for the materials are shown in Figures 54 through 70 of the Appendix and have been assembled in Figure 13 for comparison. The data from which these curves were plotted are shown in Tables 35 through 51 of the Appendix. On all of the materials, points obtained at a reduced temperature, after the material had been to the top temperature exposure, indicated a reduced conductivity. This suggests a nonreversible cure at the higher temperatures. Generally, the additional cure reduced the conductivity about 15 percent.

From Figure 13, observe that most of the materials fell within a close range with material No. SRI 1-1, No. SRI 1-2, No. SRI 2, No. SRI 11, and No. SRI 12, phenolics and epoxies, indicating a decreasing conductivity earlier during the temperature increase than most materials. This is probably the result of additional resin cure and then subsequent resin destruction. Material No. SRI 3, a foam core, had a lower conductivity than the other materials but continued to increase to the maximum temperature. This constant increase in conductivity was probably the result of increasing convection as well as the natural character of the silicone.

As was expected, the conductivity of material No. SRI 8, a phenolic-glass with a regular layup, increased as the orientation of the fabric to the heat flow direction was varied from normal to the panel, to 45° to normal, to 90° to normal or edgewise to the panel. This progression in conductivity can be noted from Figure 13. As seen in the more detailed curves on Figures 64 and 65, this material also had an unusual S-shaped character when run edgewise and at 45° to the panel. This shape has not been exhibited before by glass-reinforced laminates. Some glass does have a characteristic conductivity curve that increases sharply with temperature. It is possible that this characteristic of glass is controlling in these planes.

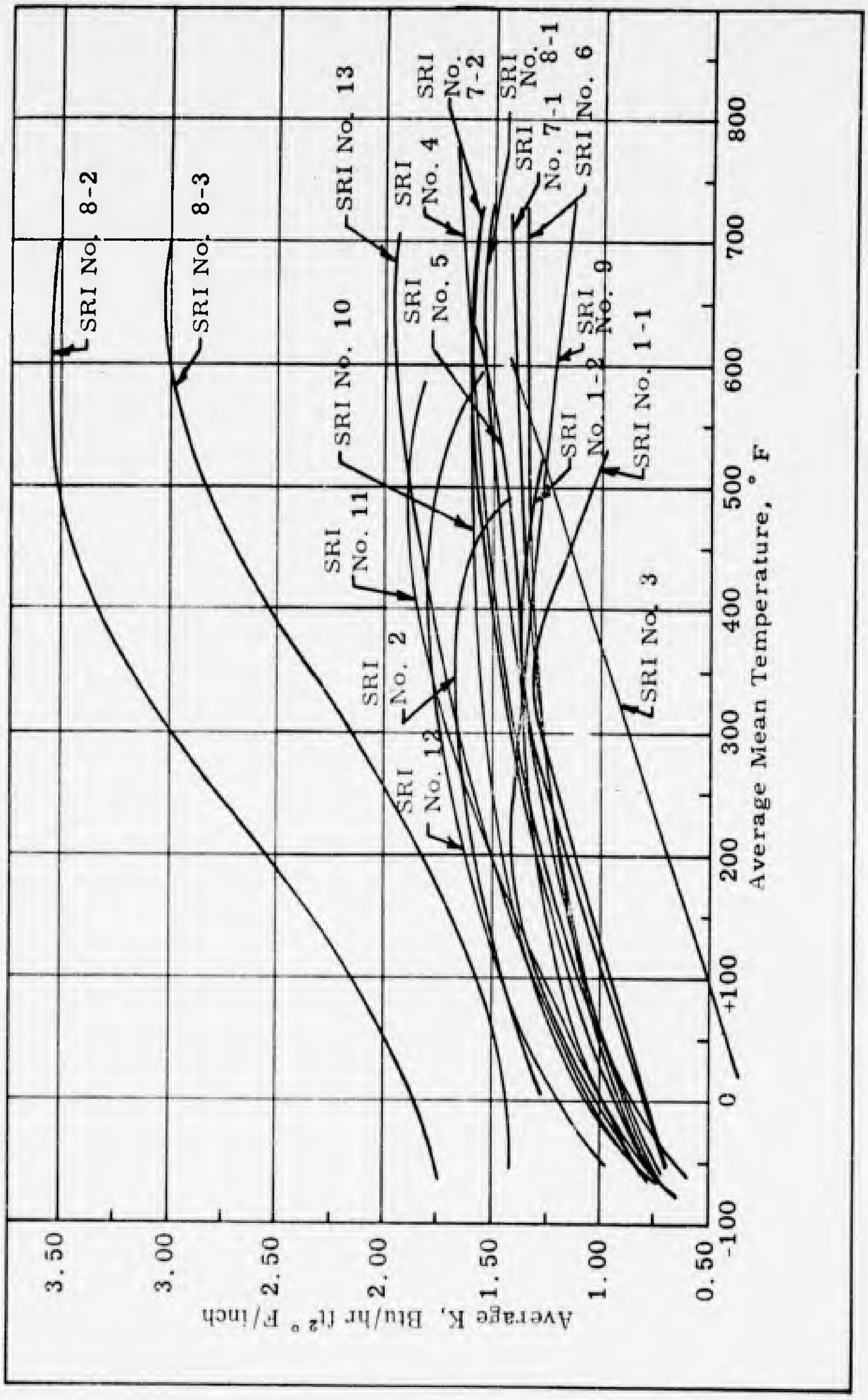

Figure 13. Composite of All Conductivity Curves.

Material No. SRI 9 decreased in conductivity earlier during the increasing temperature exposure than the rest of the materials probably because of the properties of the nylon reinforcement.

Because of the many varied physical constructions and fabrication procedures used in the different panels, it is difficult to correlate many of these characteristics with the conductivity. However, an interesting analysis can be made from the curves in Figures 60, 61, and 62 of the Appendix. These curves, which have been assembled in Figure 14, are for material No. SRI 6, No. SRI 7-1, and No. SRI 7-2, which are the Astrolite laminate with SC-1008 phenolic resin, a light cure, and different reinforcements. Material No. SRI 6 and No. SRI 7-1 had practically identical conductivity curves, although they contained different reinforcements. This would indicate that the conductivity normal to a panel is probably primarily influenced by the resin. The curve of material No. SRI 7-2 indicates a conductivity reasonably similar in character to that of the other two materials but somewhat higher since the conductivity was determined edgewise rather than normal. In this aspect, the glass could conduct continuously through the panel. Another interesting observation is that the curve of material No. SRI 7-1 was determined using a 14 inch x 14 inch specimen, while the one for material No. SRI 6 was determined using an 8 inch x 8 inch specimen. For these similar materials the specimen size had no appreciable influence on conductivity.

CONCLUSIONS

From the materials evaluated, the specific heat seemed to be influenced by the reinforcement materials more than any other single parameter probably because the heat capacity of the different reinforcements varied more than that of the different resins. The glass-reinforced materials had the lowest specific heats, the asbestos-reinforced materials were next, and the one nylon-reinforced material had the highest value.

The expansion coefficient was influenced by both the over-all composition and the orientation of the reinforcing fibers. The coefficient progressed from a minimum when determined at 0° to the major axis of the fibers, to a maximum when determined at 90° and parallel to the major axis of the fibers. The expansion properties of a material may be completely altered after the material has been exposed to a certain critical temperature.

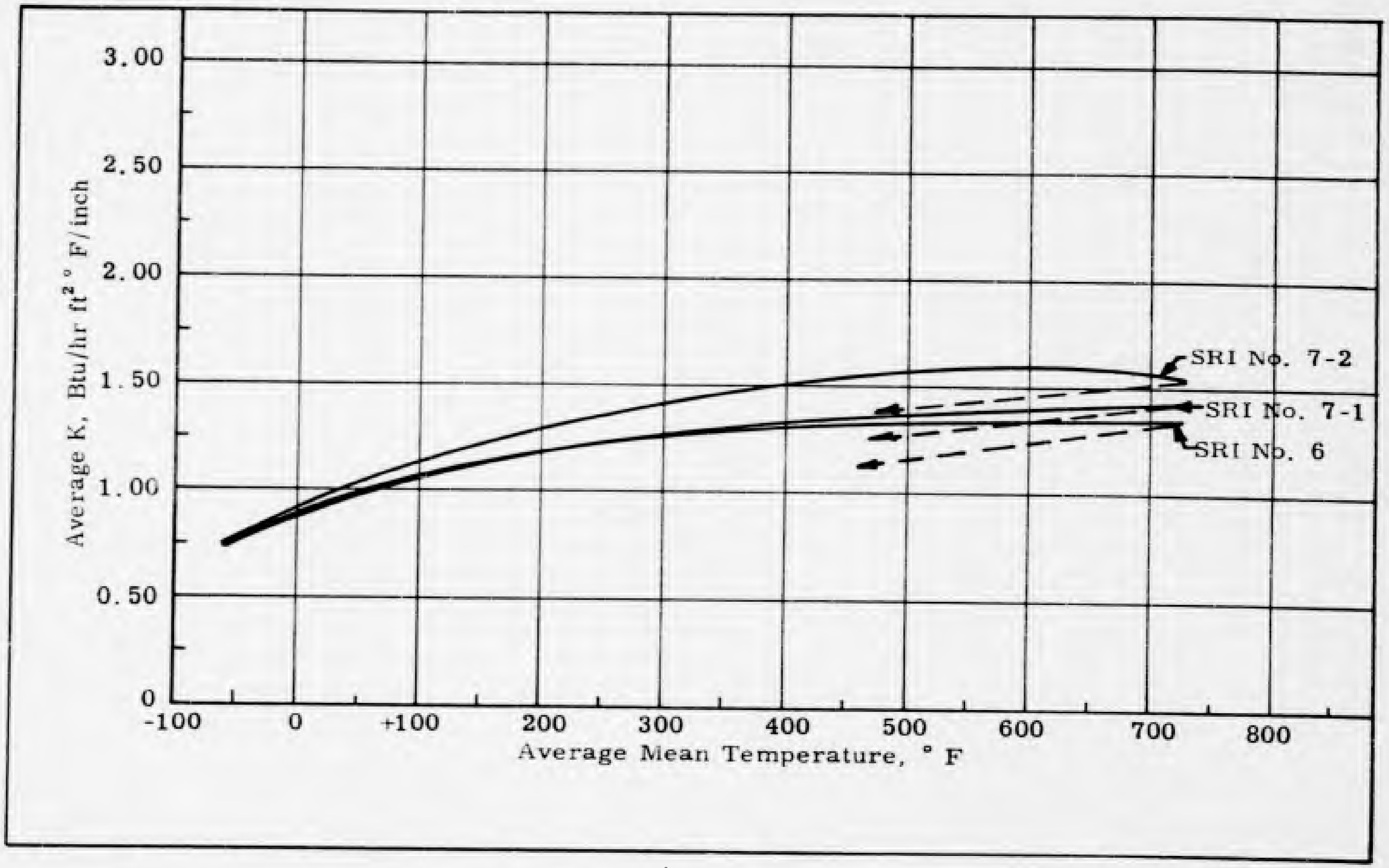

Figure 14. Thermal Conductivity for Material SRI No. 6, SRI No. 7-1, and SRI No. 7-2.

Conductivity determined edgewise to a panel was influenced more by the reinforcement than by the resin. In the case of panels with glass reinforcement, the conductivity was higher edgewise than normal to the panel. In contrast to this, the conductivity normal to a panel was influenced more by the resin than the reinforcement.

APPENDIX

Individual Curves for all Properties

Individual Tables for all Properties

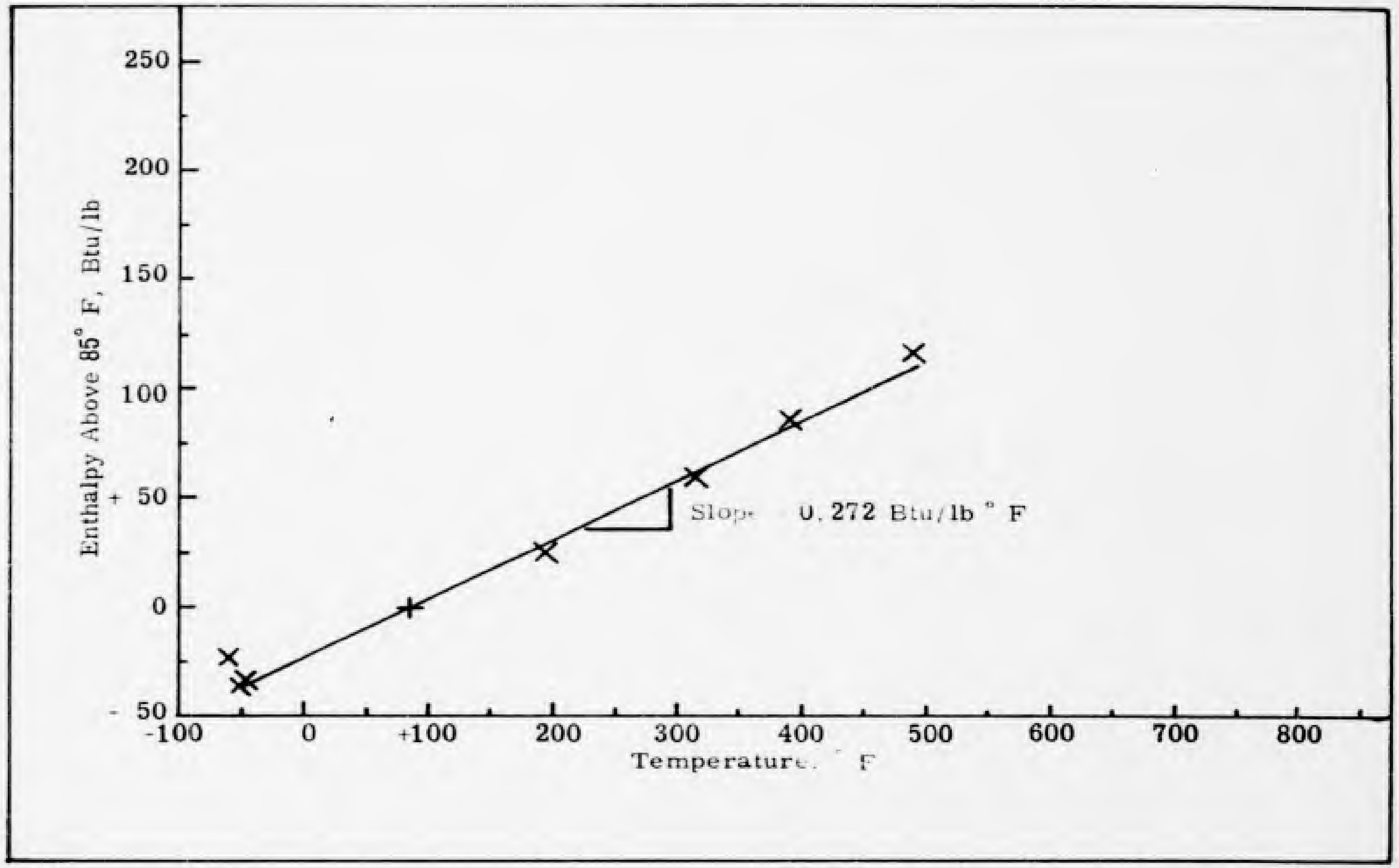

Figure 15. Heat Content Curve for Material SRI No. 1-1, 60N Roving, Epoxy Resin, Unidirectional.

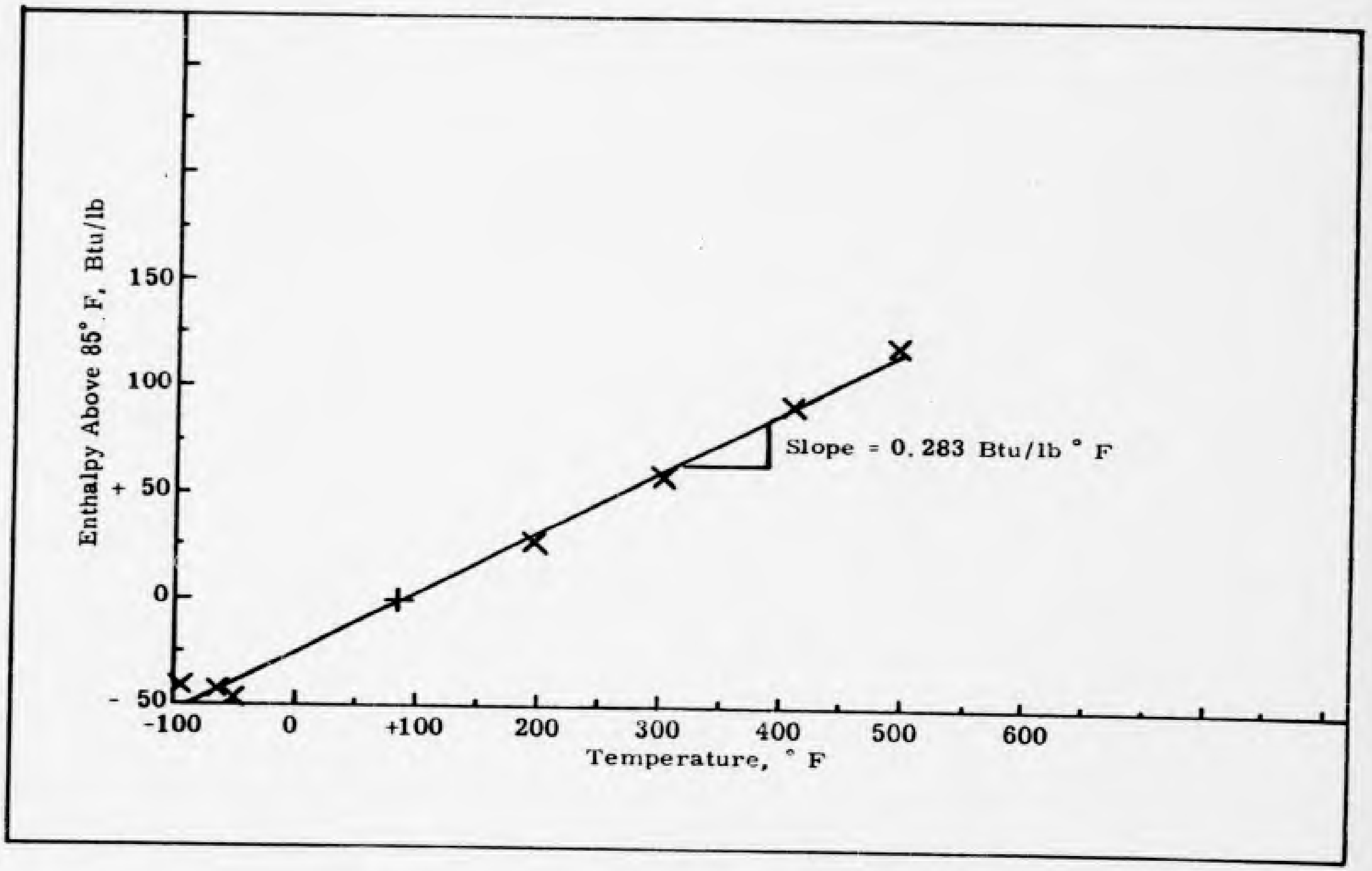

Figure 16. Heat Content Curve for Material SRI No. 1-2, 60N Roving, Epoxy Resin, Isotropic.

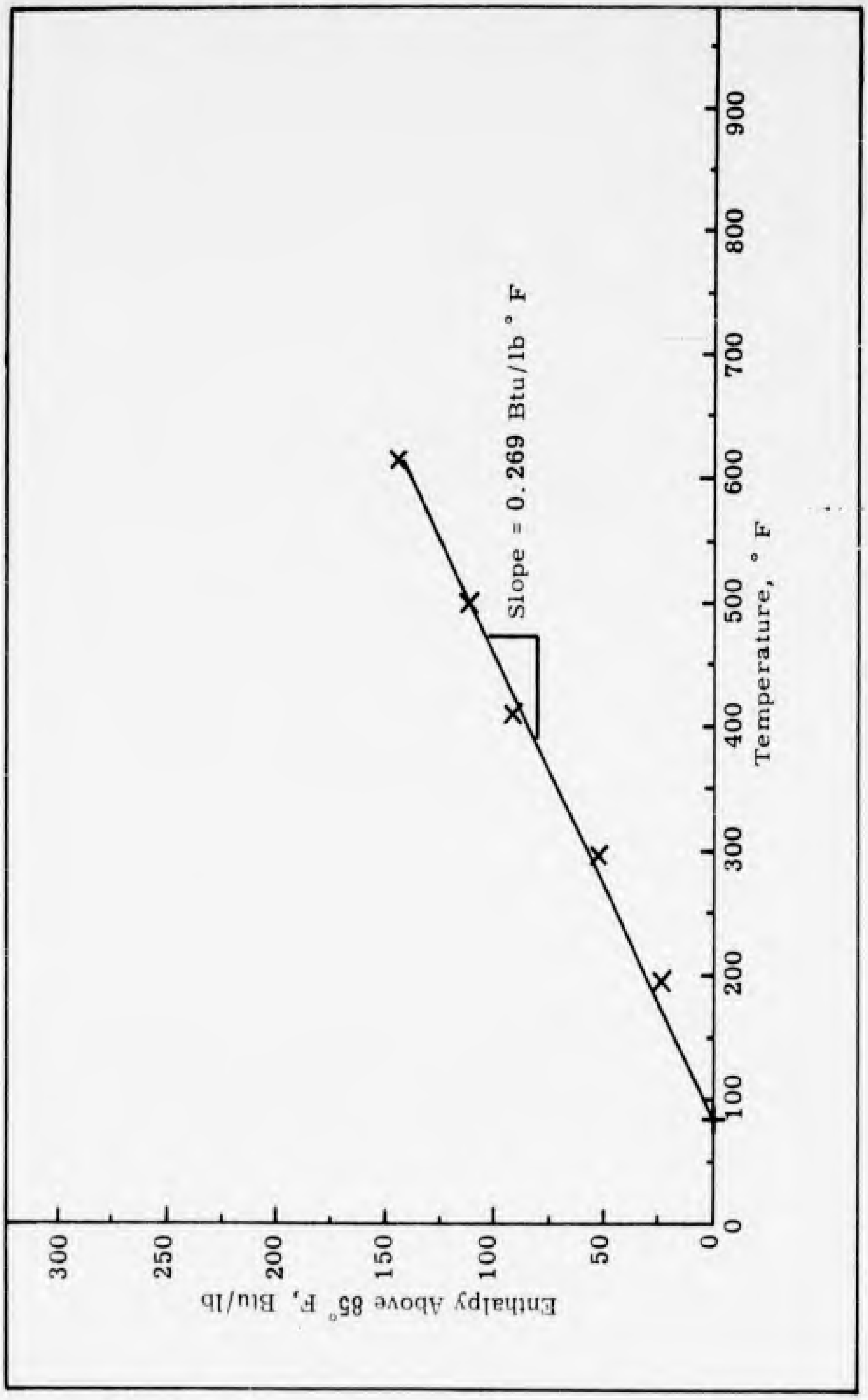

Figure 17. Heat Content Curve for Material SRI No. 2, Chopped Glass, Phenolic Resin.

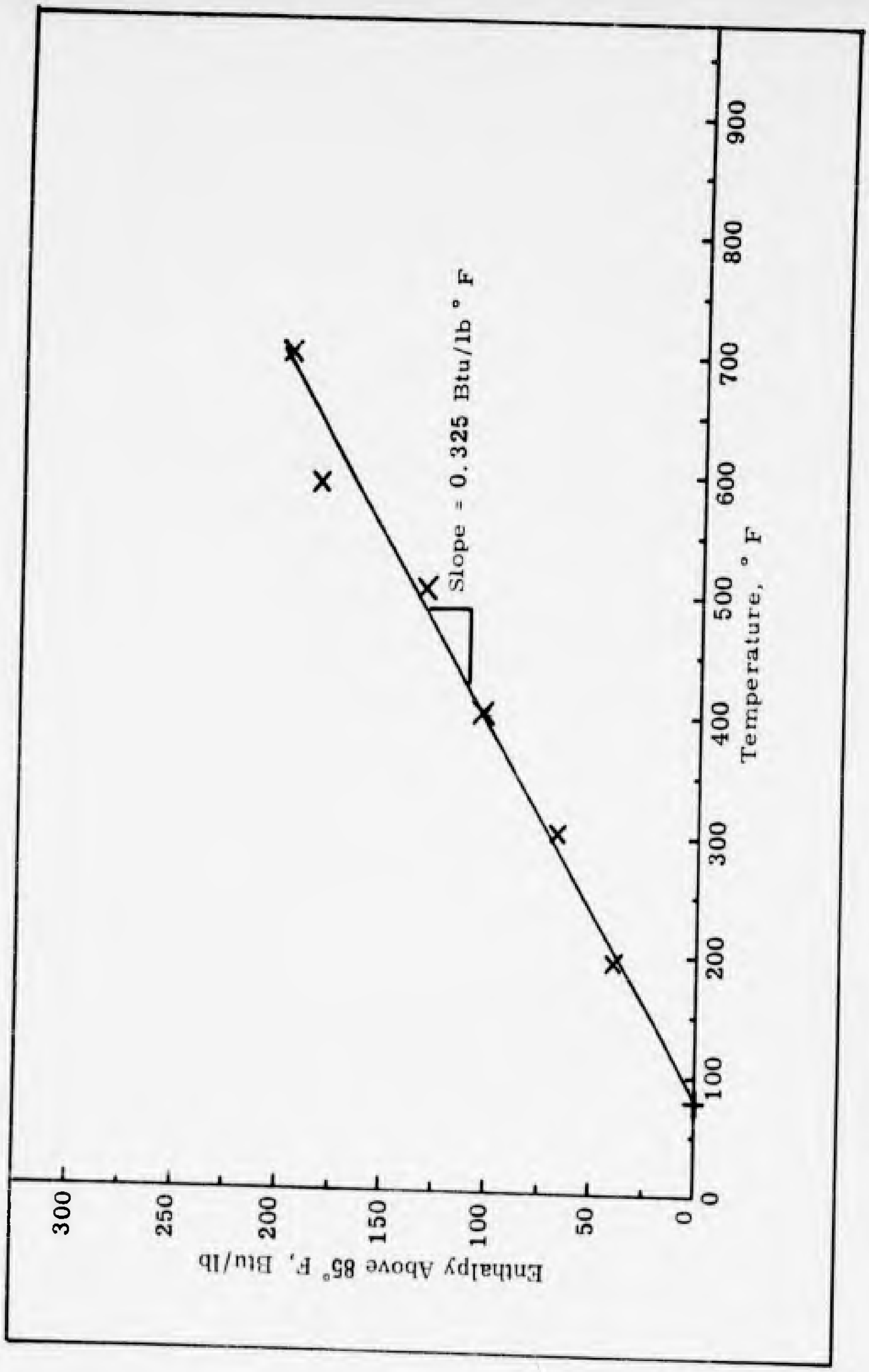

Figure 18. Heat Content Curve for Material SRI No. 3, Silicone Foam.

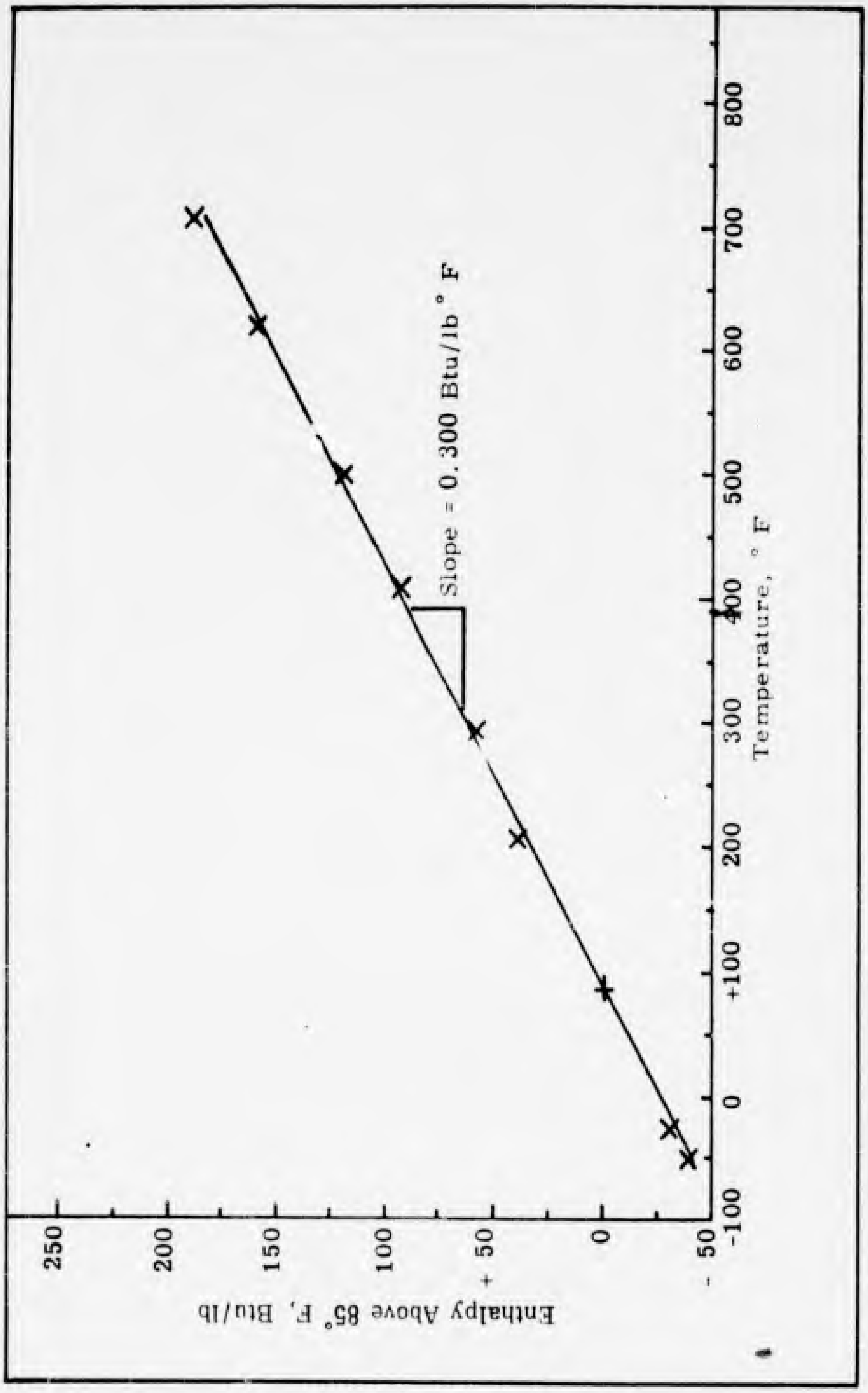

Figure 19. Heat Content Curve for Material SRI No. 4, Glass Roving, Phenolic Resin.

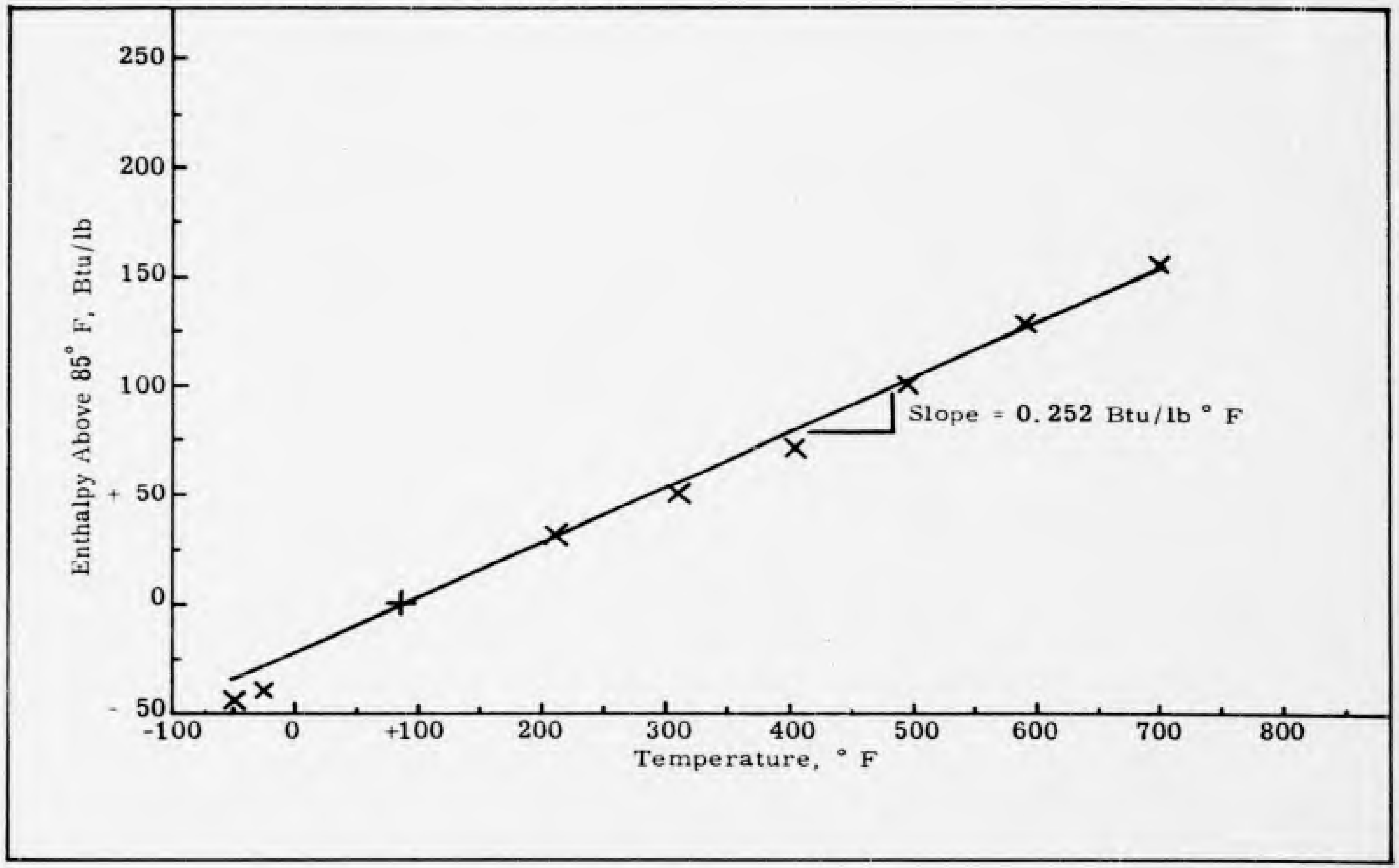

Figure 20. Heat Content Curve for Material SRI No. 5, Chopped Glass, Silicone Resin.

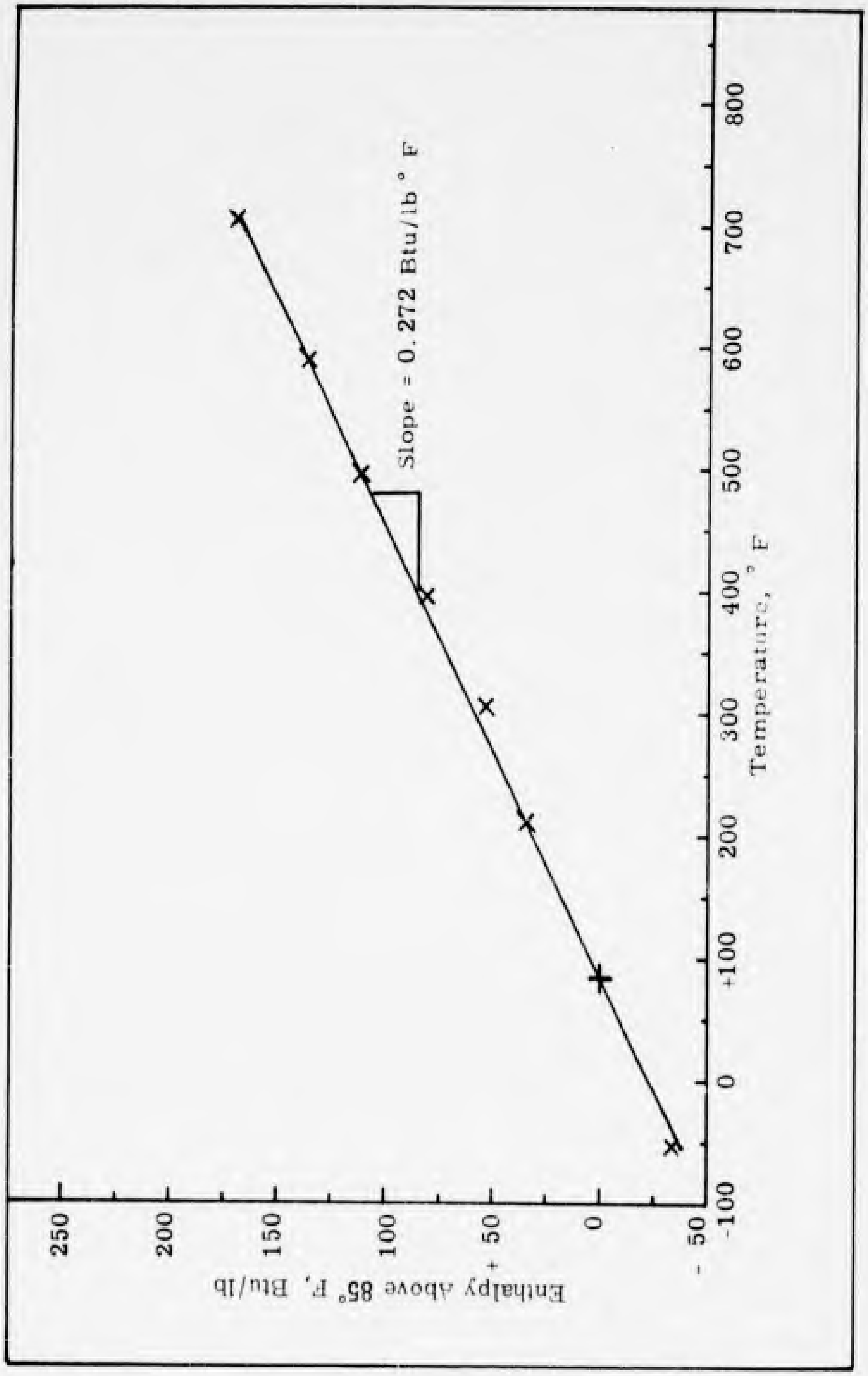

Figure 21. Heat Content Curve for Material SRI No. 6, $\frac{1}{2}$-inch Squares Glass, Phenolic Resin.

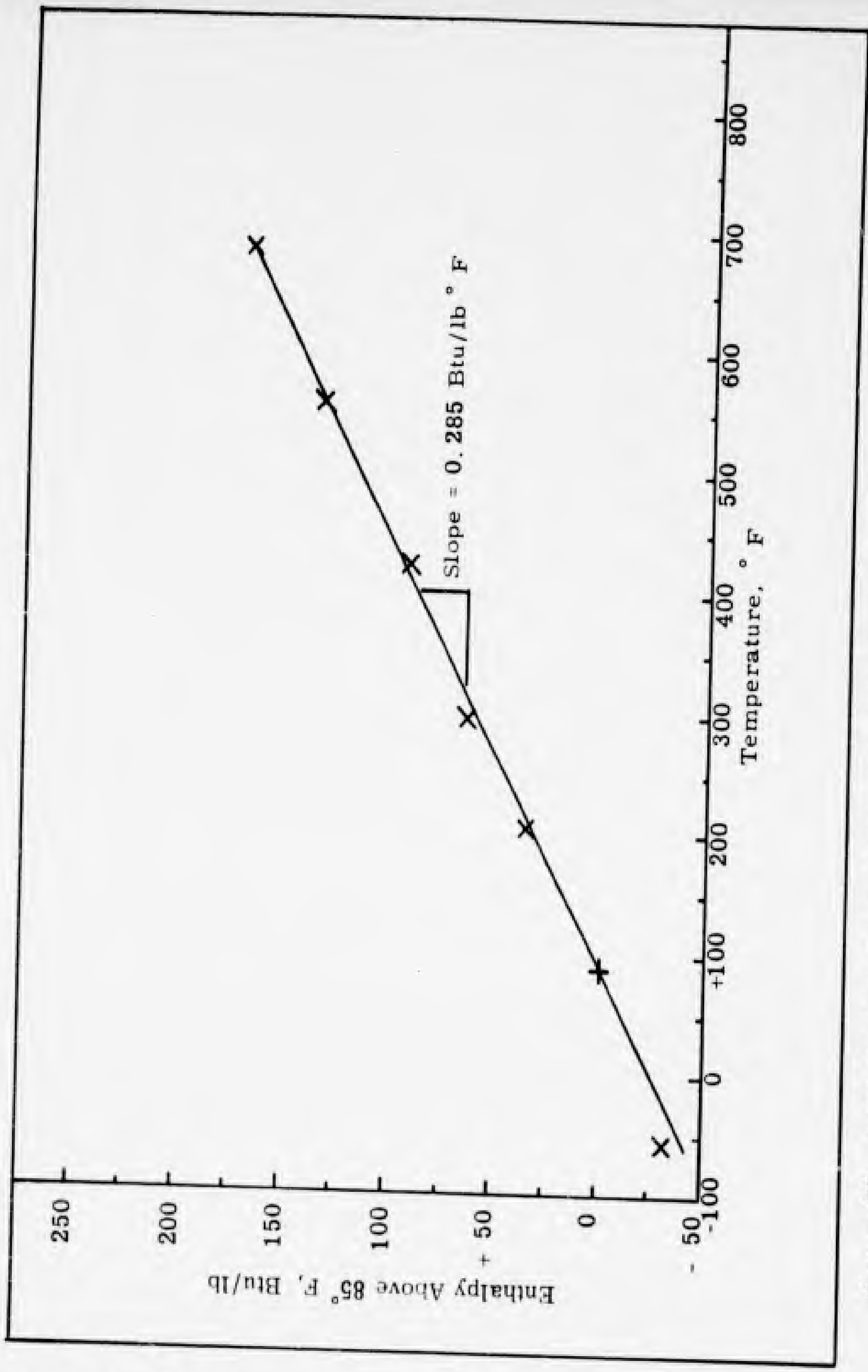

Figure 22. Heat Content Curve for Material SRI No. 7-1, Refrasil Fabric, Phenolic Resin.

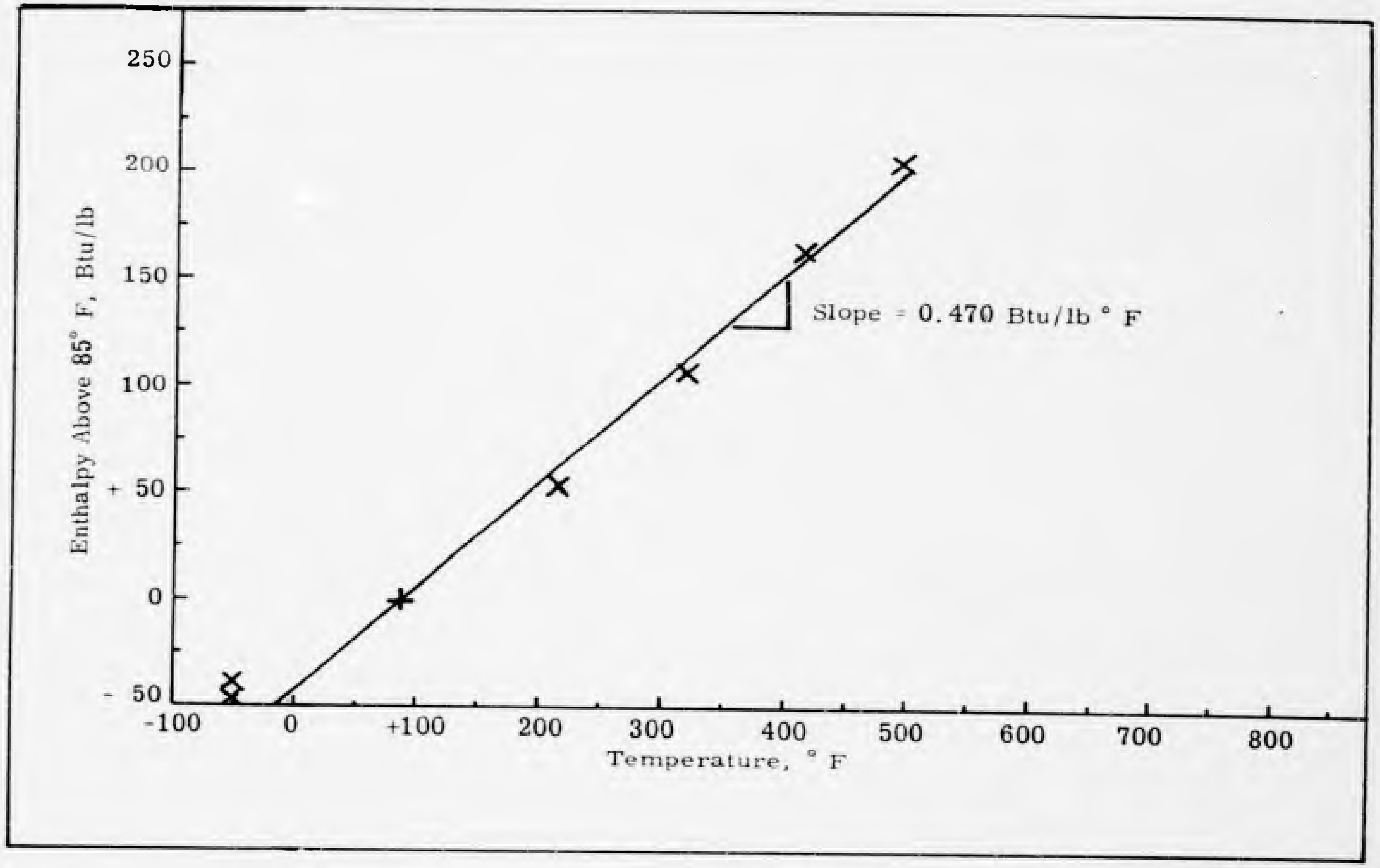

Figure 23. Heat Content Curve for Material SRI No. 9, Chopped Nylon, Phenolic Resin.

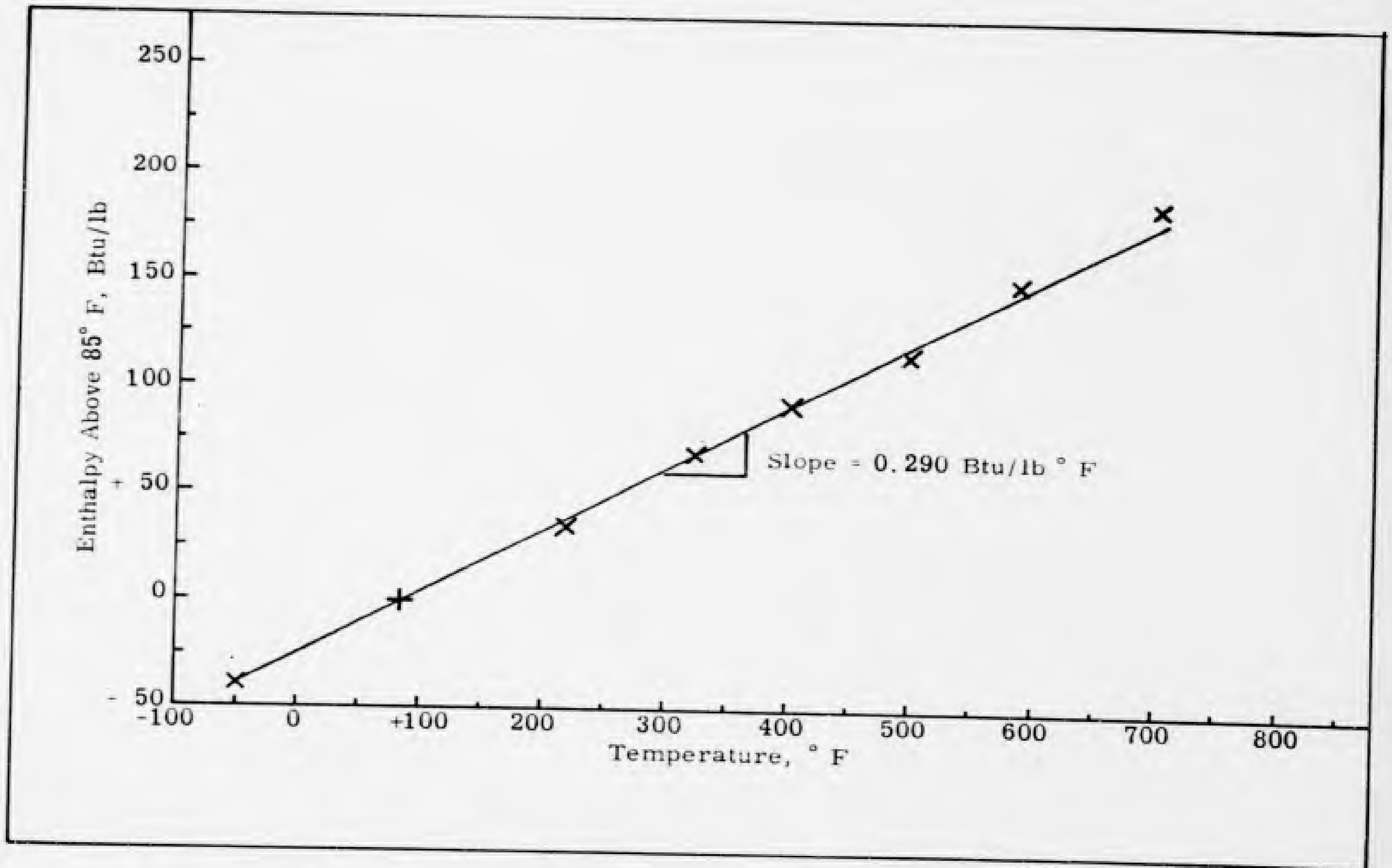

Figure 24. Heat Content Curve for Material SRI No. 10, Asbestos, Silicone Resin.

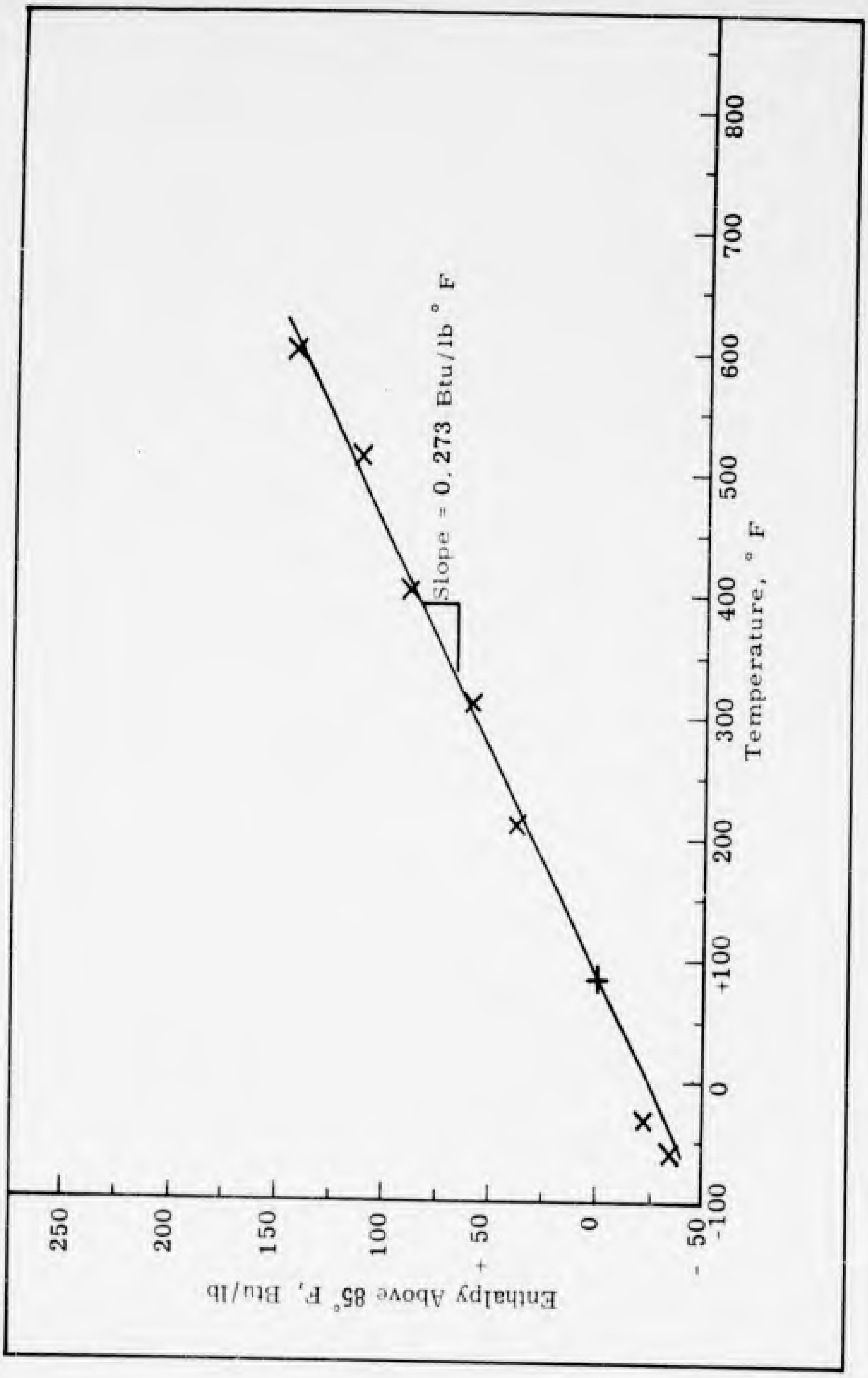

Figure 25. Heat Content Curve for Material SRI No. 11, Glass Fabric, Phenolic Resin.

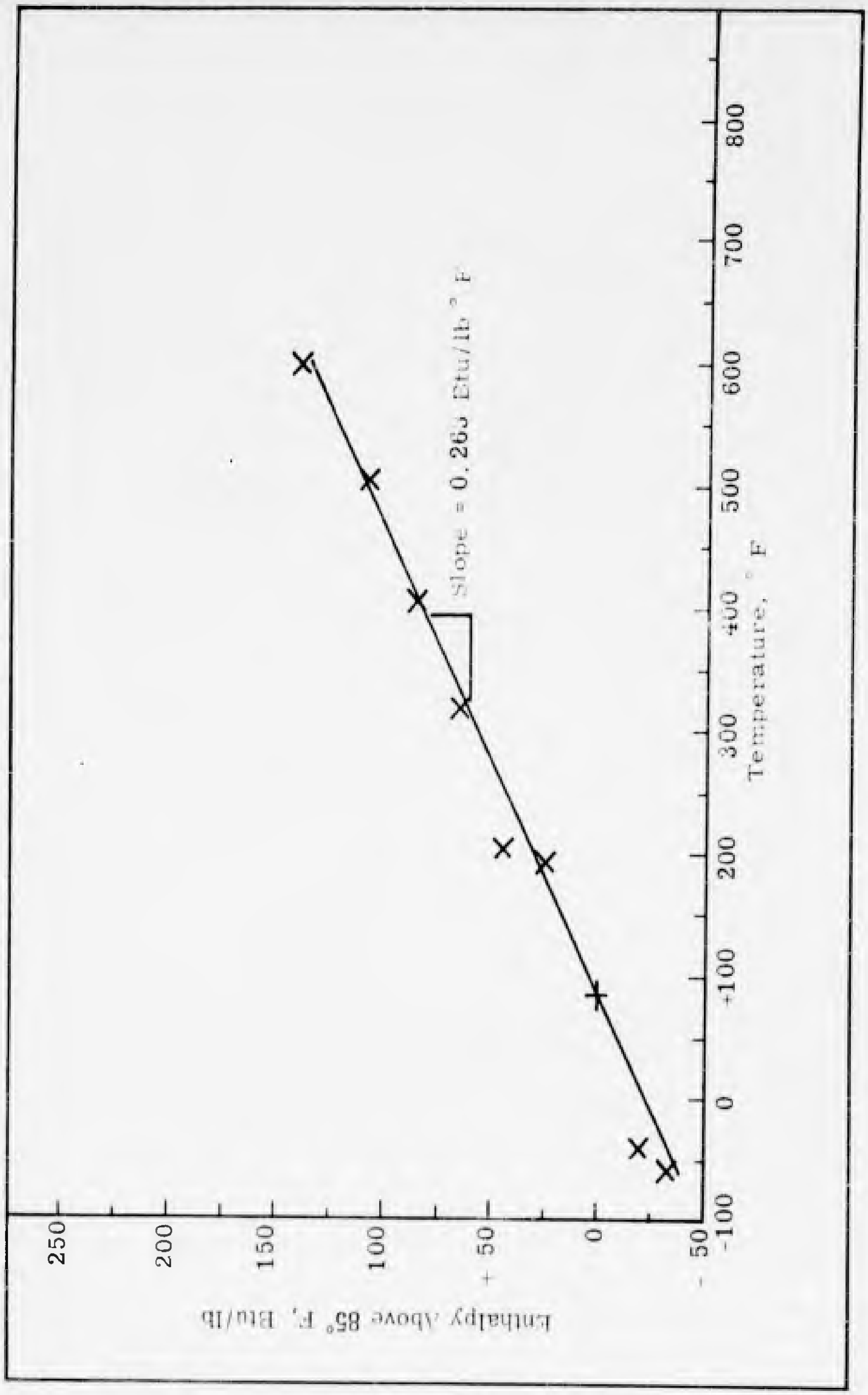

Figure 26. Heat Content Curve for Material SRI No. 12. Glass Fabric, Epoxy Resin.

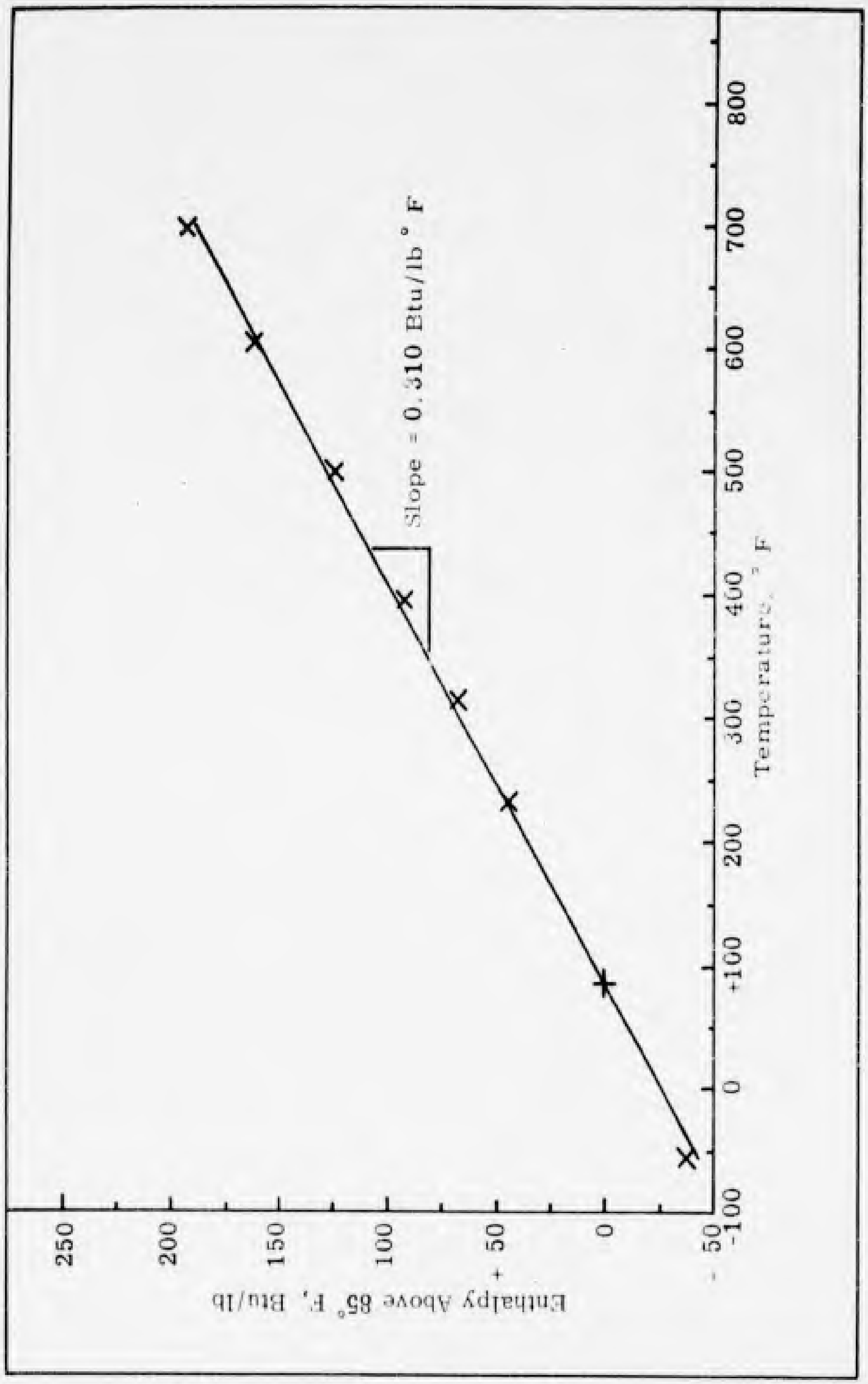

Figure 27. Heat Content Curve for Material SRI No. 13, Asbestos, Phenolic Resin.

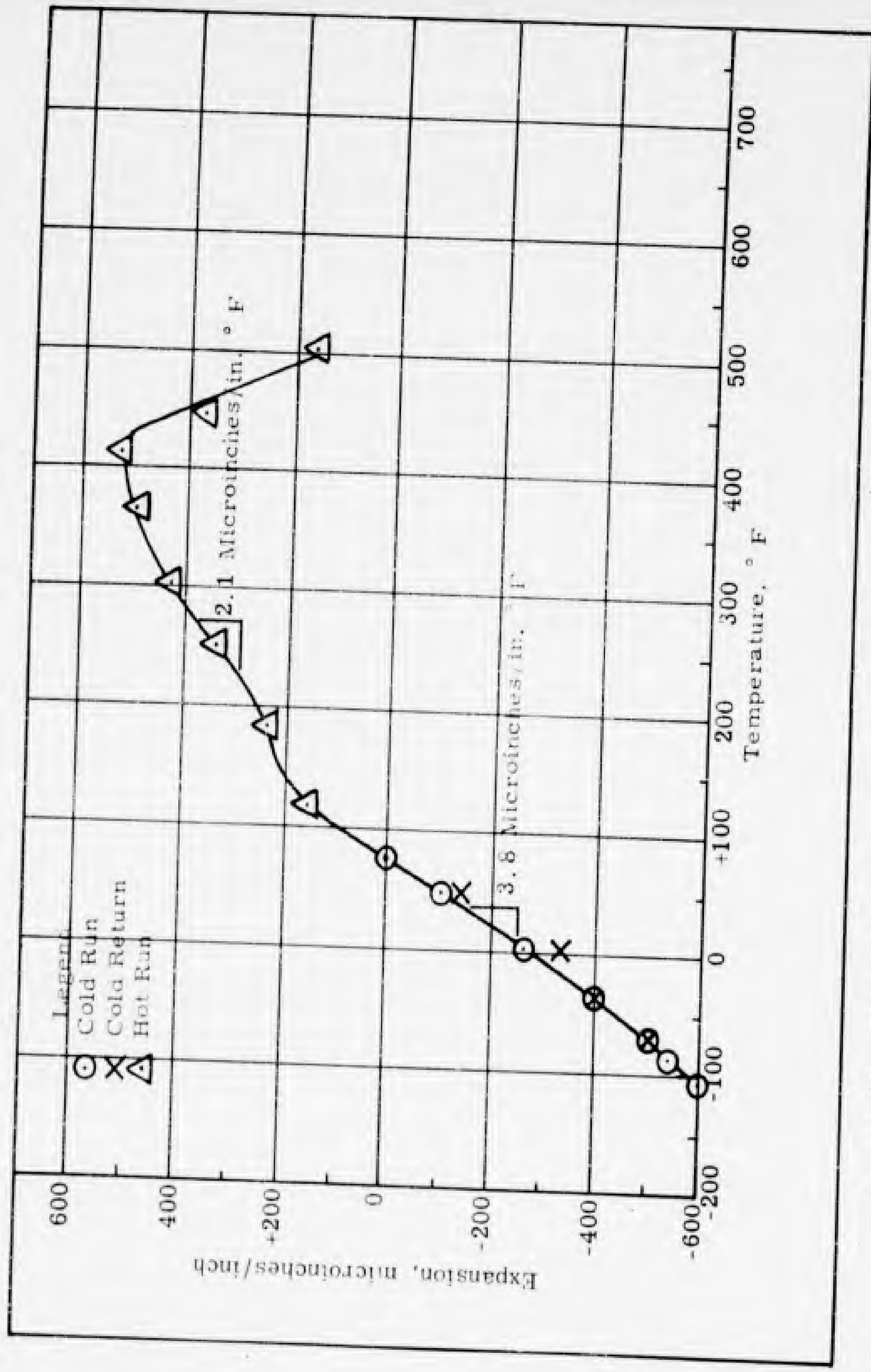

Figure 28. Thermal Expansion Parallel and at 0° to Major Axis of Fibers, Material SRI No. 1-1, 60N Roving, Epoxy Resin, Unidirectional.

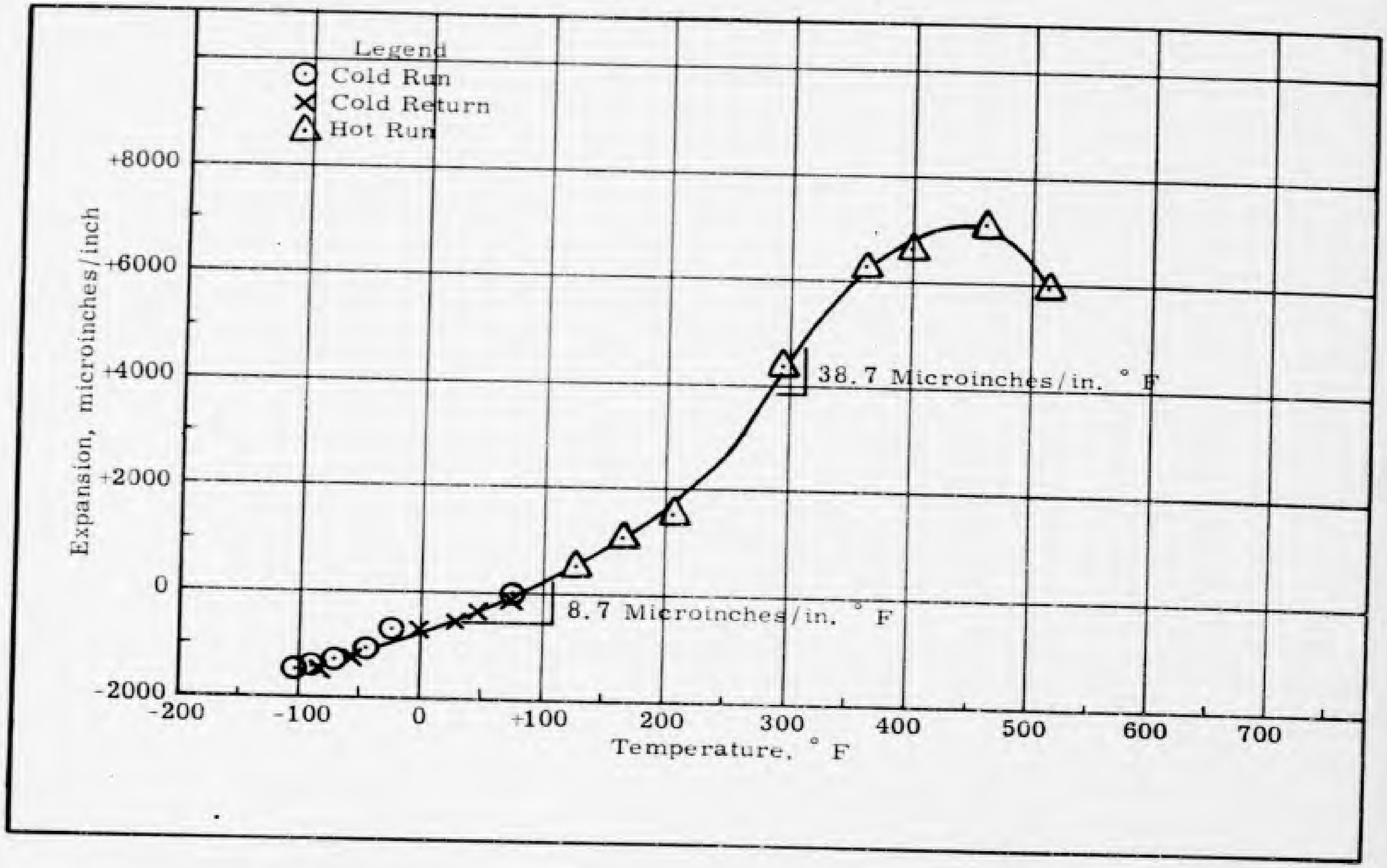

Figure 29. Thermal Expansion Parallel and at 45° to Major Axis of Fibers, Material SRI No. 1-1, 60N Roving, Epoxy Resin, Unidirectional.

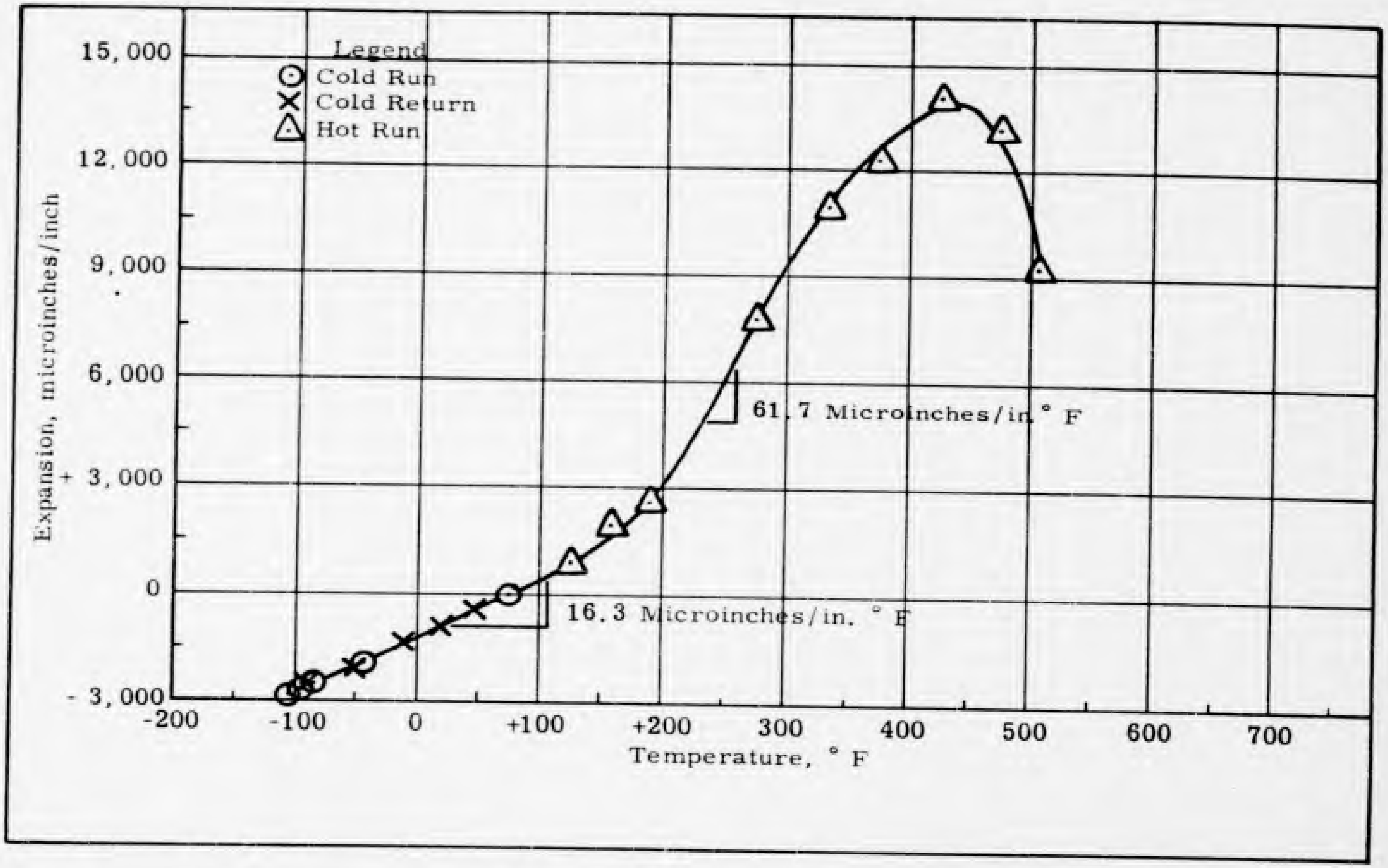

Figure 30. Thermal Expansion Parallel and at 90° to Major Axis of Fibers, Material SRI No. 1-1, 60N Roving, Epoxy Resin, Unidirectional.

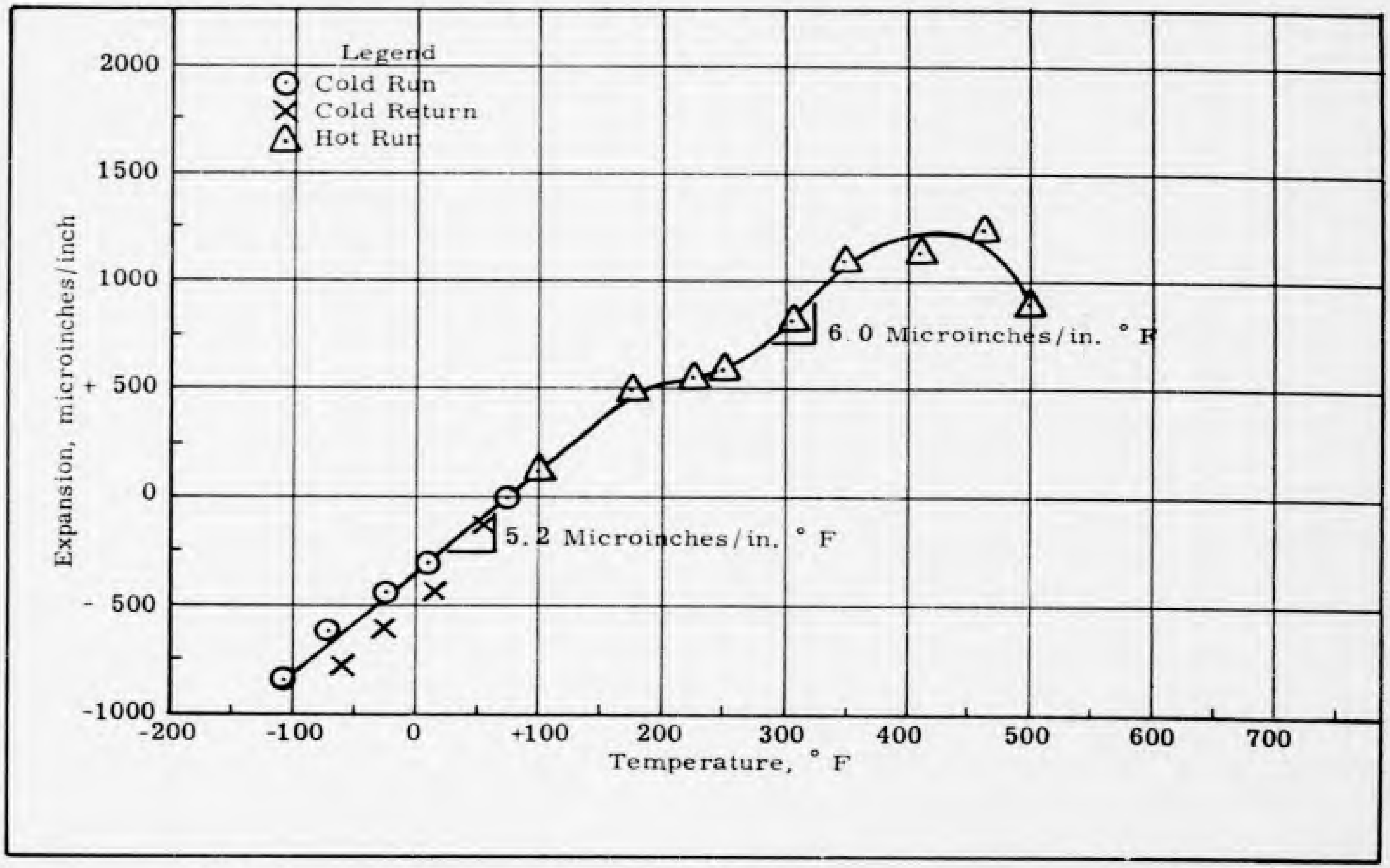

Figure 31. Thermal Expansion Parallel to Panel, Material SRI No. 1-2, 60N Roving, Epoxy Resin, Isotropic.

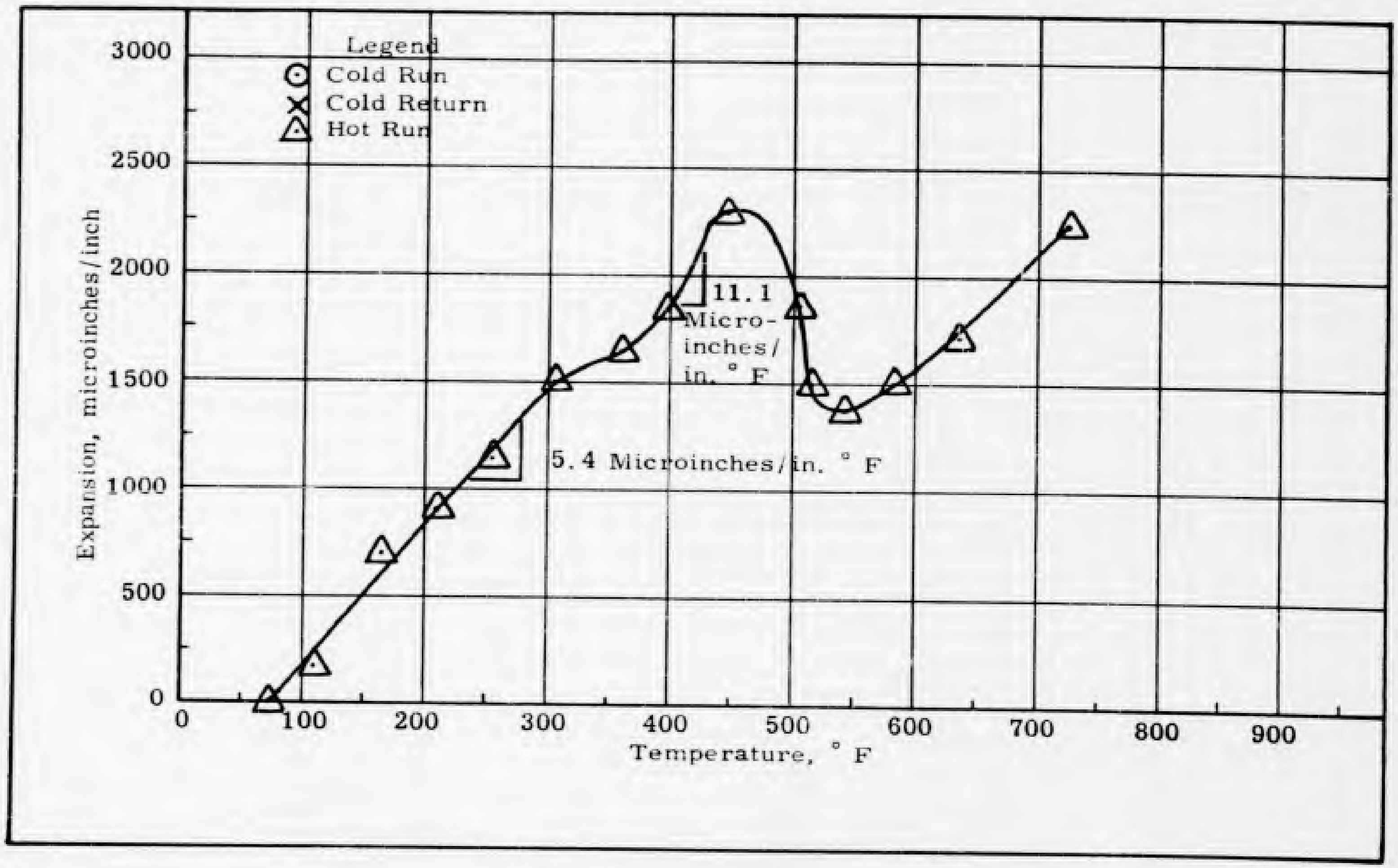

Figure 32. Thermal Expansion Parallel to Panel, Material SRI No. 2, Chopped Glass, Phenolic Resin.

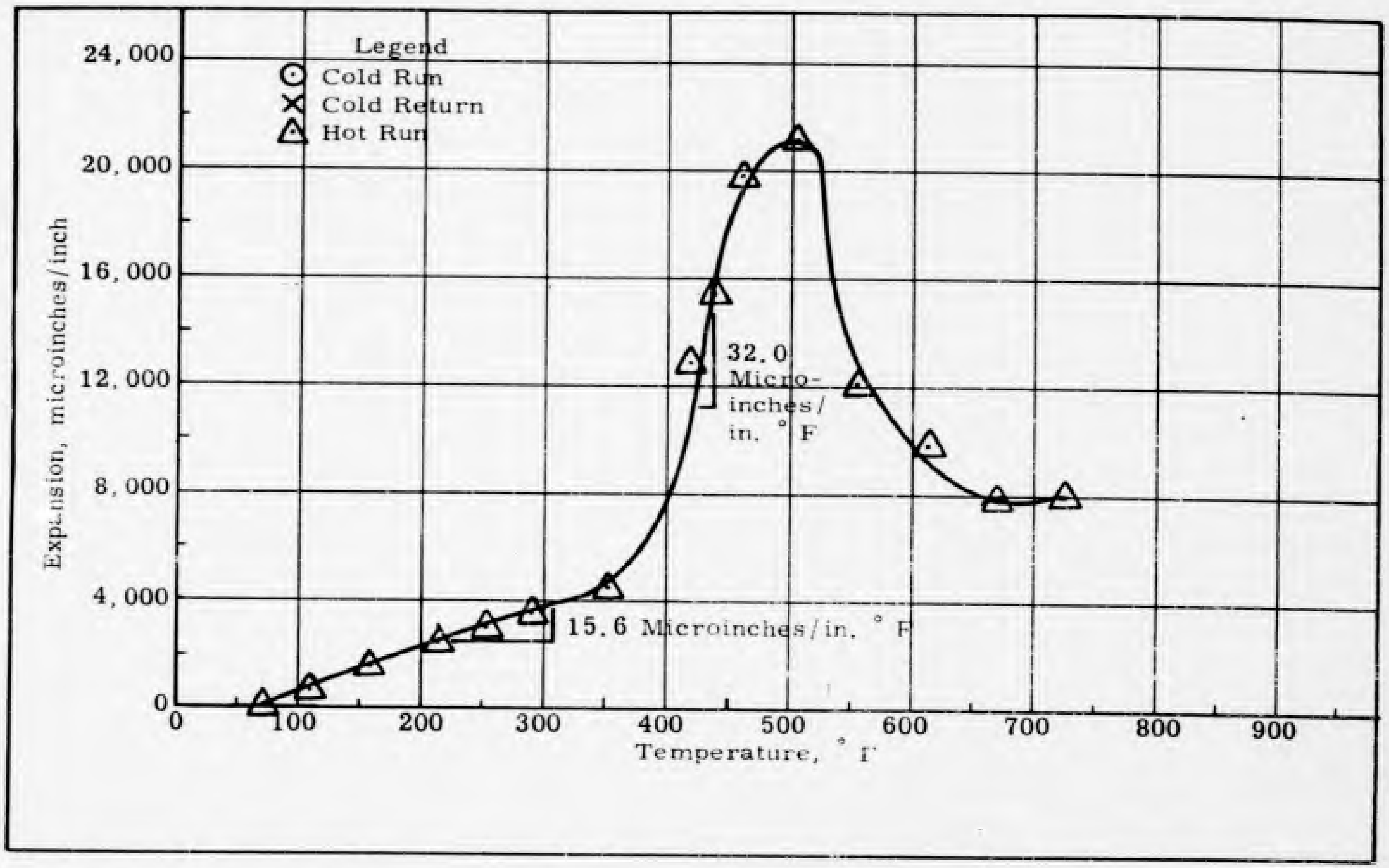

Figure 33. Thermal Expansion Normal to Panel, Material SRI No. 2, Chopped Glass, Phenolic Resin.

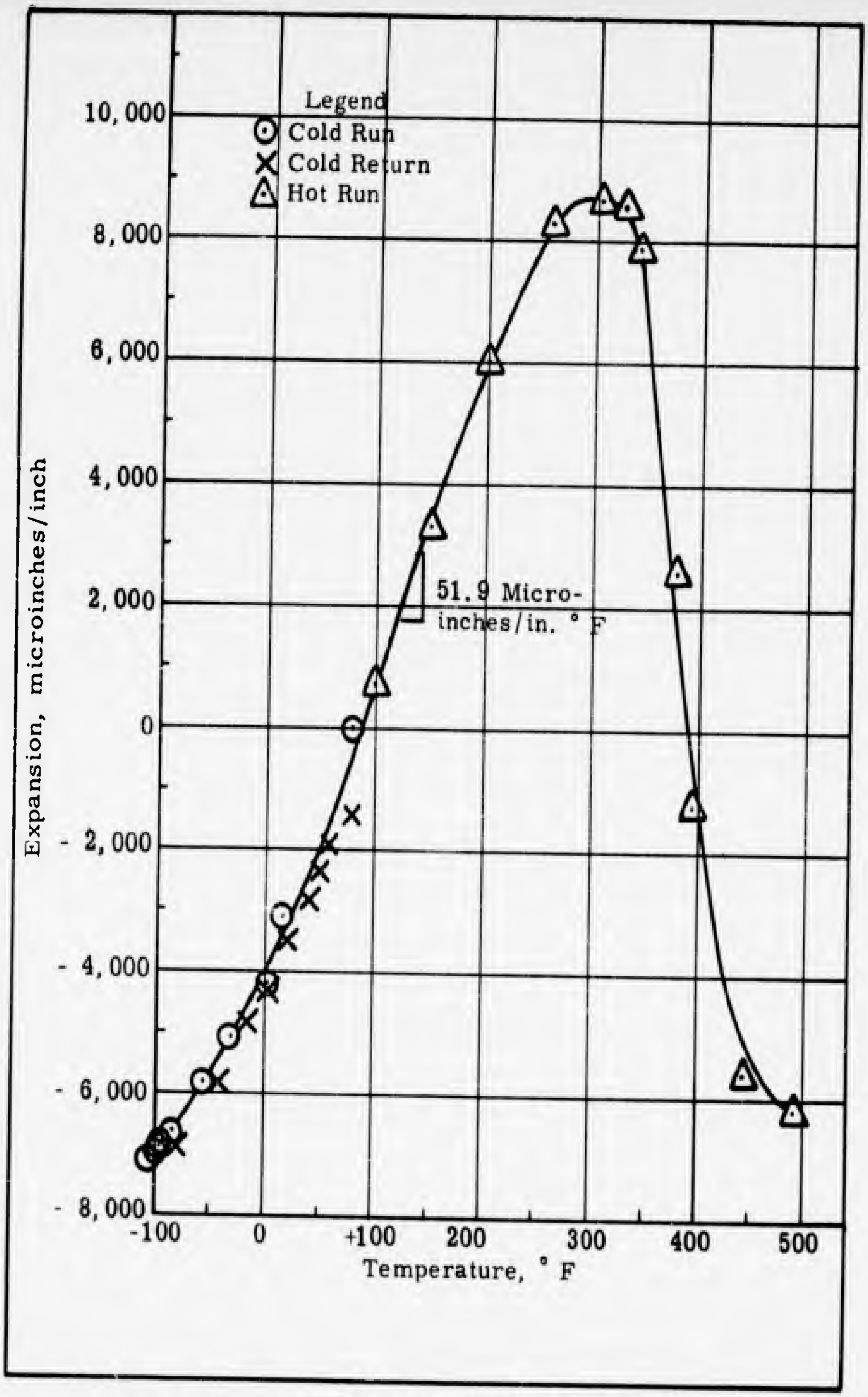

Figure 34. Thermal Expansion Parallel to Panel, Material SRI No. 3, Silicone Foam.

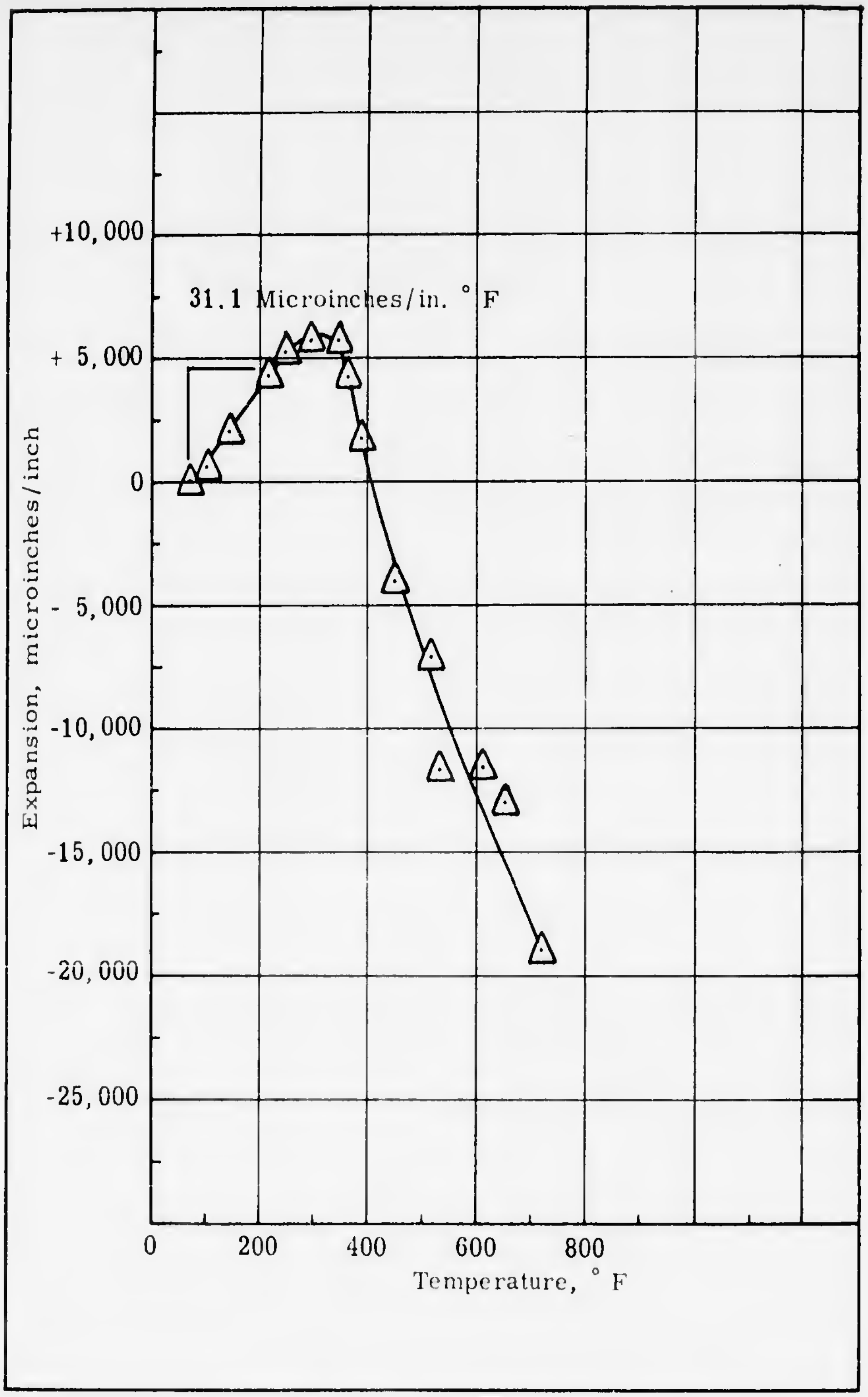

Figure 35. Thermal Expansion Normal to Panel, Material SRI No. 3, Silicone Foam.

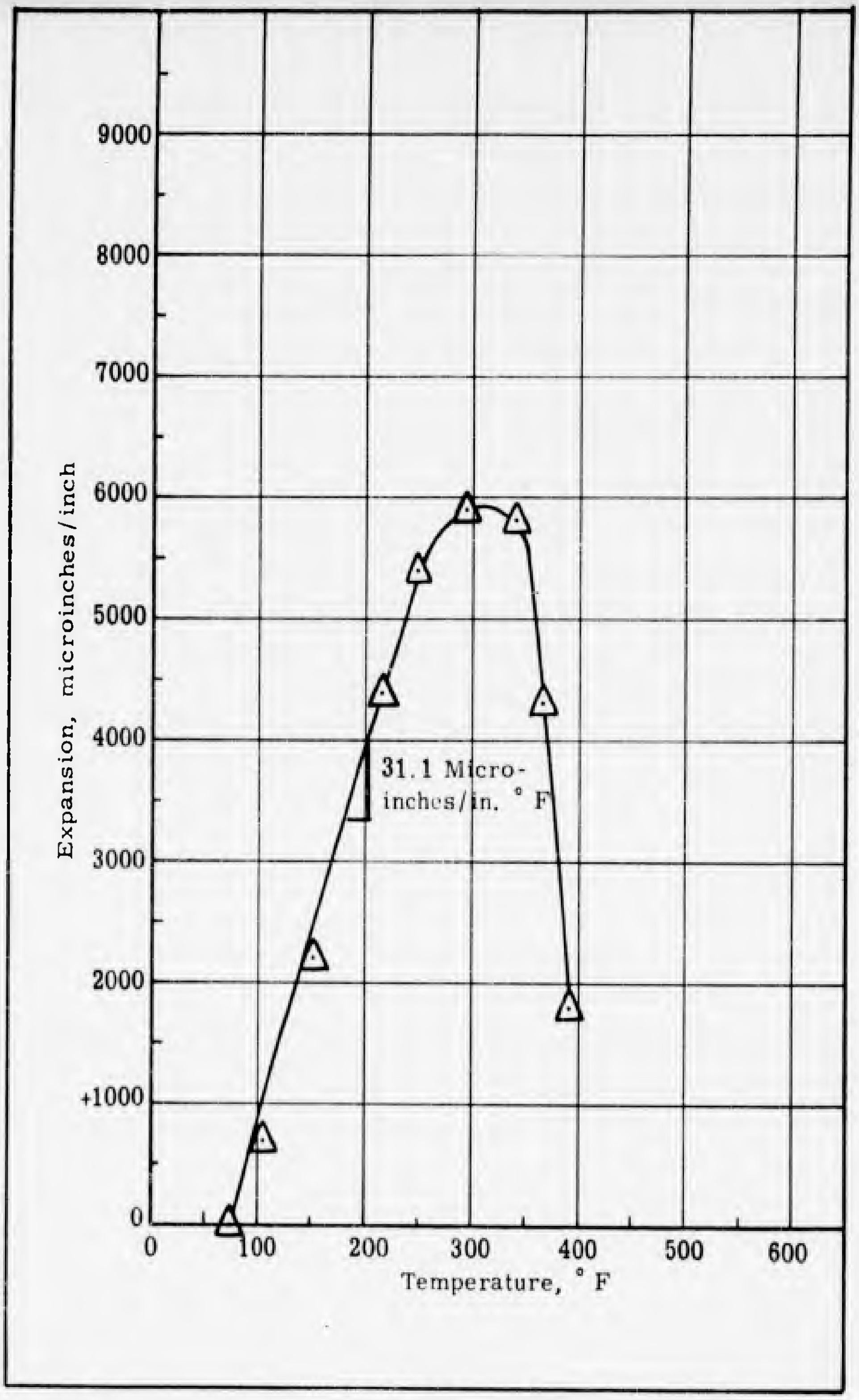

Figure 36. Enlarged View of Thermal Expansion Normal to Panel, Material SRI No. 3, Silicone Foam.

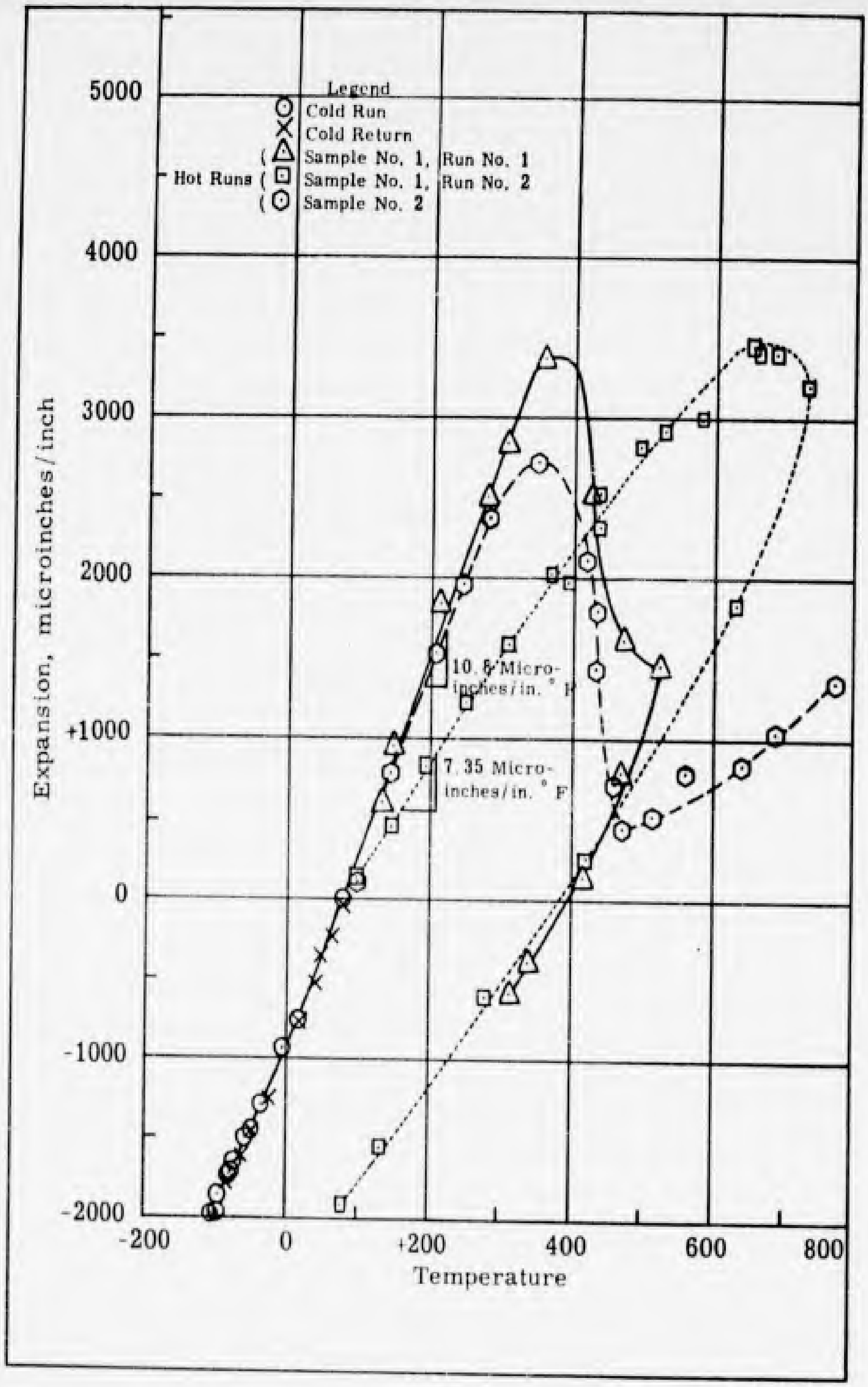

Figure 37. Thermal Expansion Parallel to Panel, Material SRI No. 4, Glass Roving, Phenolic Resin.

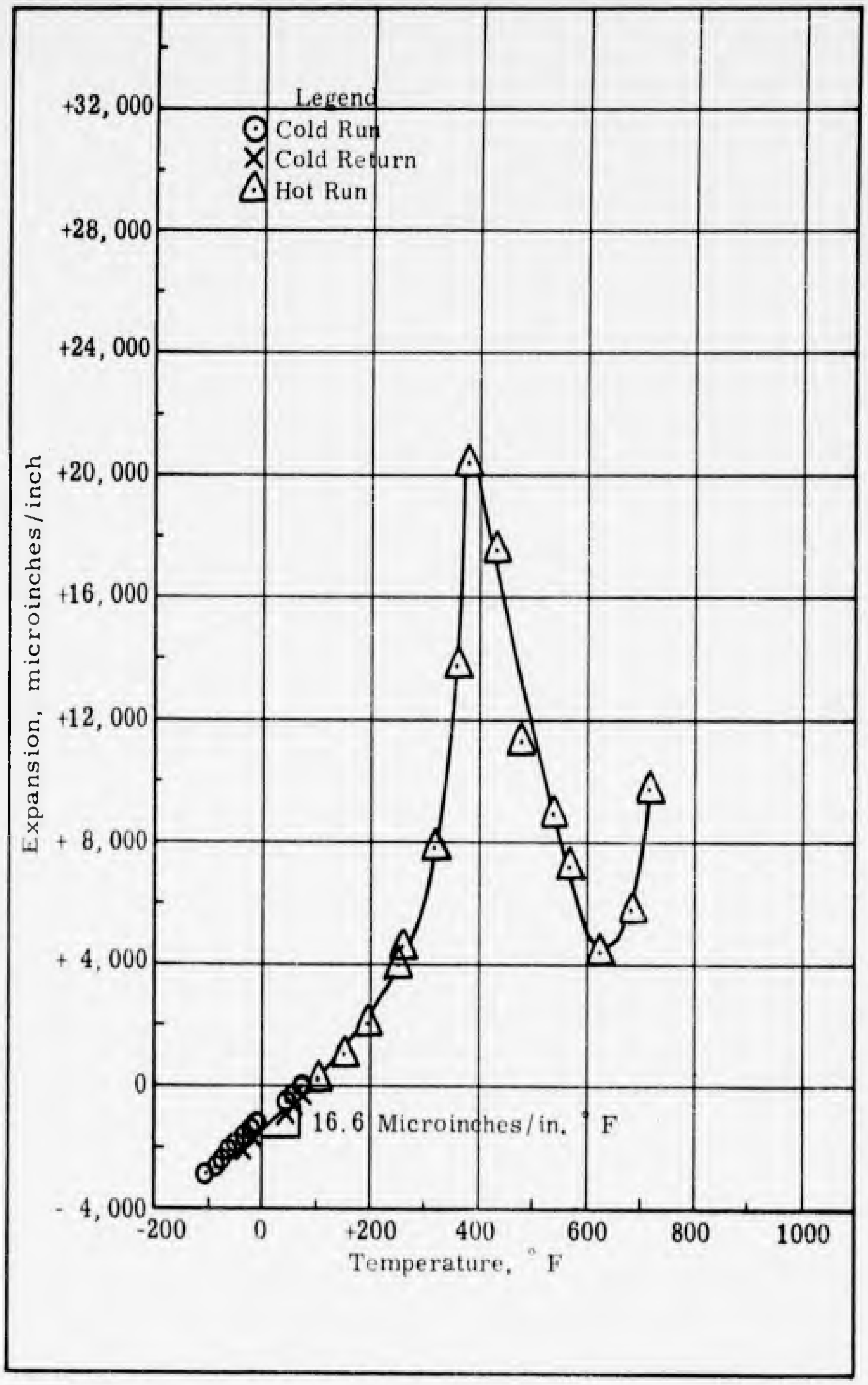

Figure 38. Thermal Expansion Normal to Panel, Material SRI No. 4, Glass Roving, Phenolic Resin.

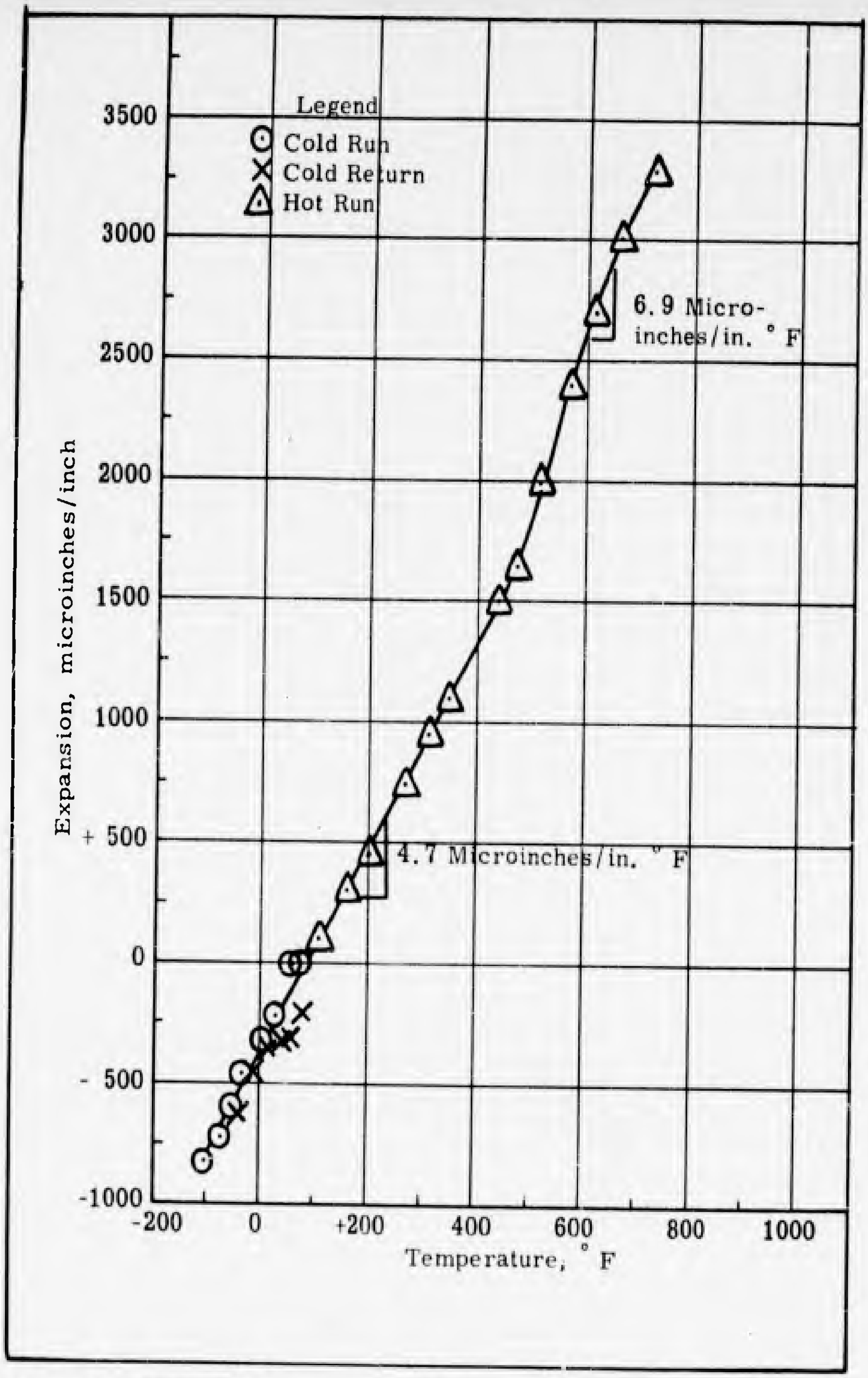

Figure 39. Thermal Expansion Parallel to Panel, Material SRI No. 5, Chopped Glass, Silicone Resin.

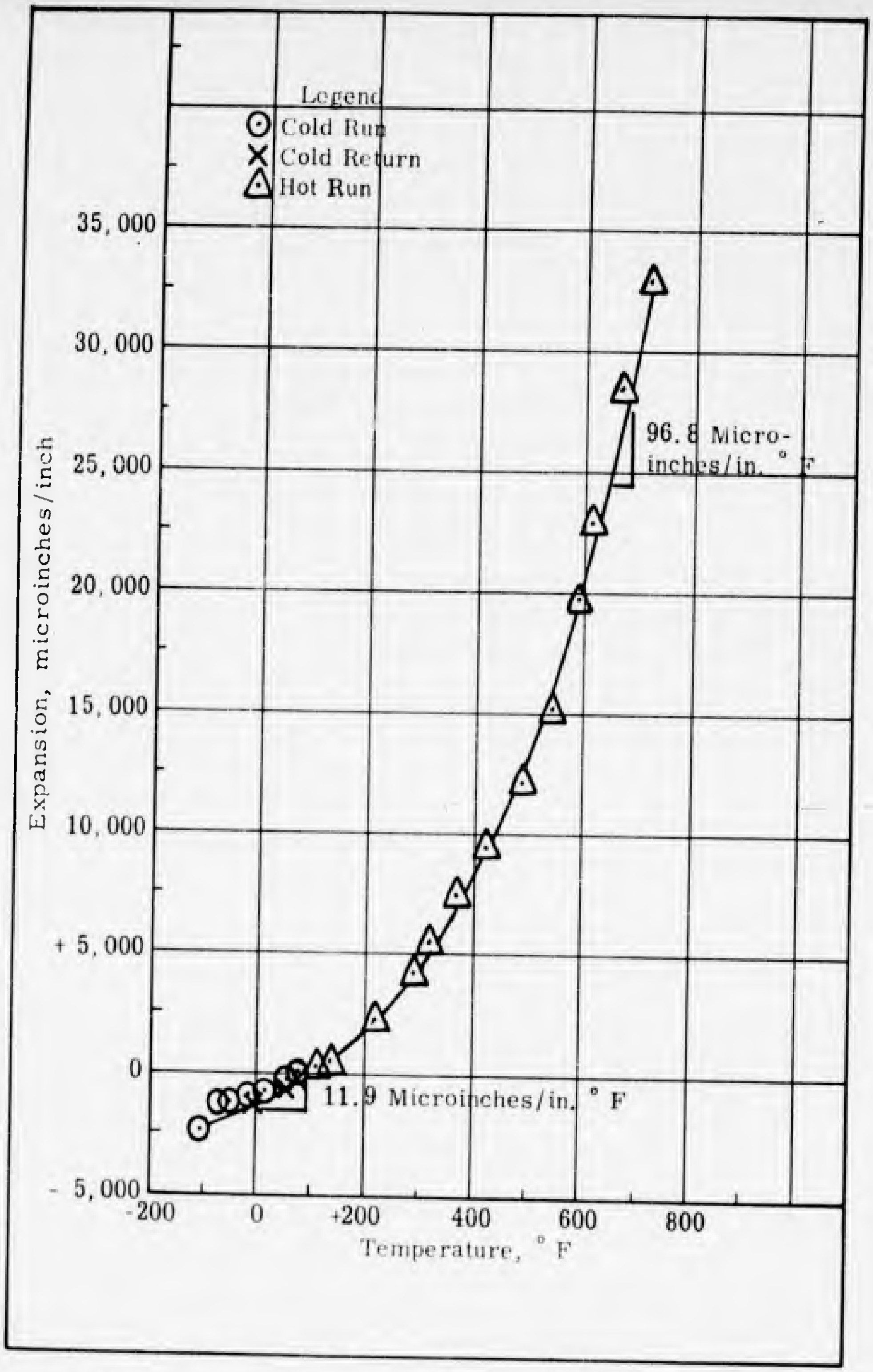

Figure 40. Thermal Expansion Normal to Panel, Material SRI No. 5, Chopped Glass, Silicone Resin.

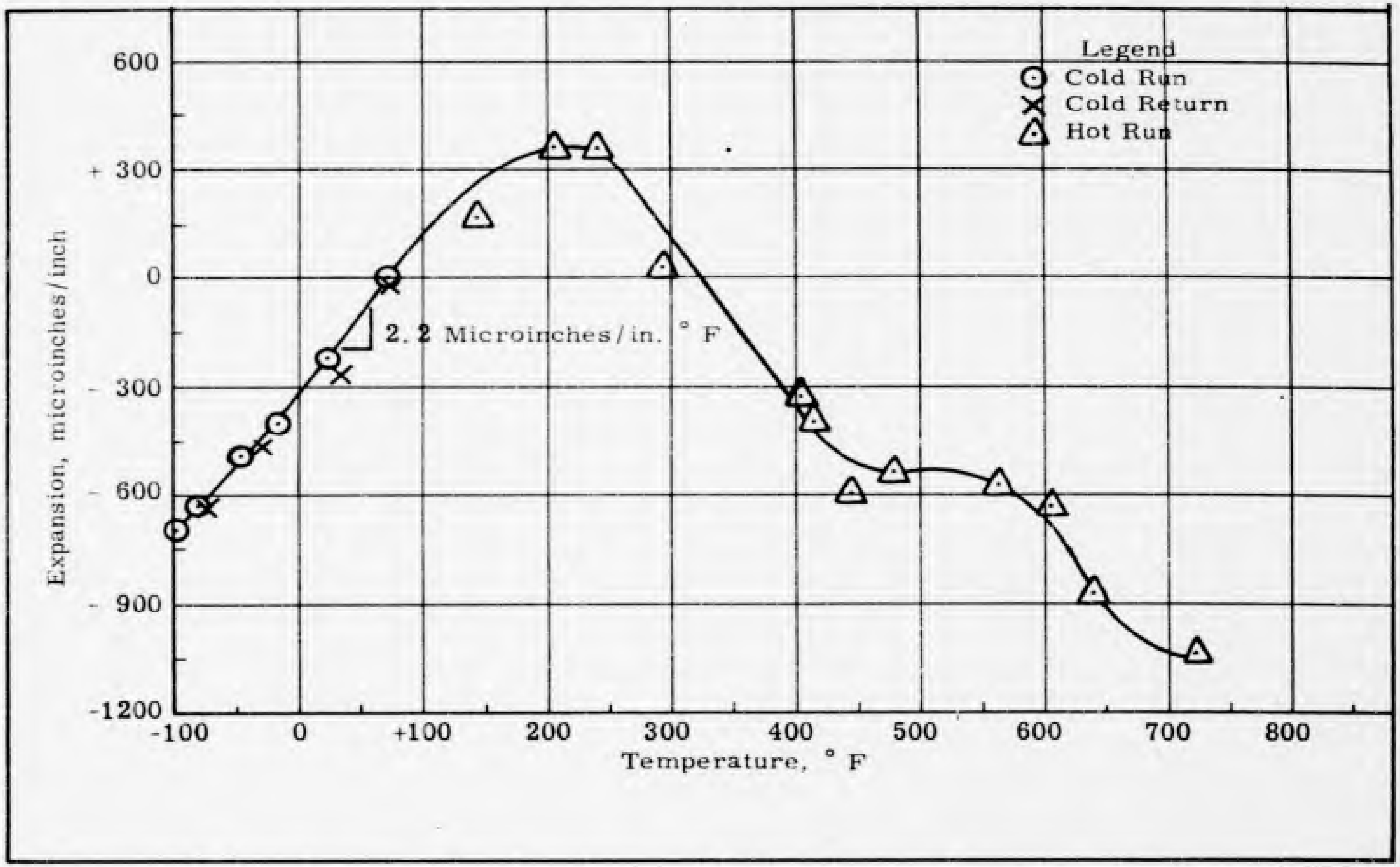

Figure 41. Thermal Expansion Parallel to Panel, Material SRI No. 6, $\frac{1}{2}$-inch Squares Glass, Phenolic Resin.

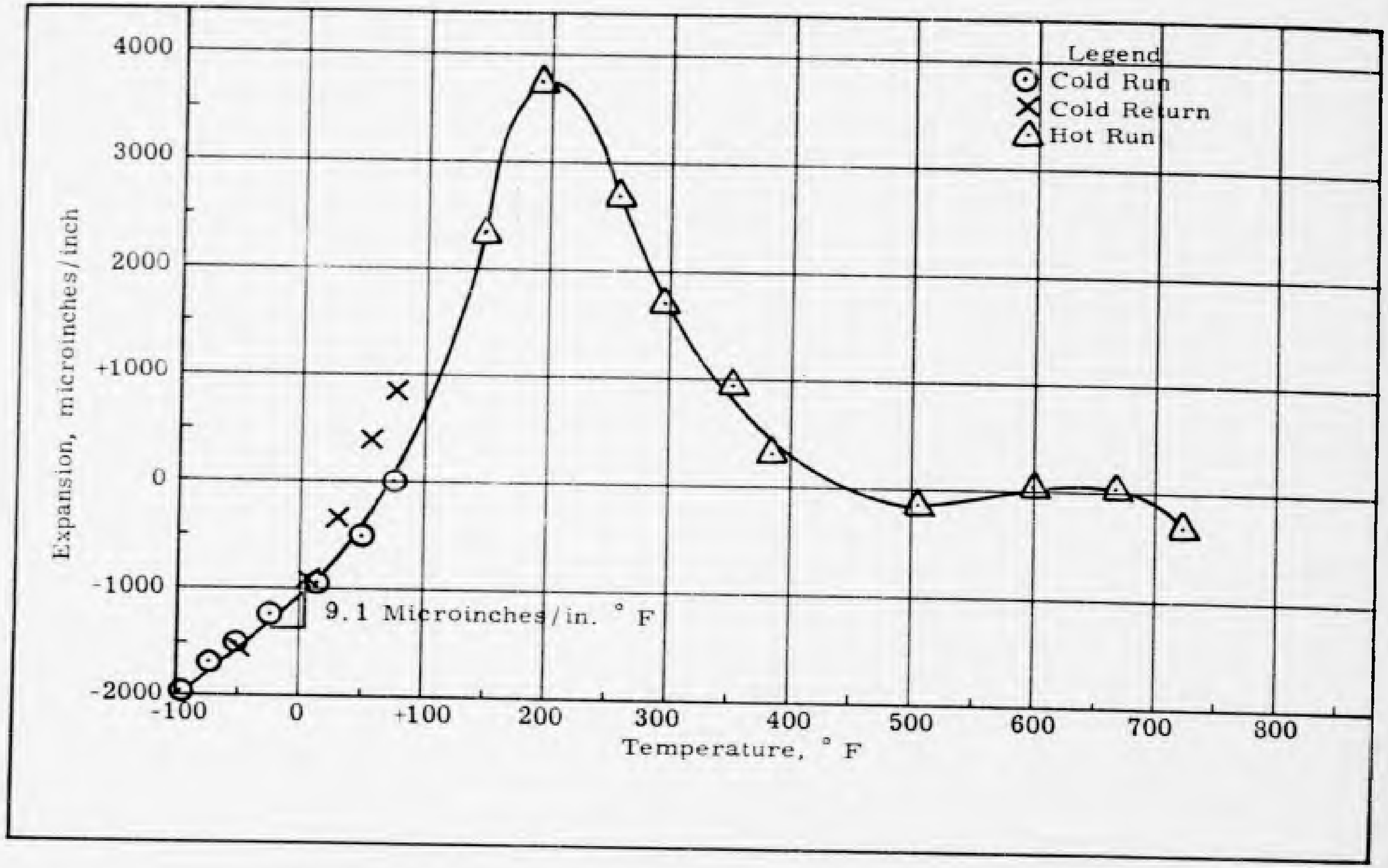

Figure 42. Thermal Expansion Normal to Panel, Material SRI No. 6, ½-inch Squares Glass, Phenolic Resin.

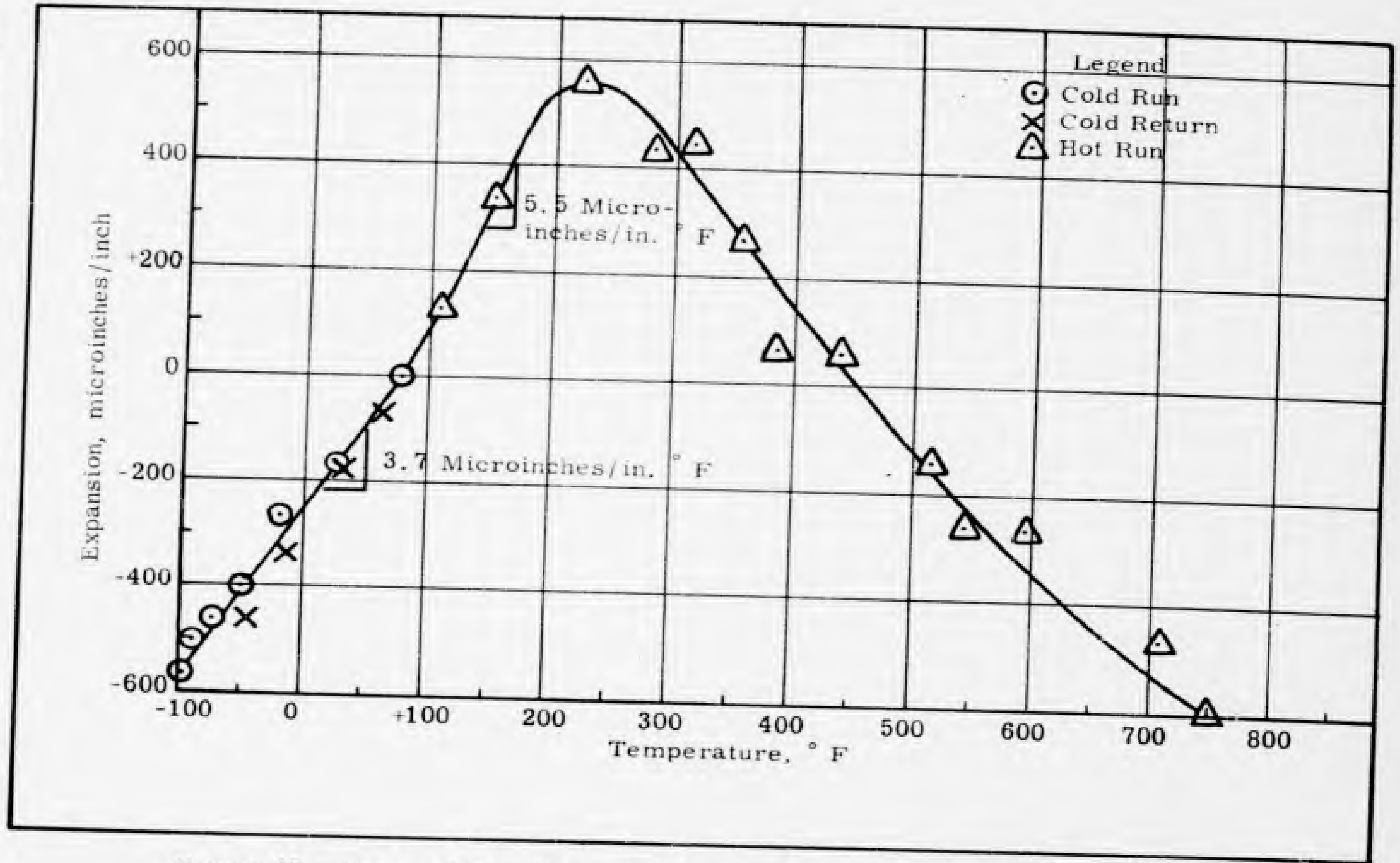

Figure 43. Thermal Expansion Parallel to Panel, Material SRI No. 7-1, Refrasil Fabric, Phenolic Resin.

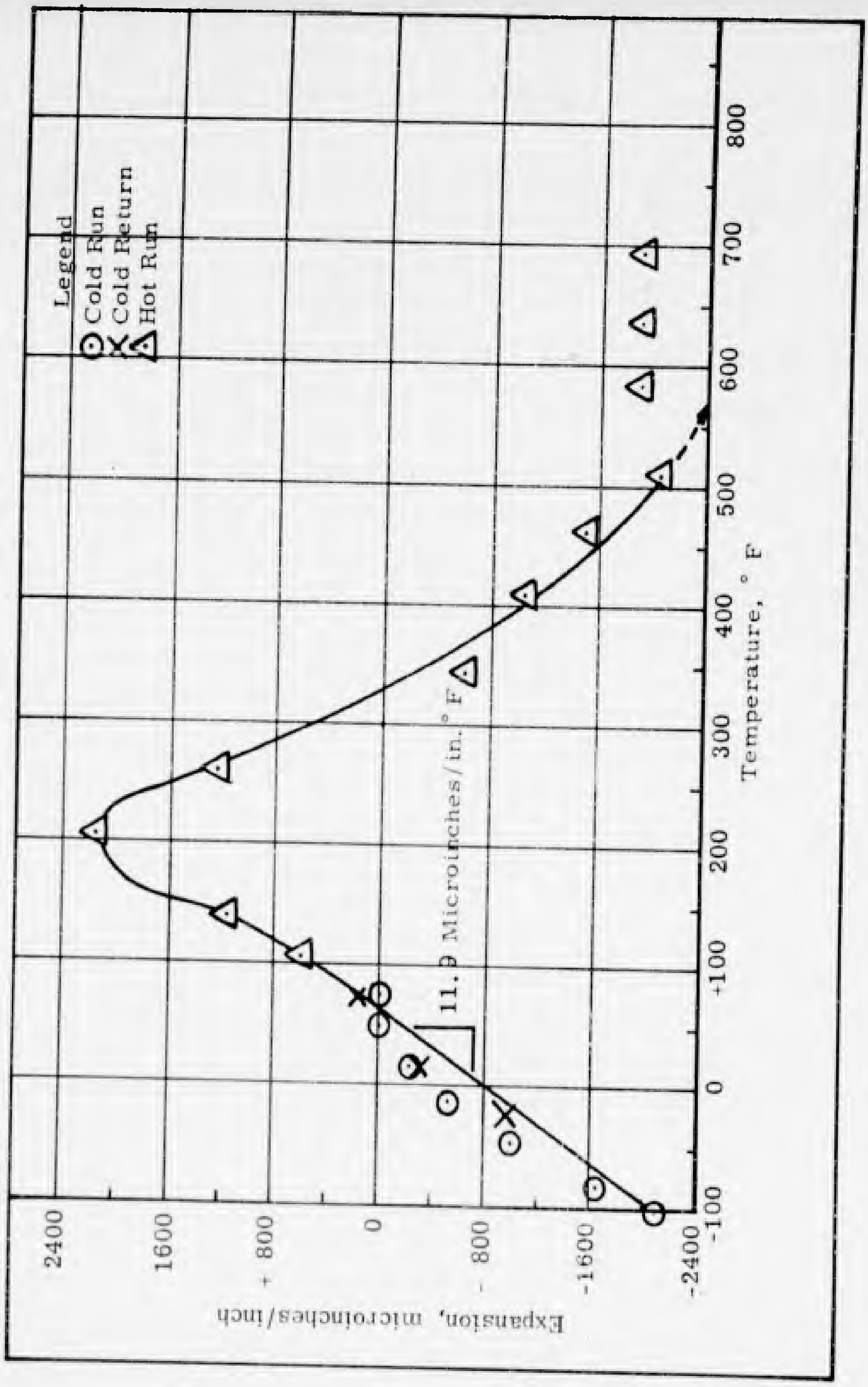

Figure 44. Thermal Expansion Normal to Panel, Material SRI No. 7-1, Refrasil Fabric, Phenolic Resin.

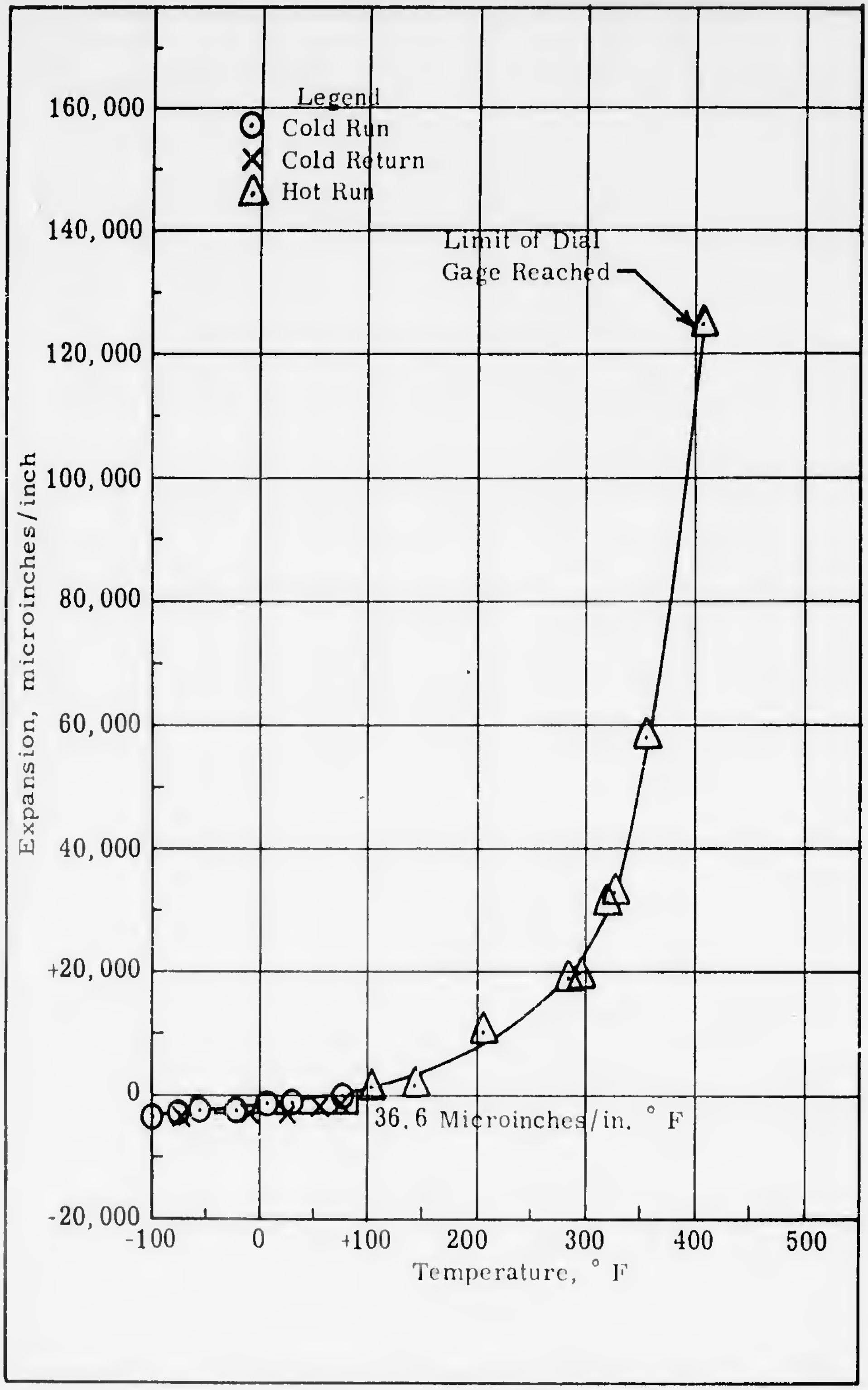

Figure 45. Thermal Expansion Normal to Panel, Material SRI No. 9, Chopped Nylon, Phenolic Resin.

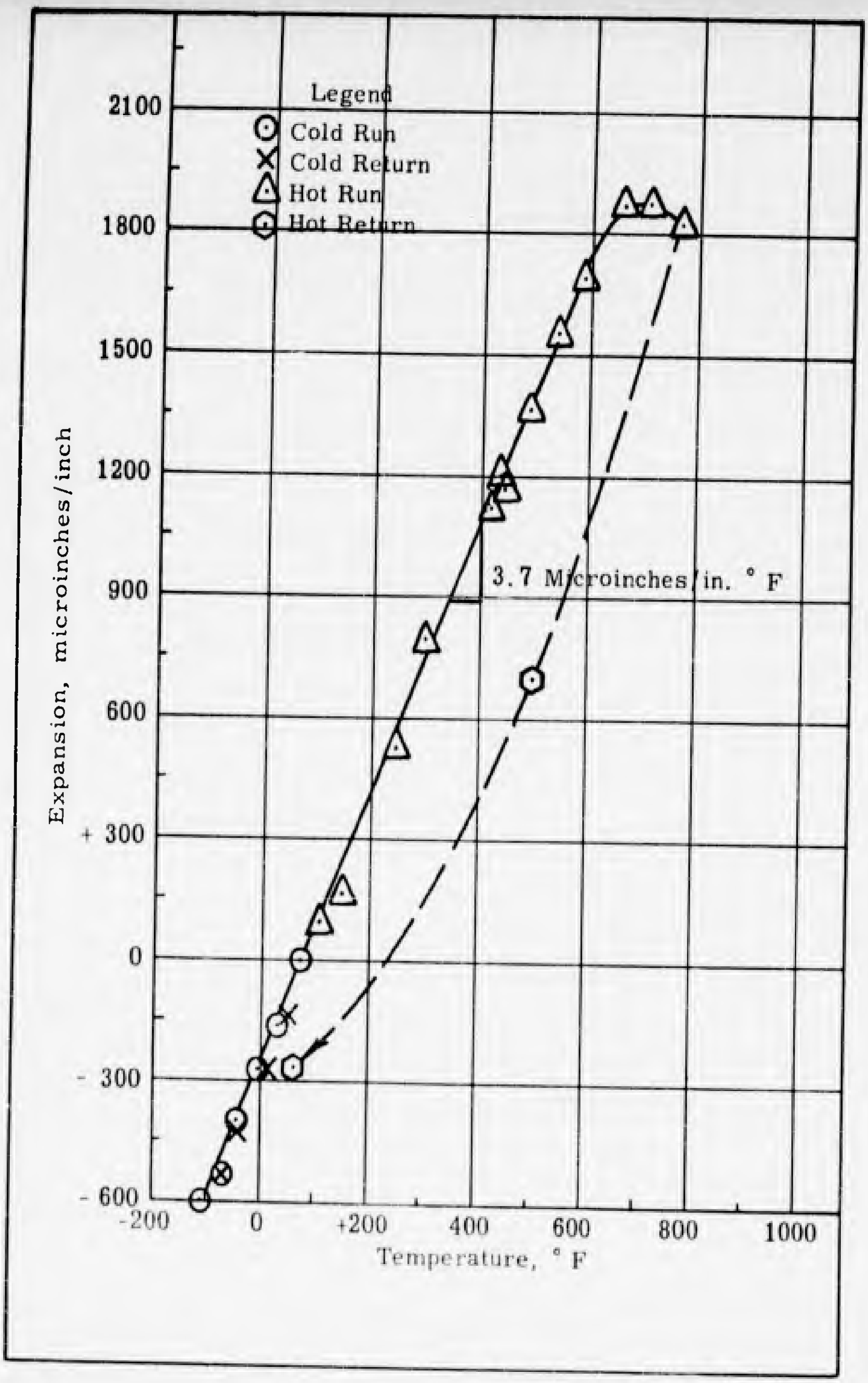

Figure 46. Thermal Expansion Parallel to Panel, Material SRI No. 10, Asbestos, Silicone Resin.

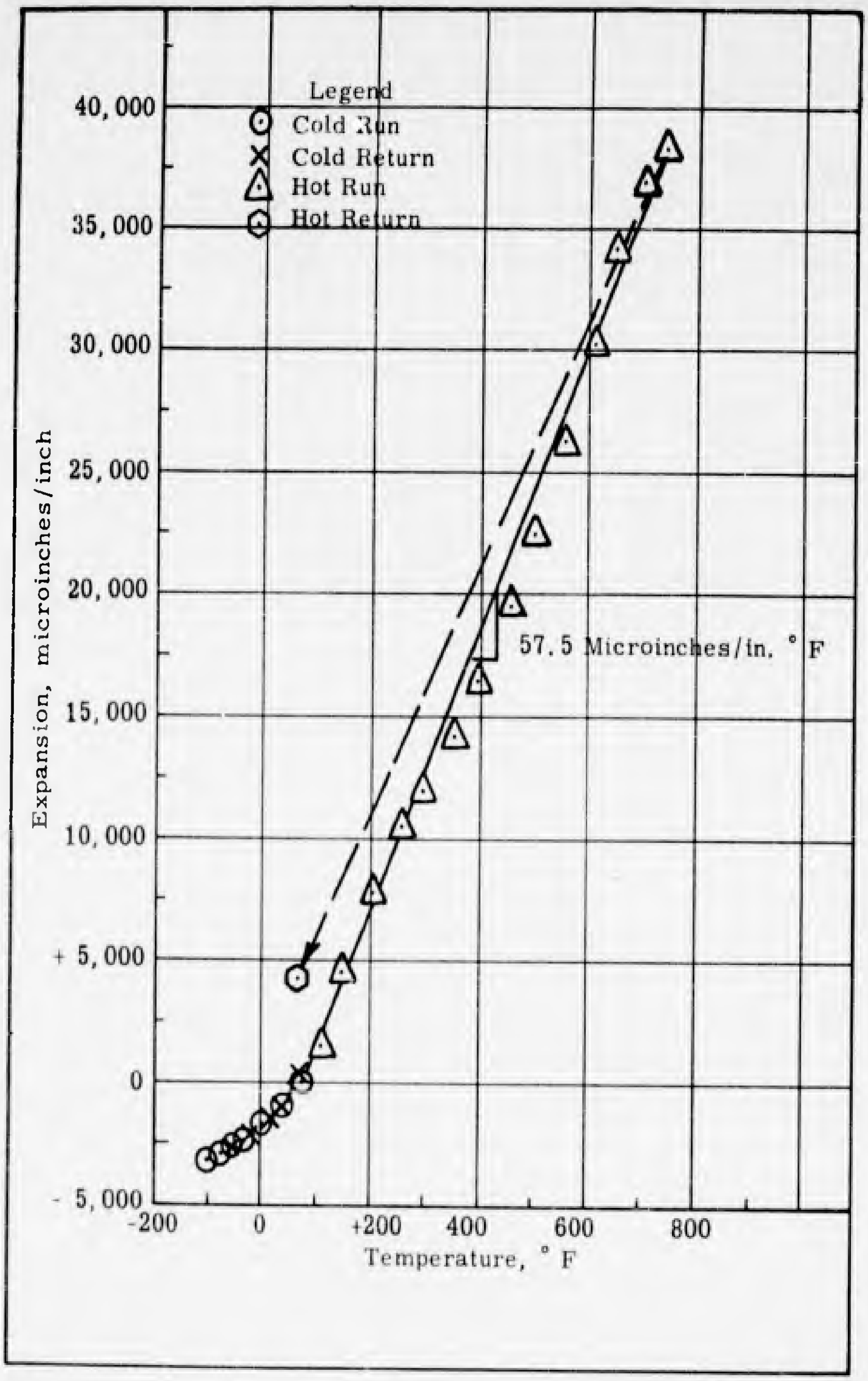

Figure 47. Thermal Expansion Normal to Panel, Material SRI No. 10, Asbestos, Silicone Resin.

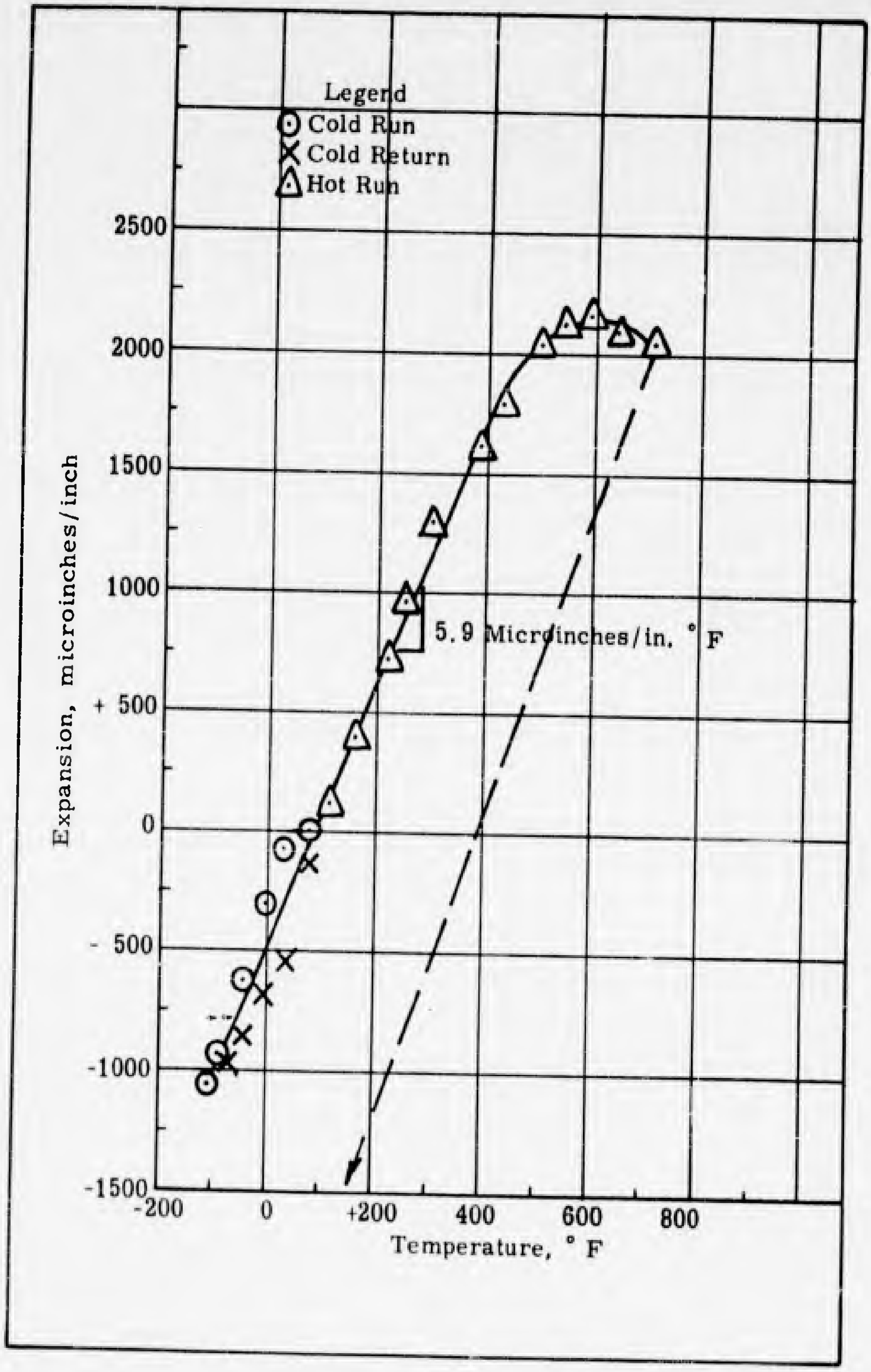

Figure 48. Thermal Expansion Parallel to Panel, Material SRI No. 11, Glass Fabric, Phenolic Resin.

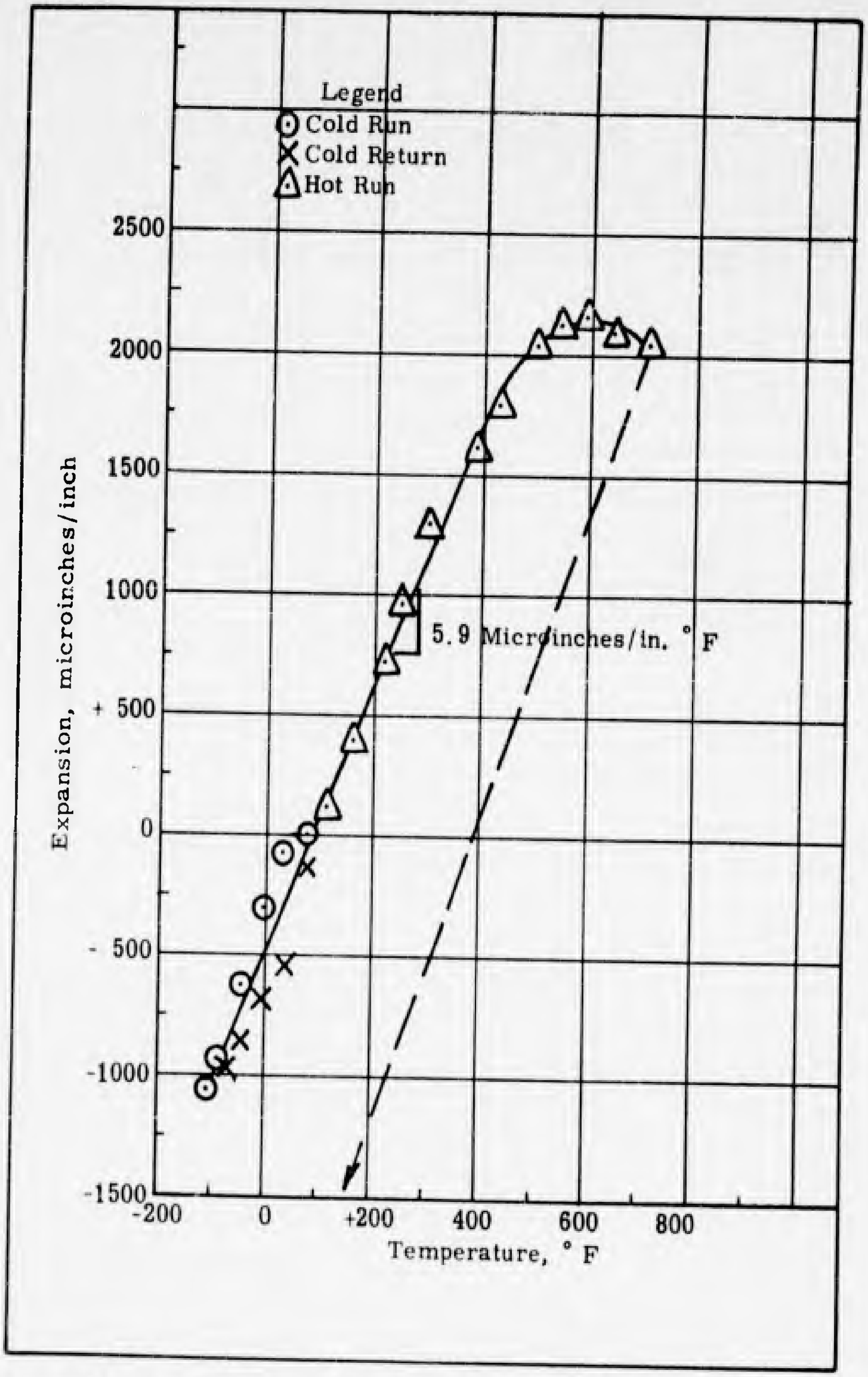

Figure 48. Thermal Expansion Parallel to Panel, Material SRI No. 11, Glass Fabric, Phenolic Resin.

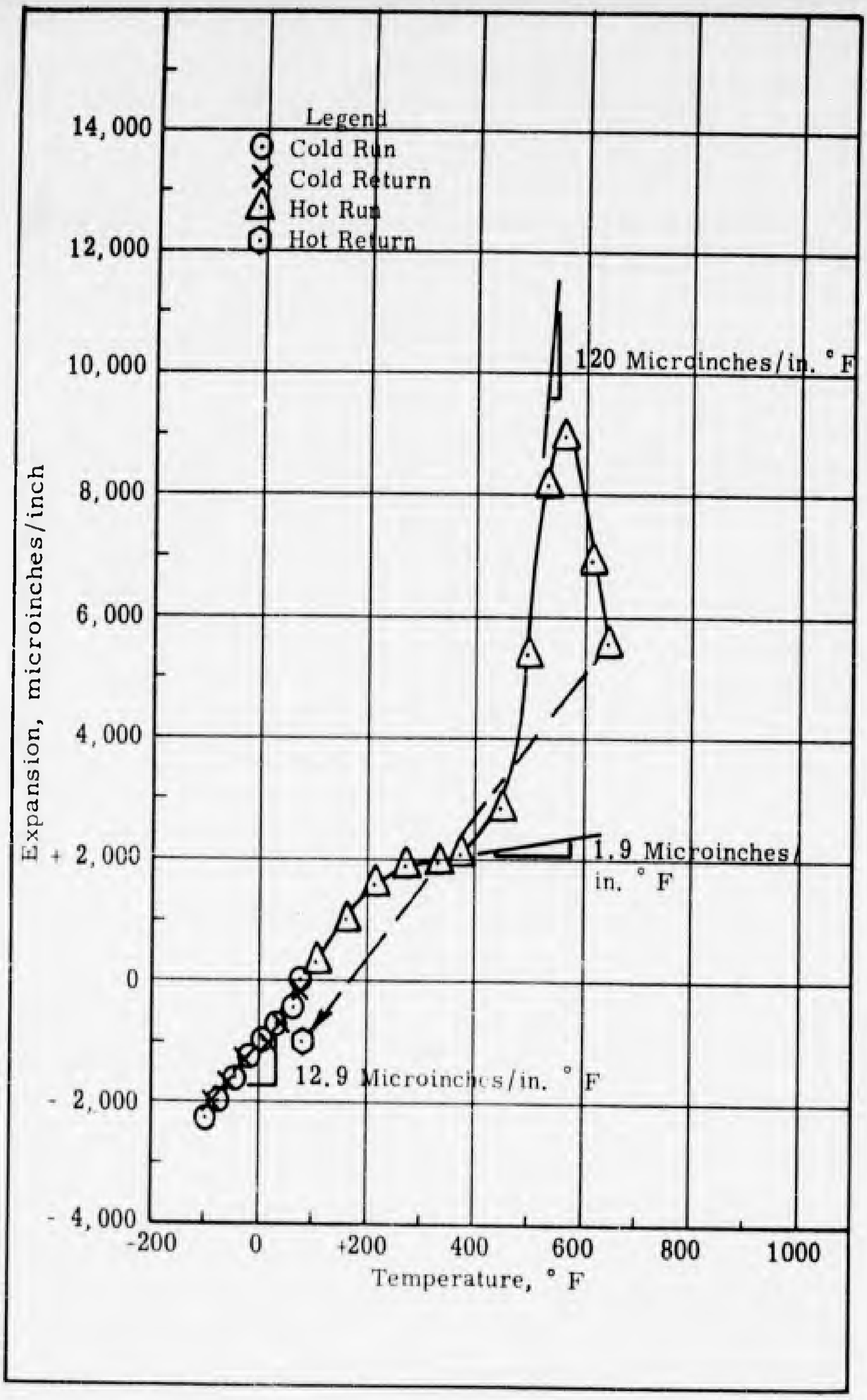

Figure 49. Thermal Expansion Normal to Panel, Material SRI No. 11, Glass Fabric, Phenolic Resin.

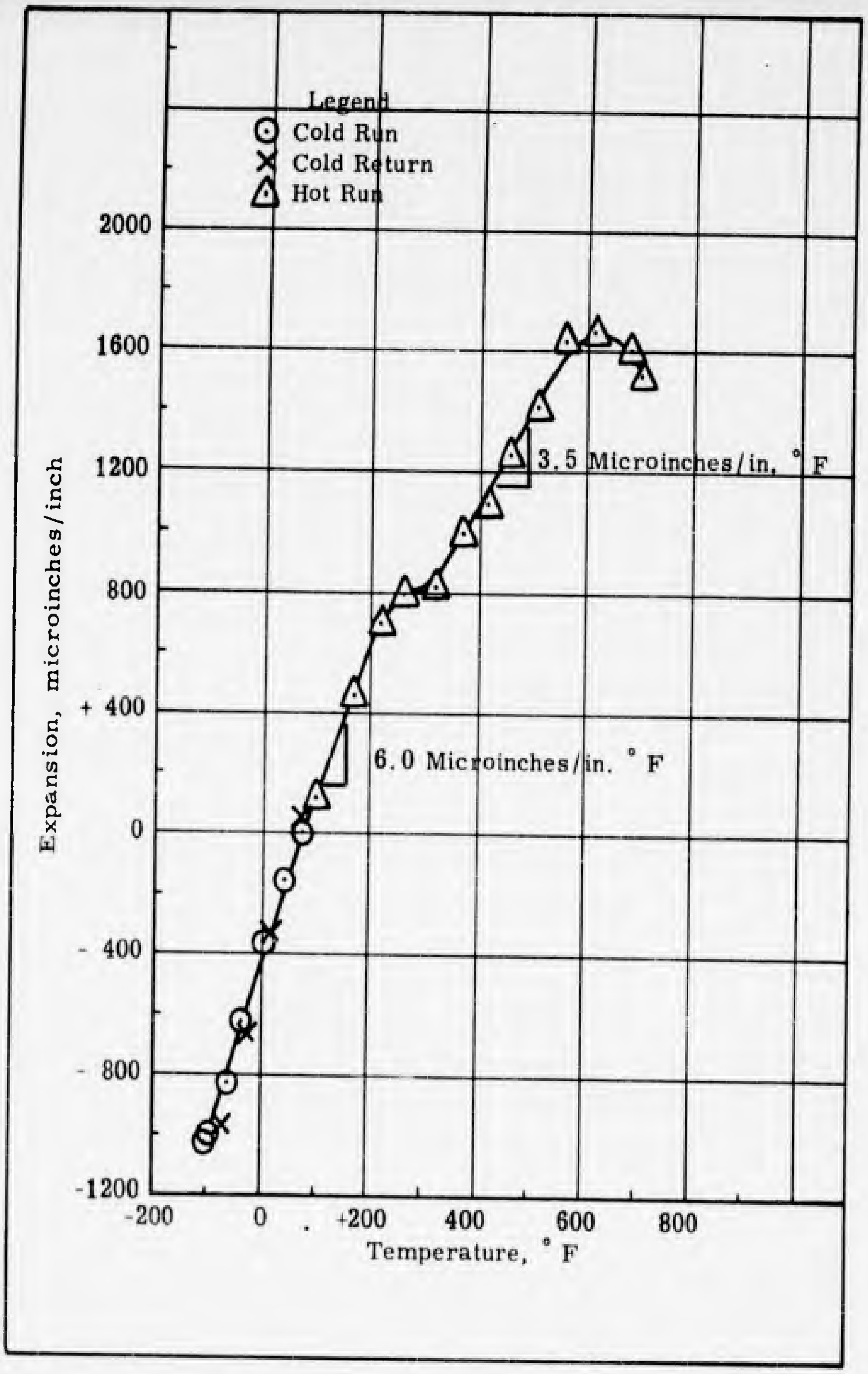

Figure 50. Thermal Expansion Parallel to Panel, Material SRI No. 12, Glass Fabric, Epoxy Resin.

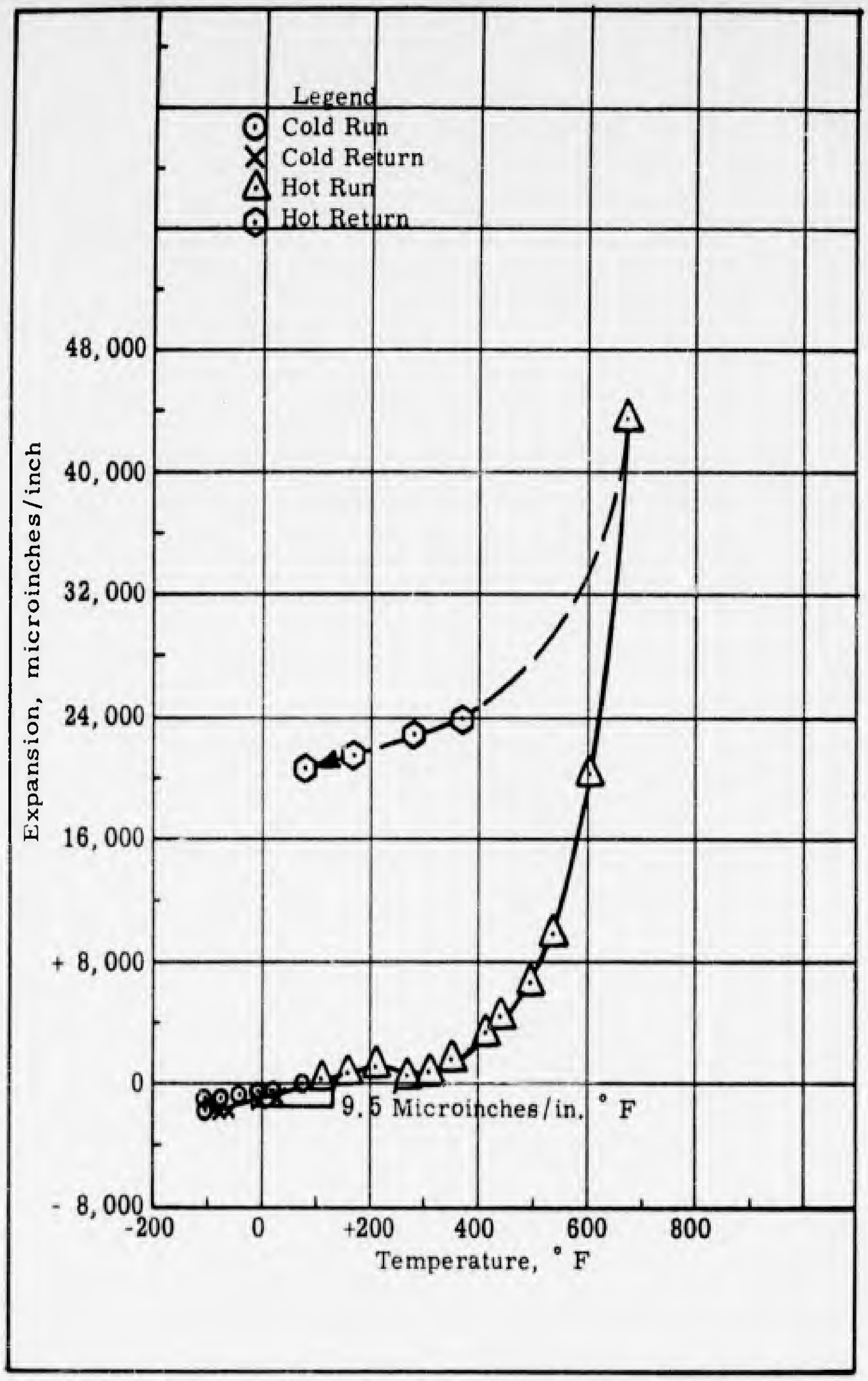

Figure 51. Thermal Expansion Normal to Panel, Material SRI No. 12, Glass Fabric, Epoxy Resin.

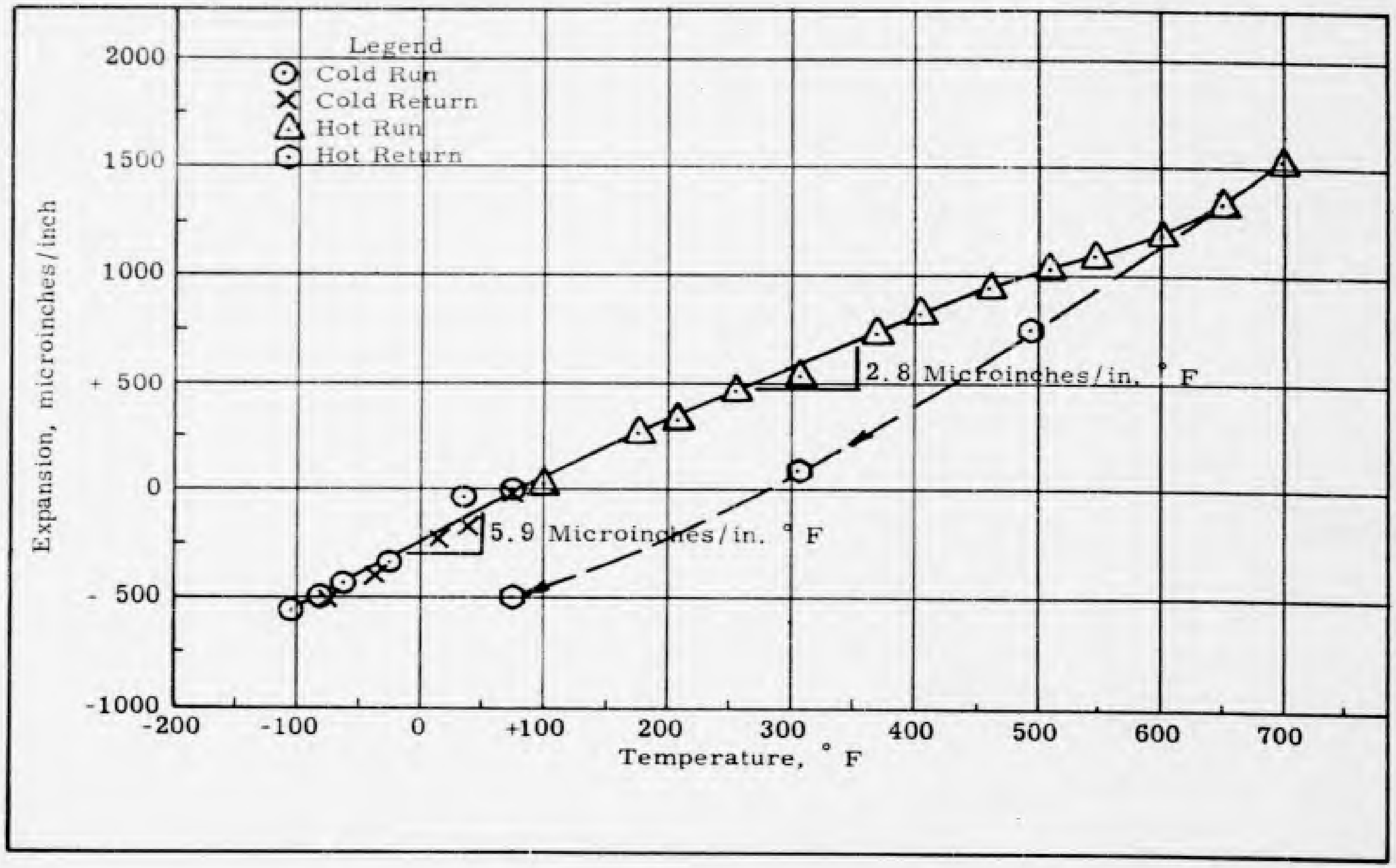

Figure 52. Thermal Expansion Parallel to Panel, Material SRI No. 13, Asbestos, Phenolic Resin.

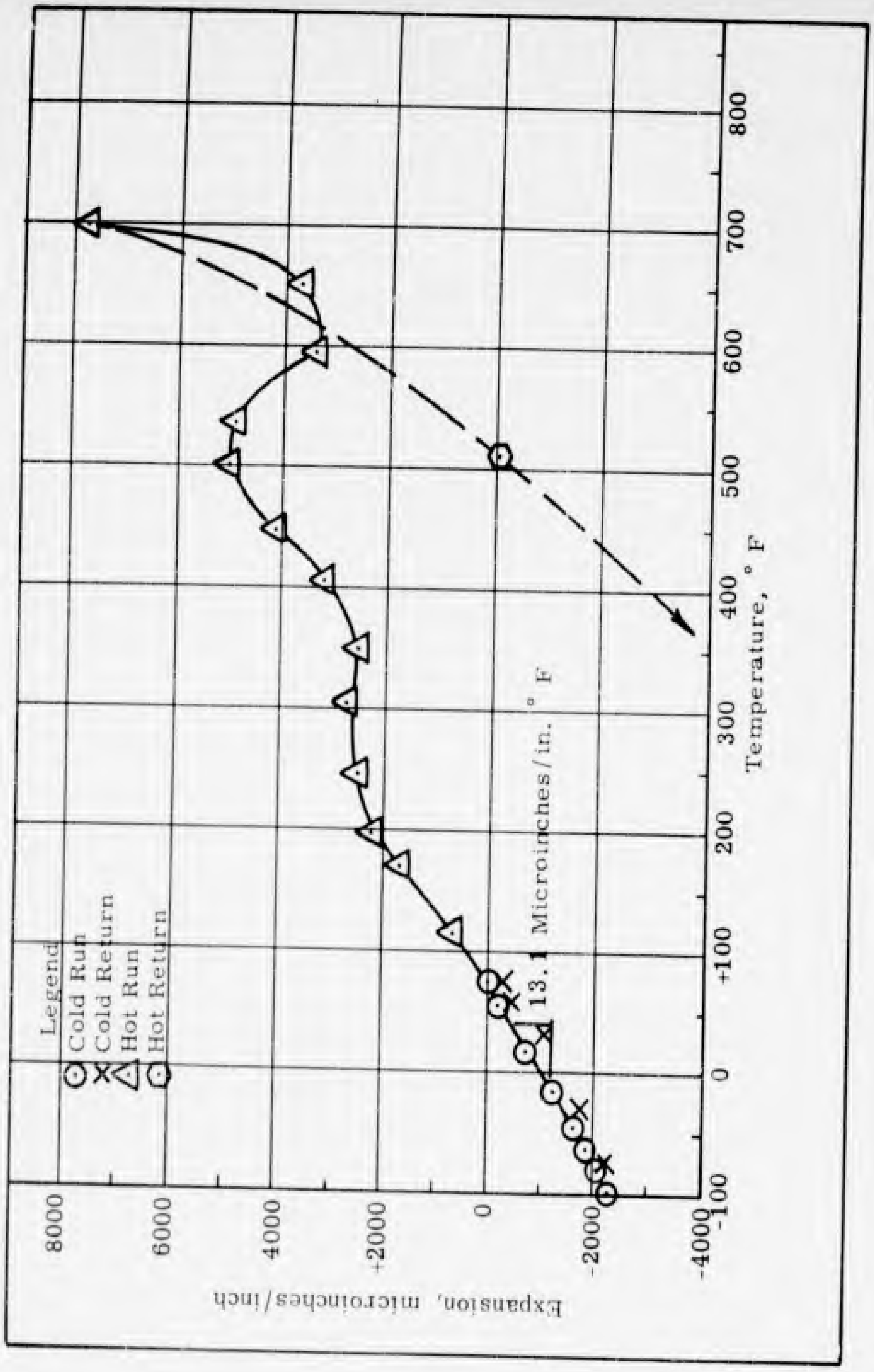

Figure 53. Thermal Expansion Normal to Panel, Material SRI No. 13, Asbestos, Phenolic Resin.

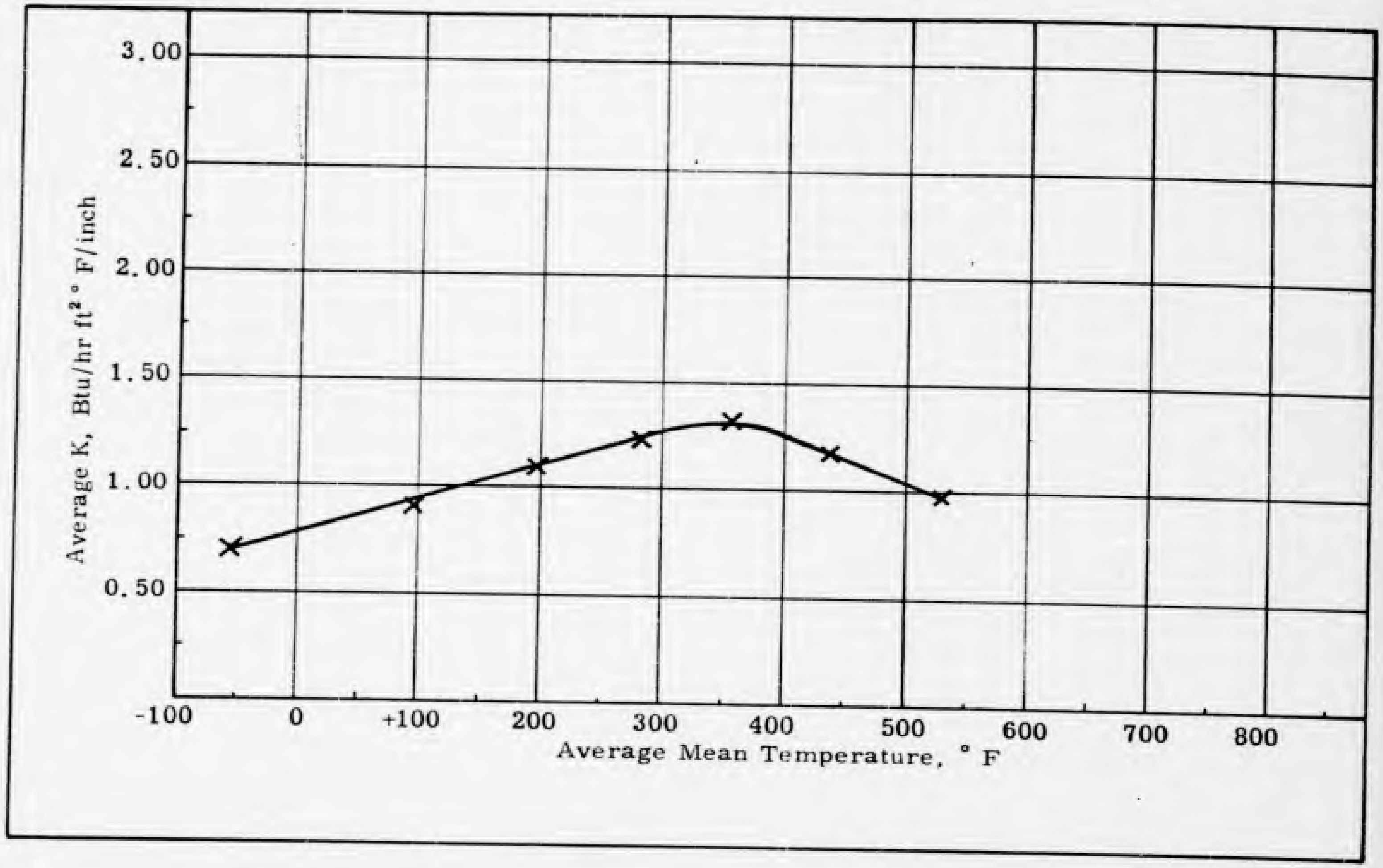

Figure 54. Thermal Conductivity Curve for Material SRI No. 1-1, 60N Roving, Epoxy Resin, Unidirectional.

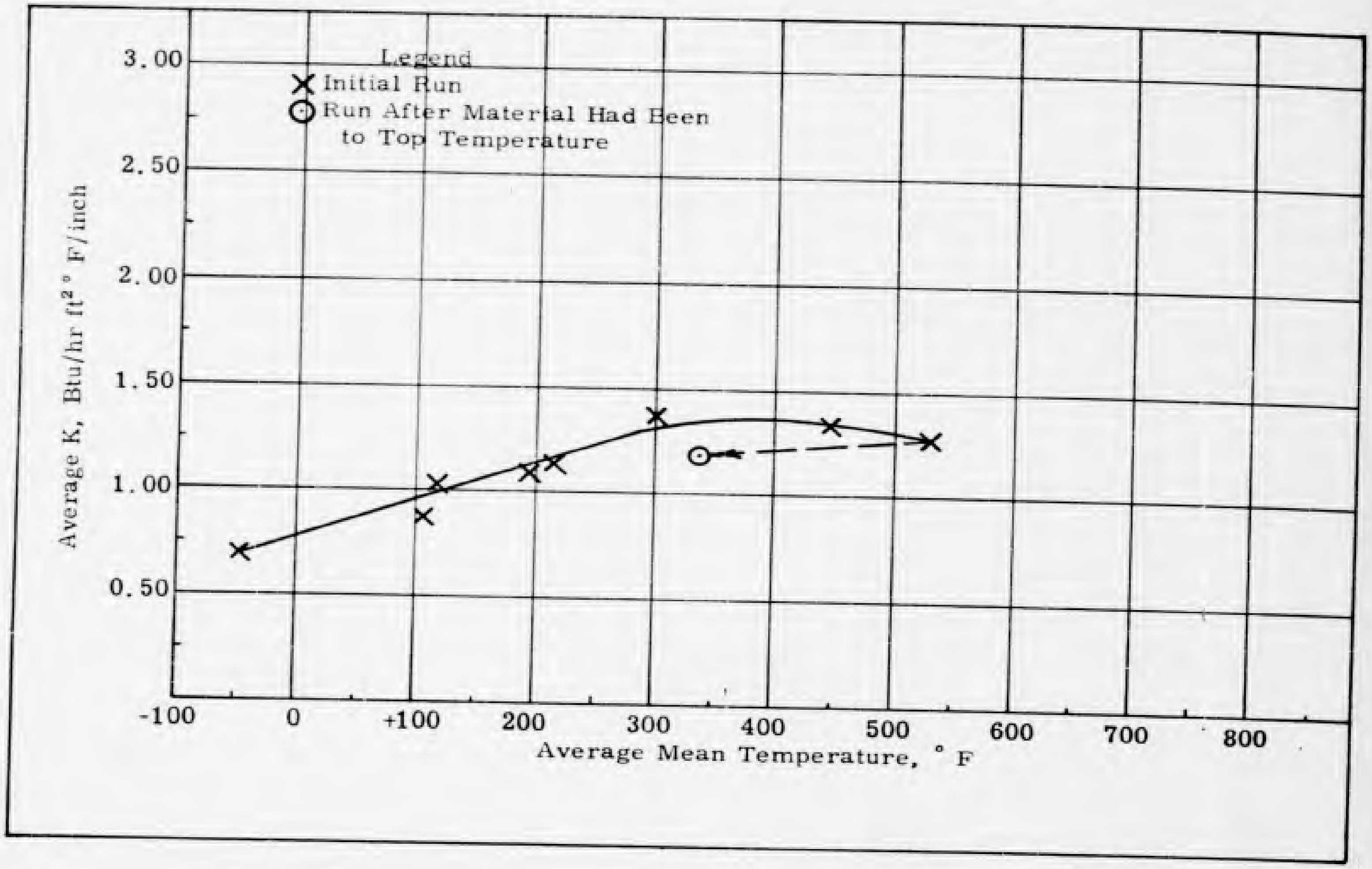

Figure 55. Thermal Conductivity Curve for Material SRI No. 1-2, 60N Roving, Epoxy Resin, Isotropic.

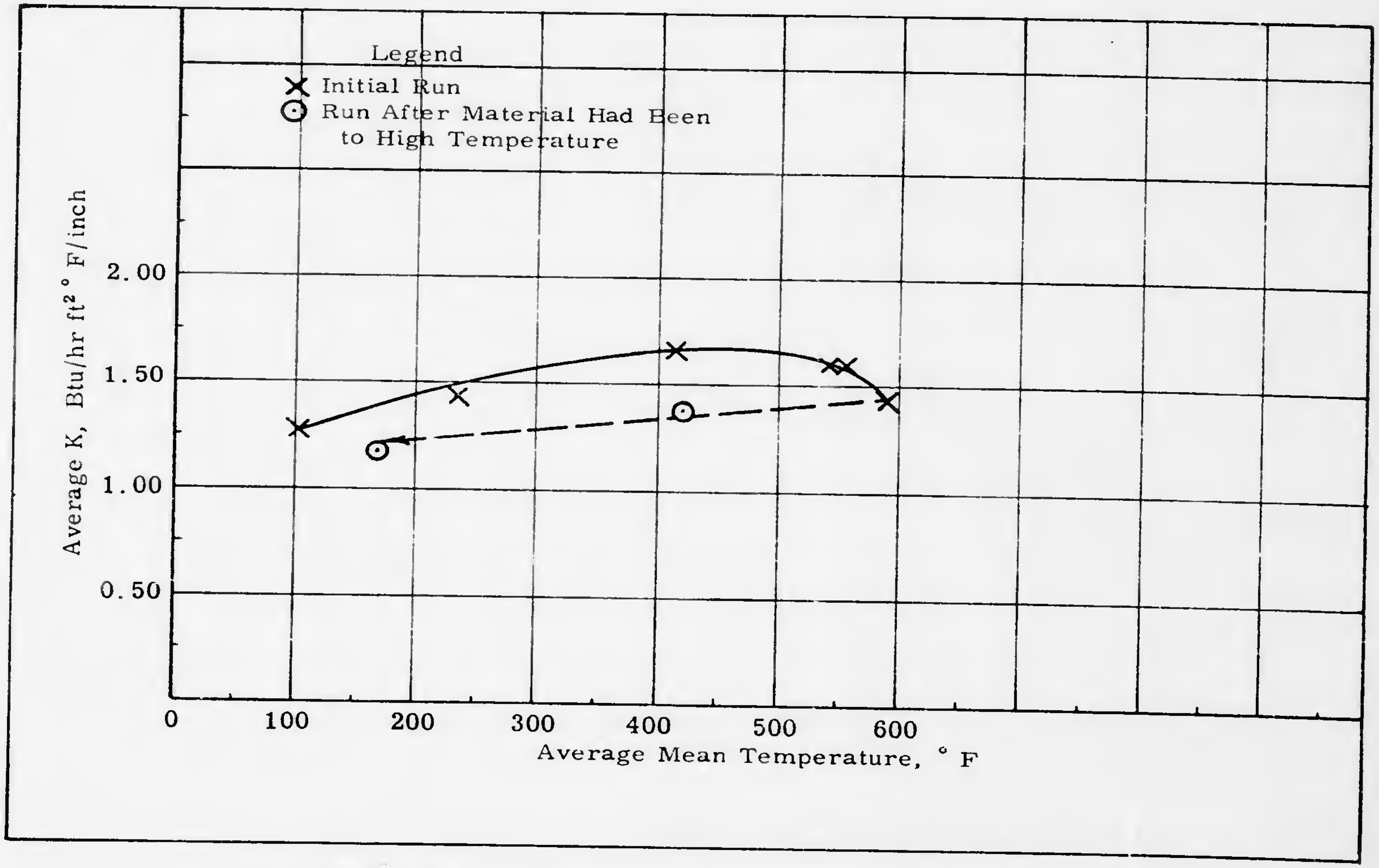

Figure 56. Thermal Conductivity Curve for Material SRI No. 2, Chopped Glass, Phenolic Resin.

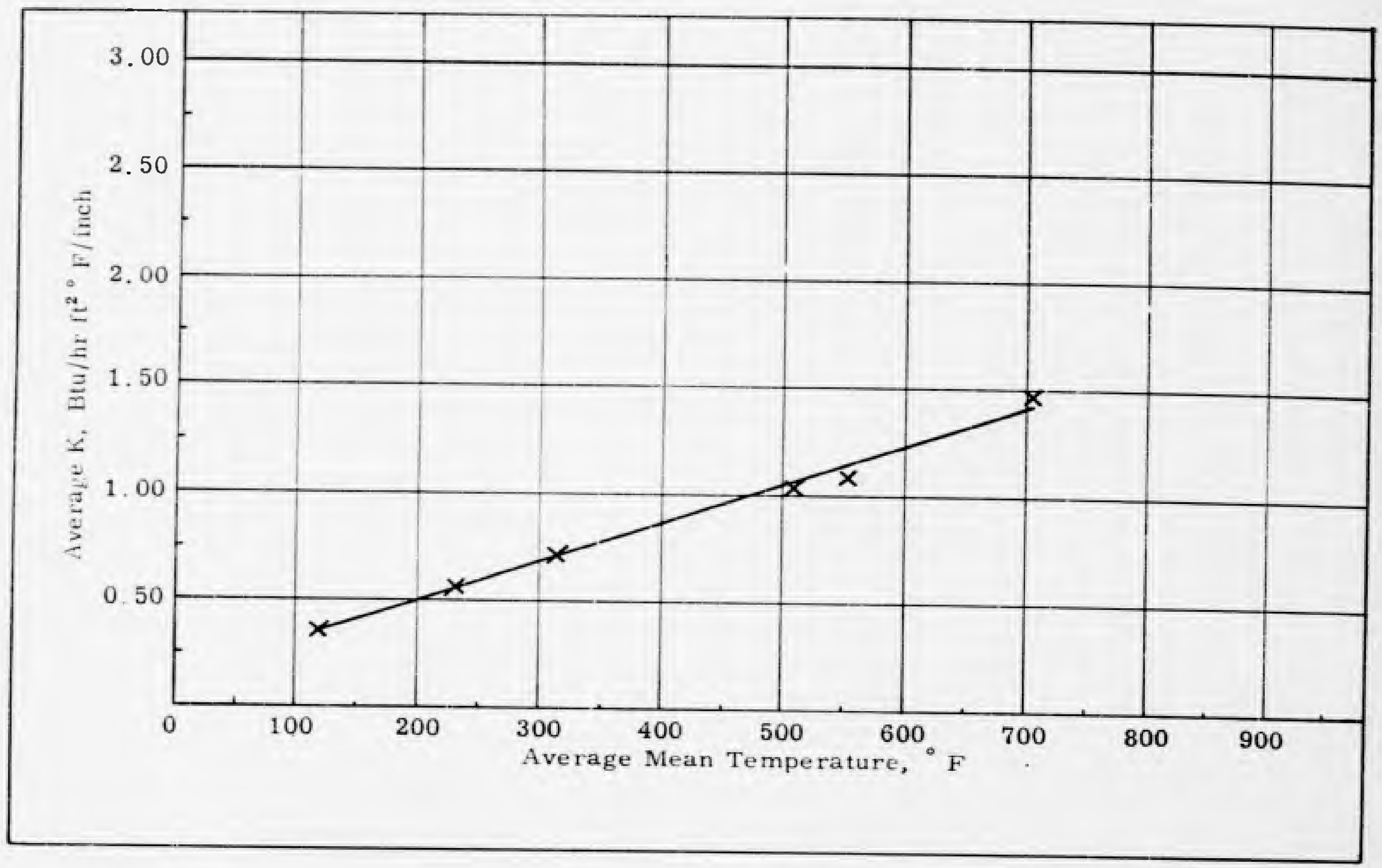

Figure 57. Thermal Conductivity Curve for Material SRI No. 3, Silicone Foam.

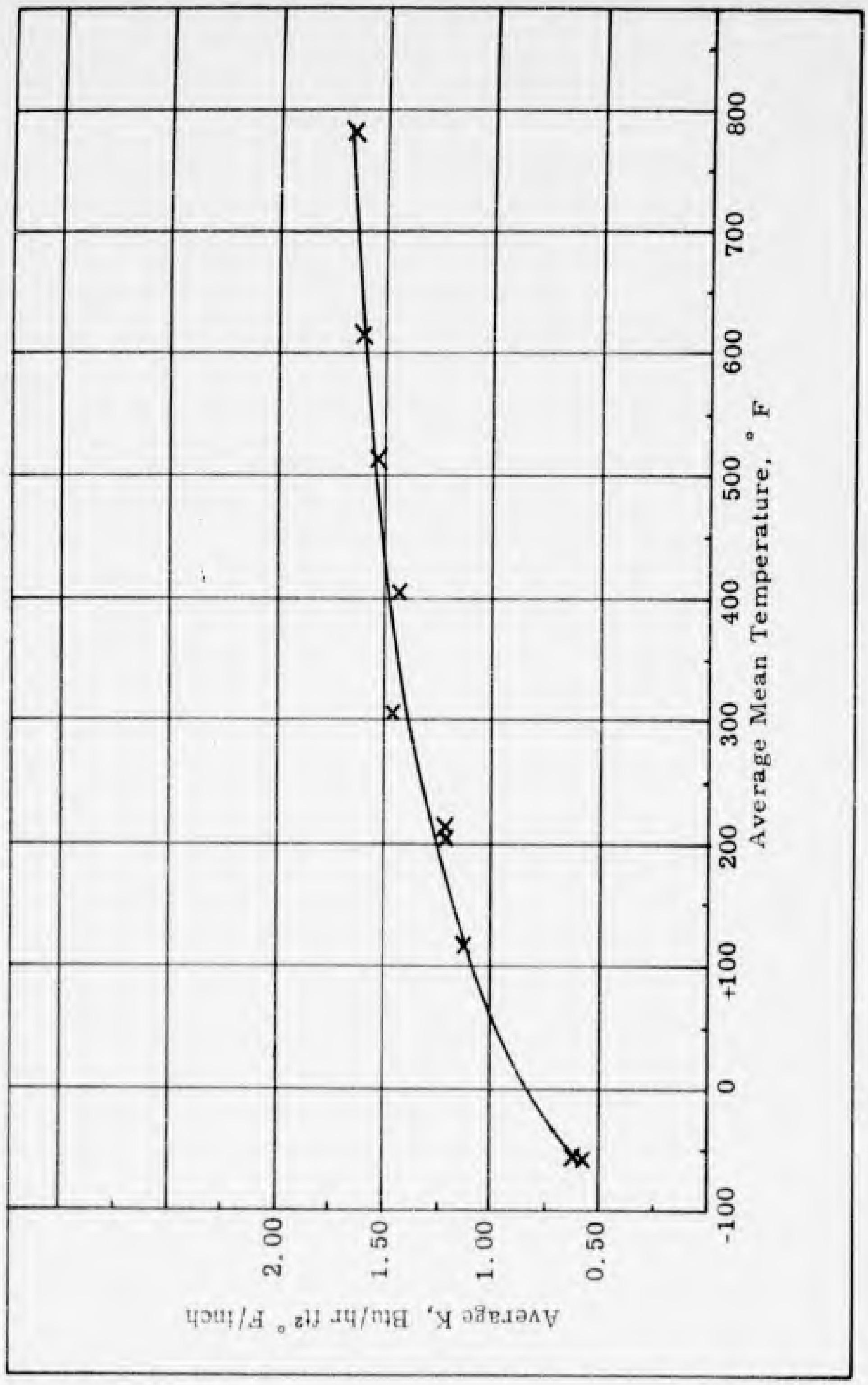

Figure 58. Thermal Conductivity Curve for Material SRI No. 4, Glass Roving, Phenolic Resin.

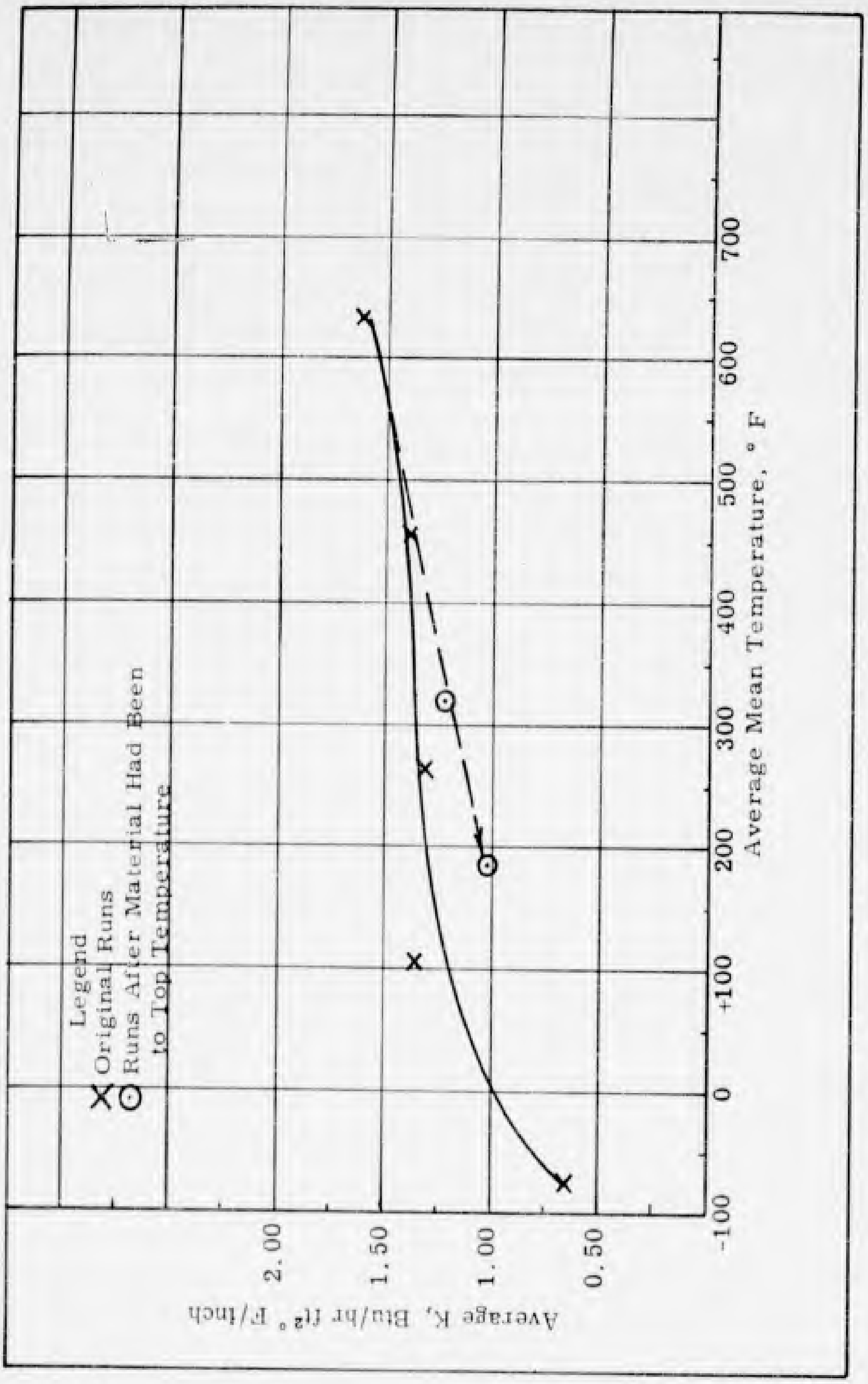

Figure 59. Thermal Conductivity Curve for Material SRI No. 5, Chopped Glass, Silicone Resin.

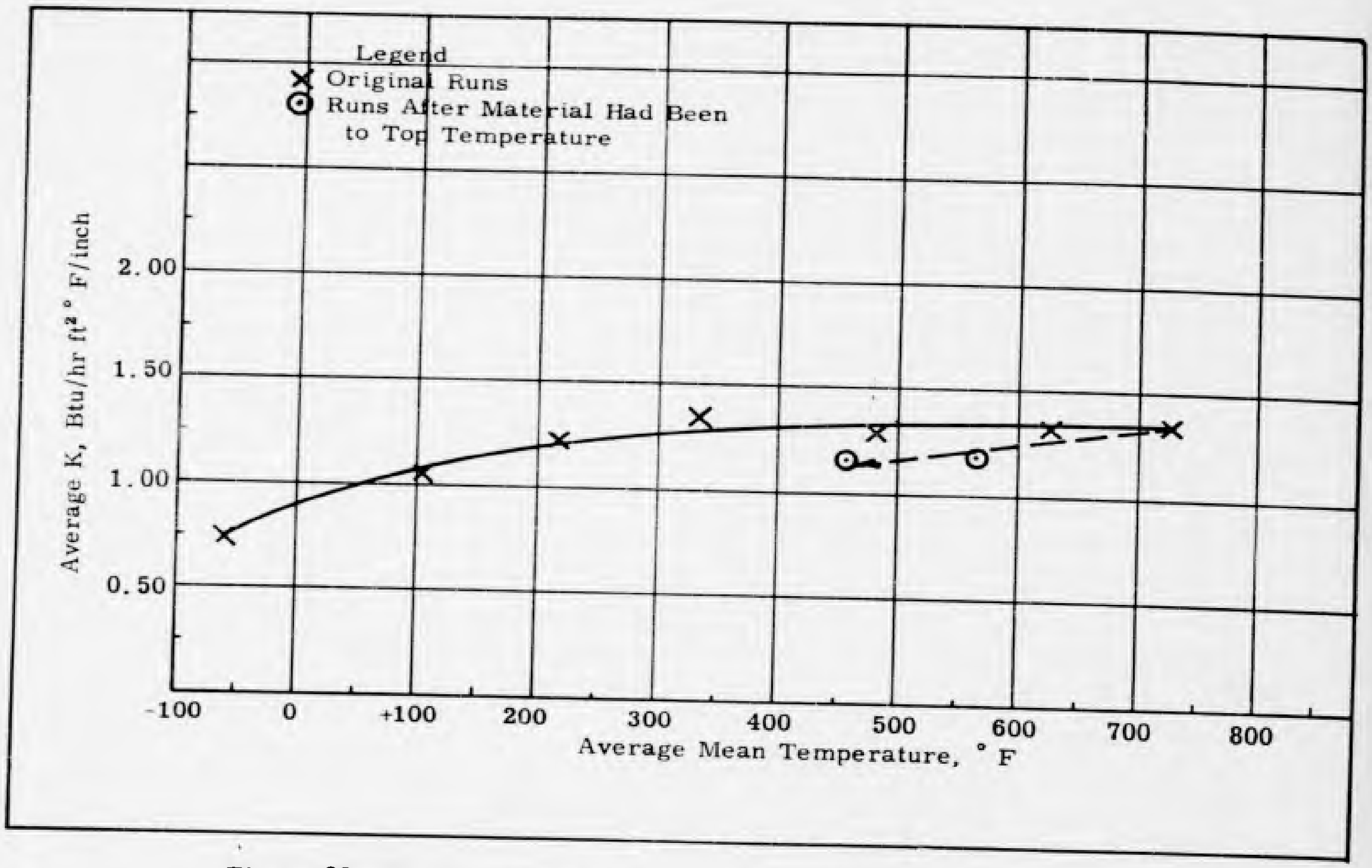

Figure 60. Thermal Conductivity Curve for Material SRI No. 6, ½-inch Squares of Glass, Phenolic Resin.

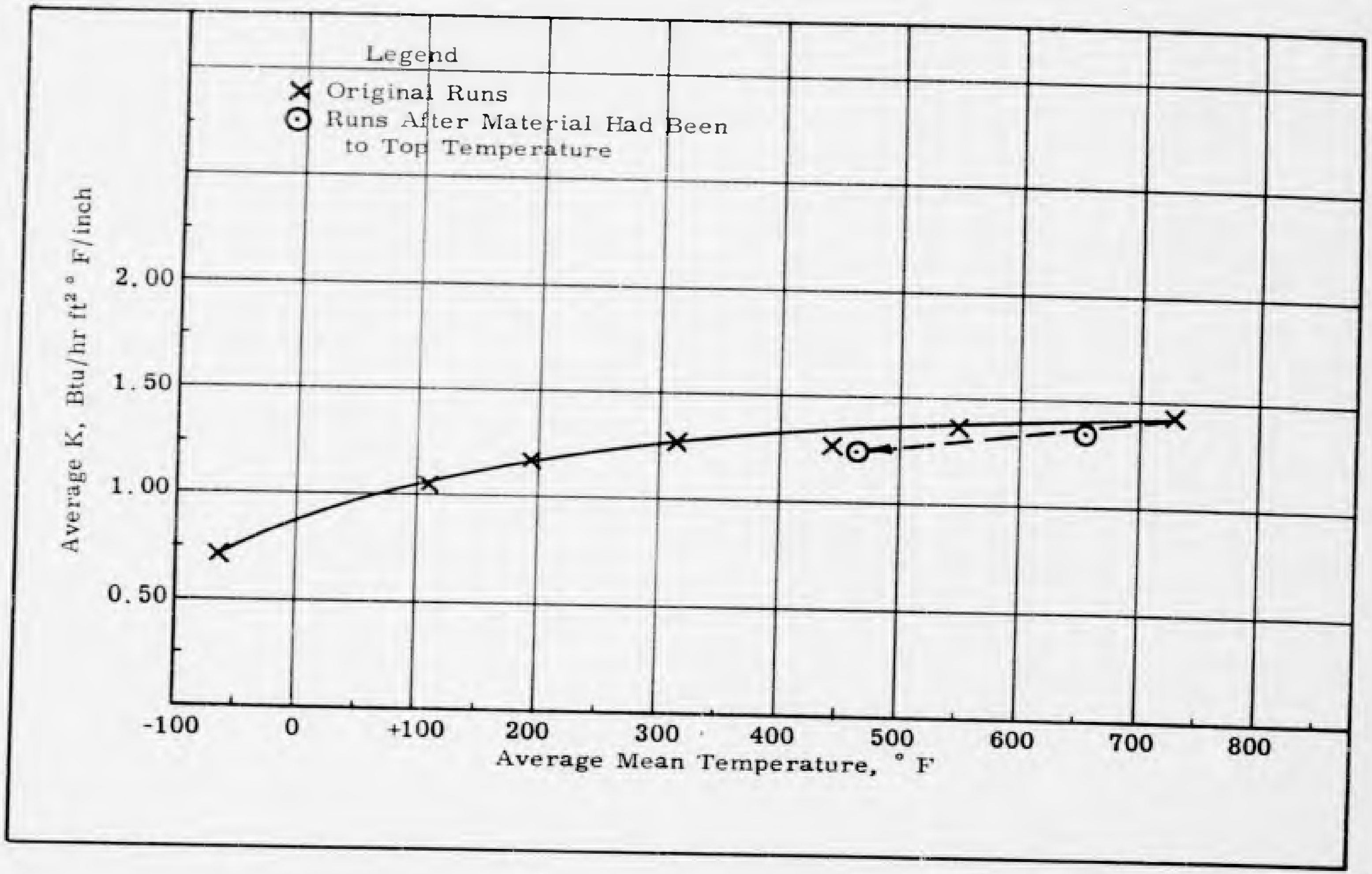

Figure 61. Thermal Conductivity Curve for Material SRI No. 7-1, Refrasil Fabric, Phenolic Resin.

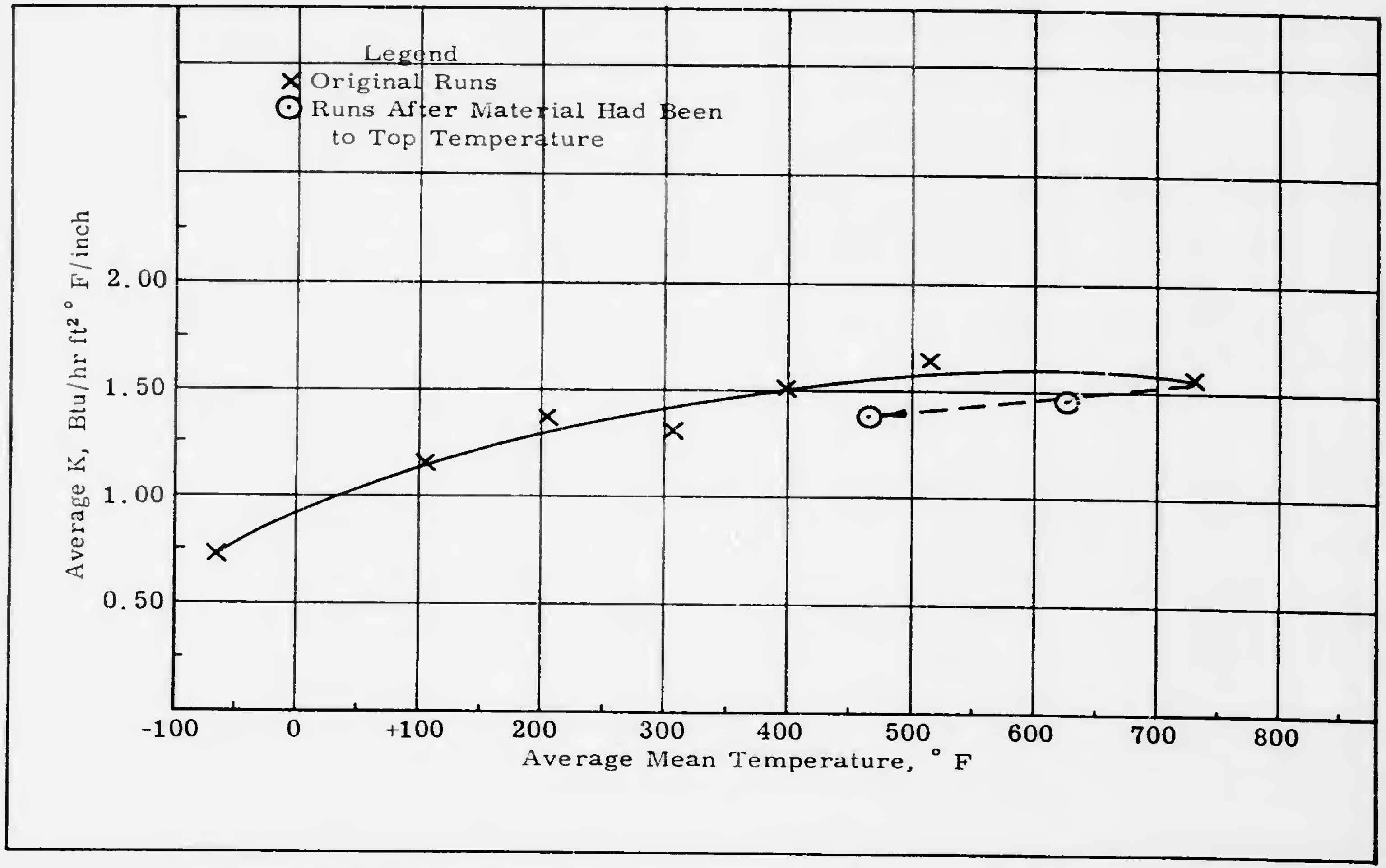

Figure 62. Thermal Conductivity Curve for Material SRI No. 7-2, Edgewise Layup, Refrasil Fabric, Phenolic Resin.

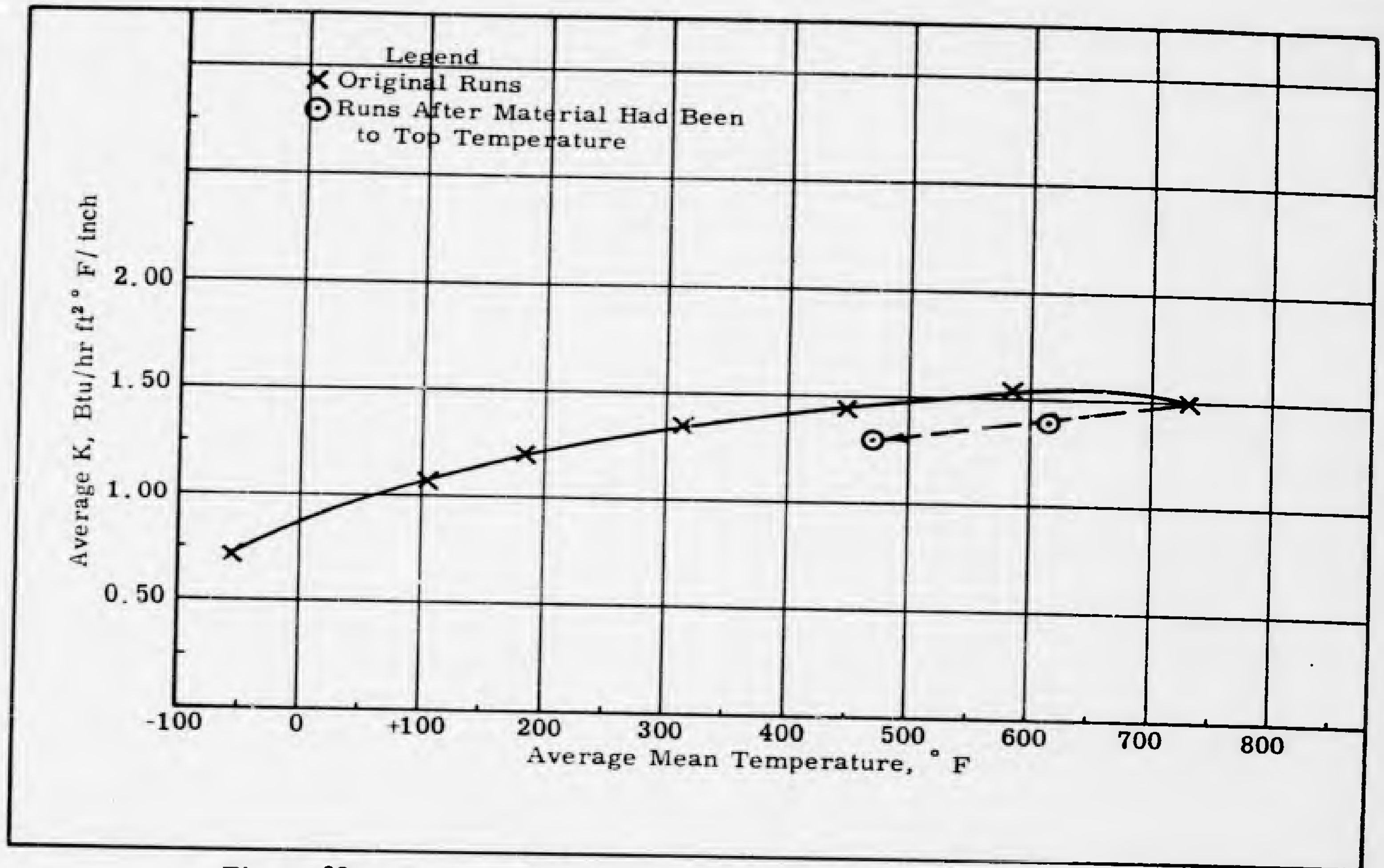

Figure 63. Thermal Conductivity Curve for Material SRI No. 8-1, Glass Fabric, Phenolic Resin.

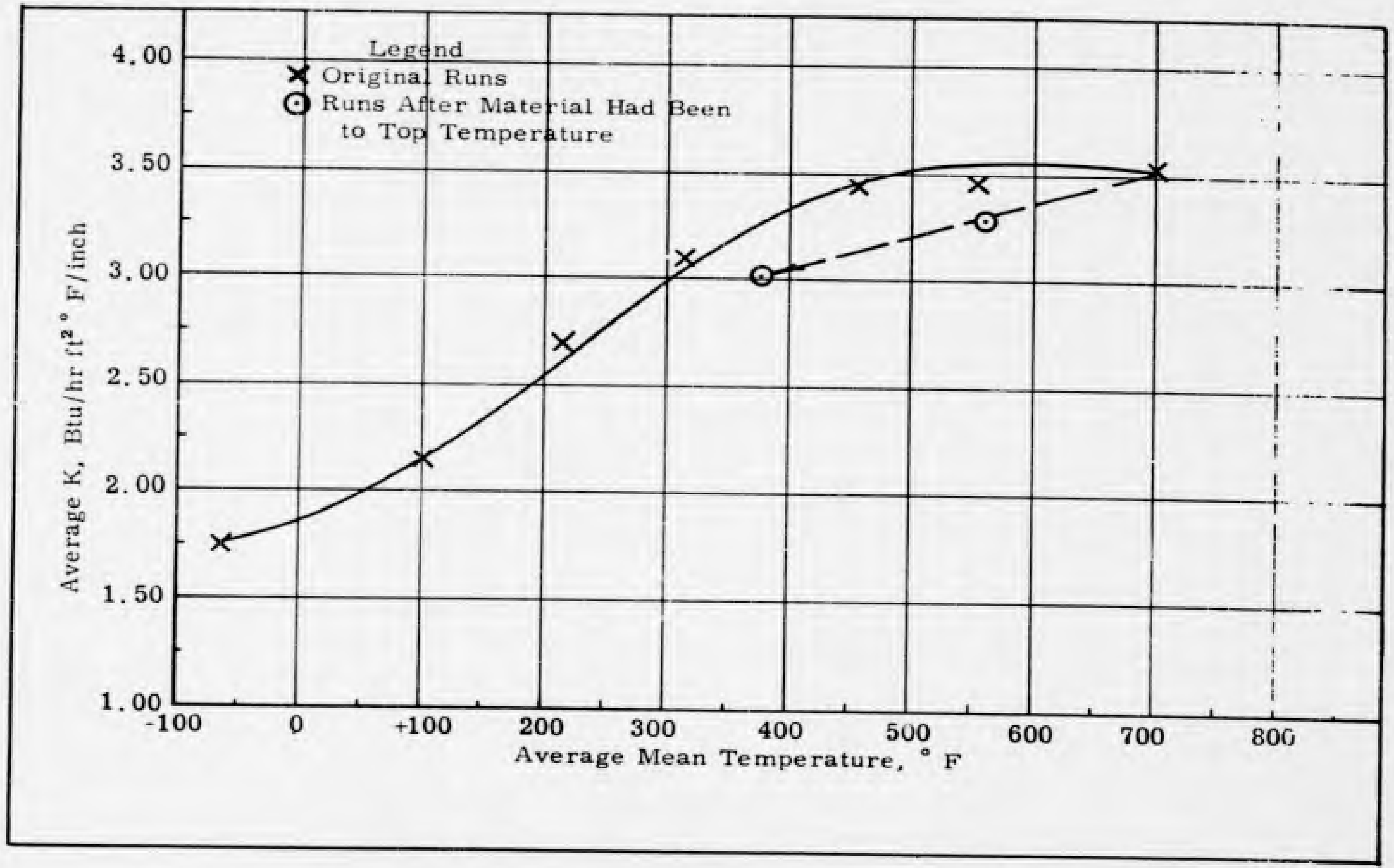

Figure 64. Thermal Conductivity Curve for Material SRI No. 8-2, Edgewise Layup, Glass Fabric, Phenolic Resin.

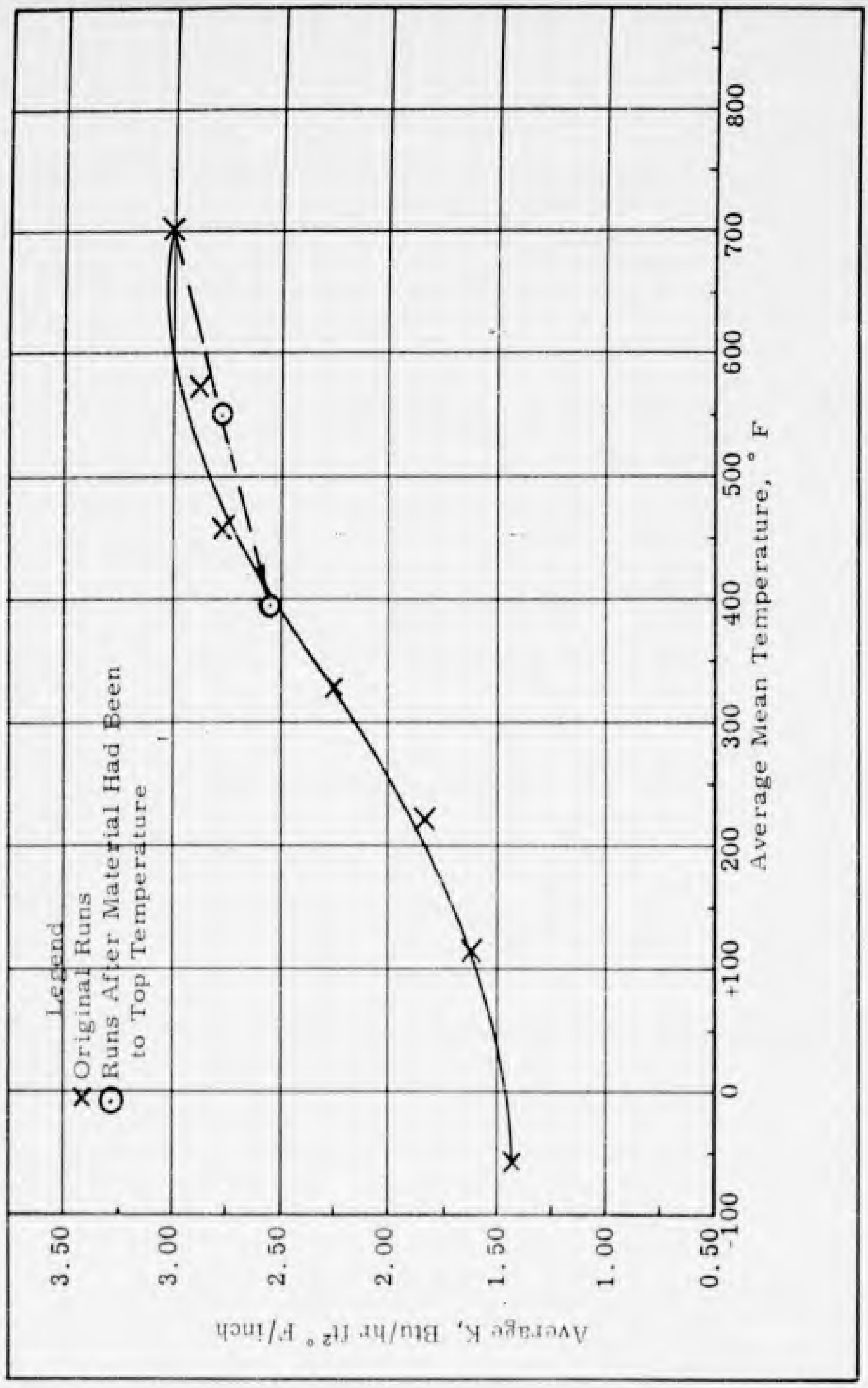

Figure 65. Thermal Conductivity Curve for Material SRI No. 8-3, 45° Shingle Layup, Glass Fabric, Phenolic Resin.

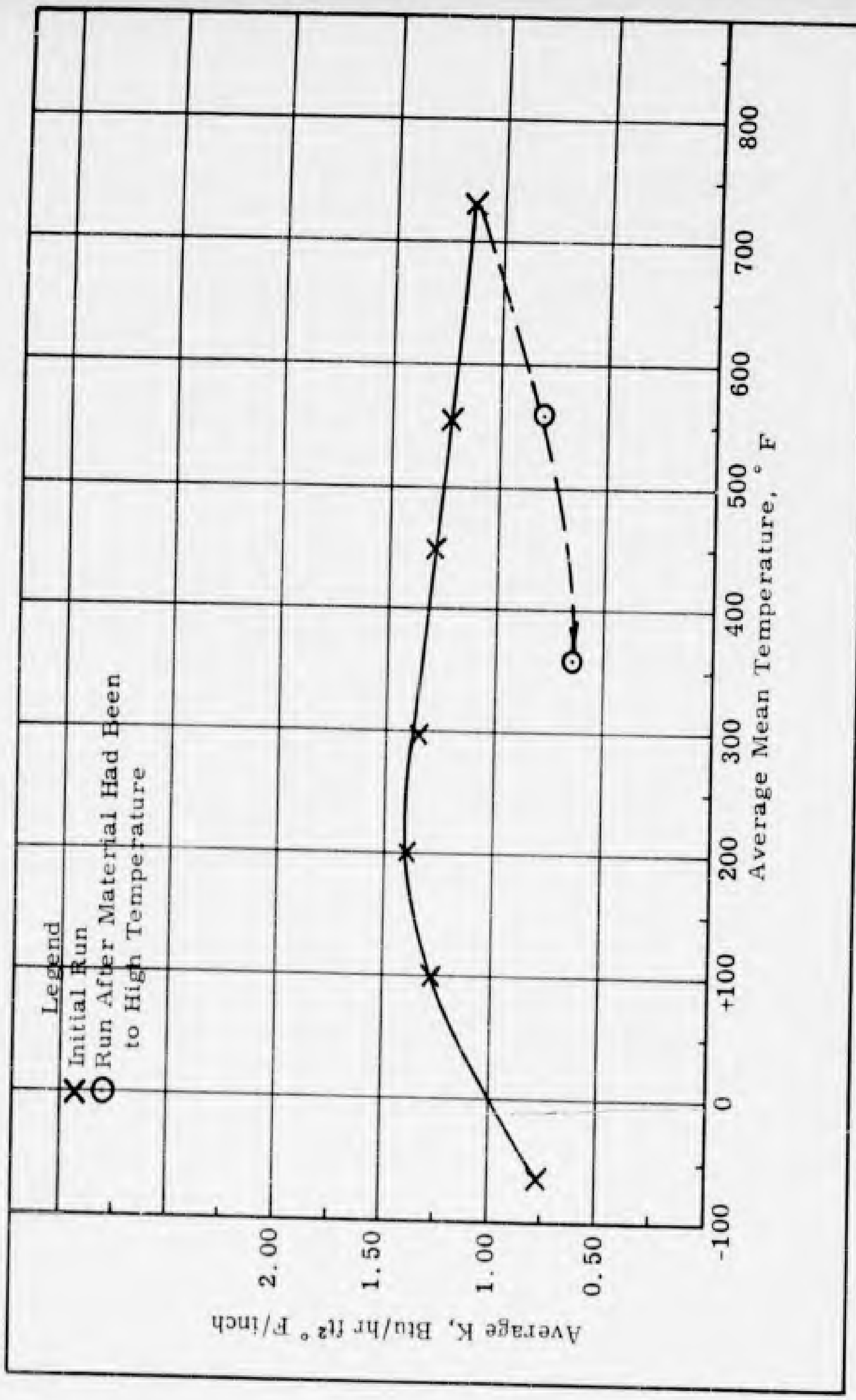

Figure 66. Thermal Conductivity Curve for Material SRI No. 9, Chopped Nylon, Phenolic Resin.

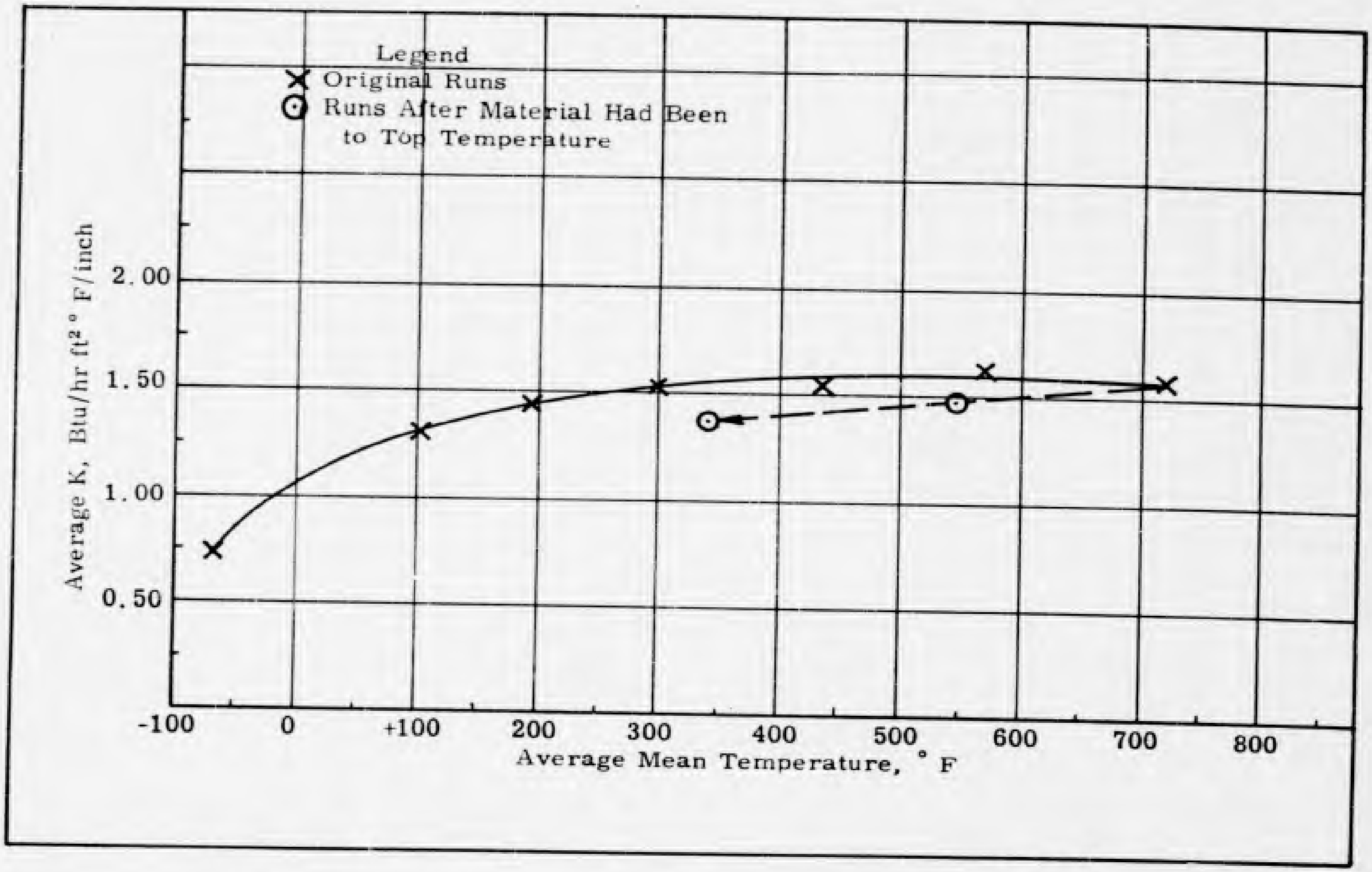

Figure 67. Thermal Conductivity Curve for Material SRI No. 10, Asbestos, Silicone Resin.

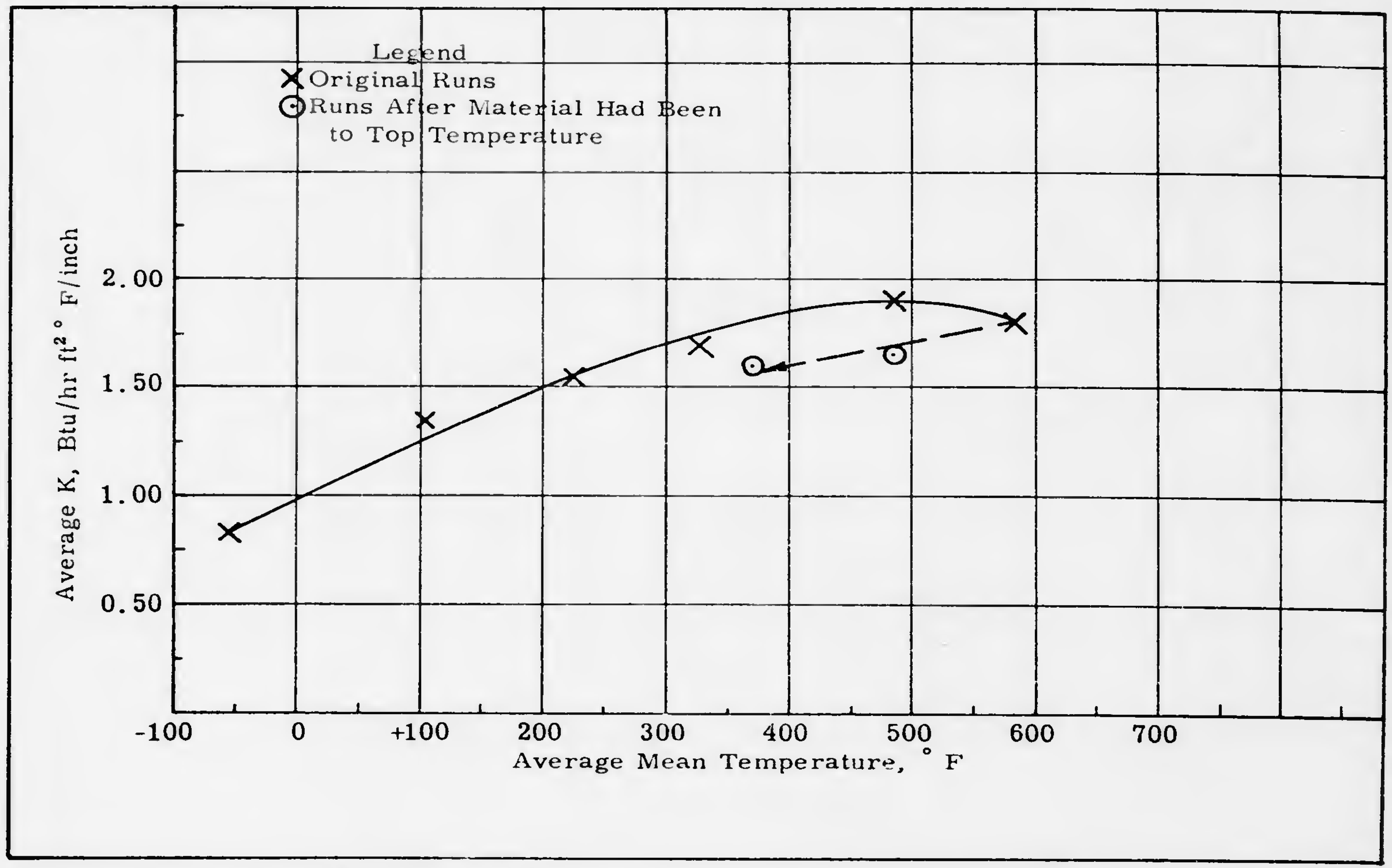

Figure 68. Thermal Conductivity Curve for Material SRI No. 11, Glass Fabric, Phenolic Resin.

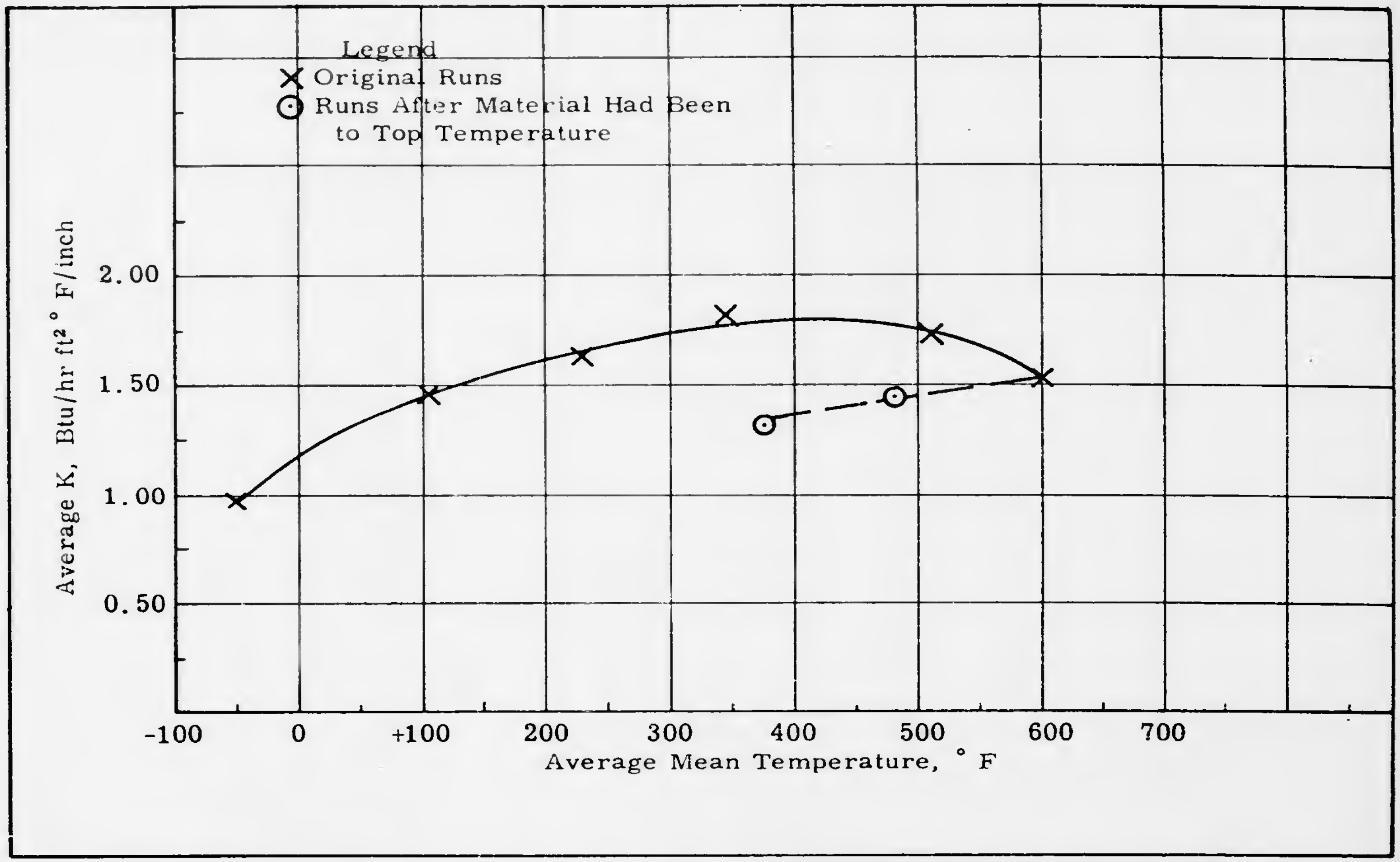

Figure 69. Thermal Conductivity Curve for Material SRI No. 12, Glass Fabric, Epoxy Resin.

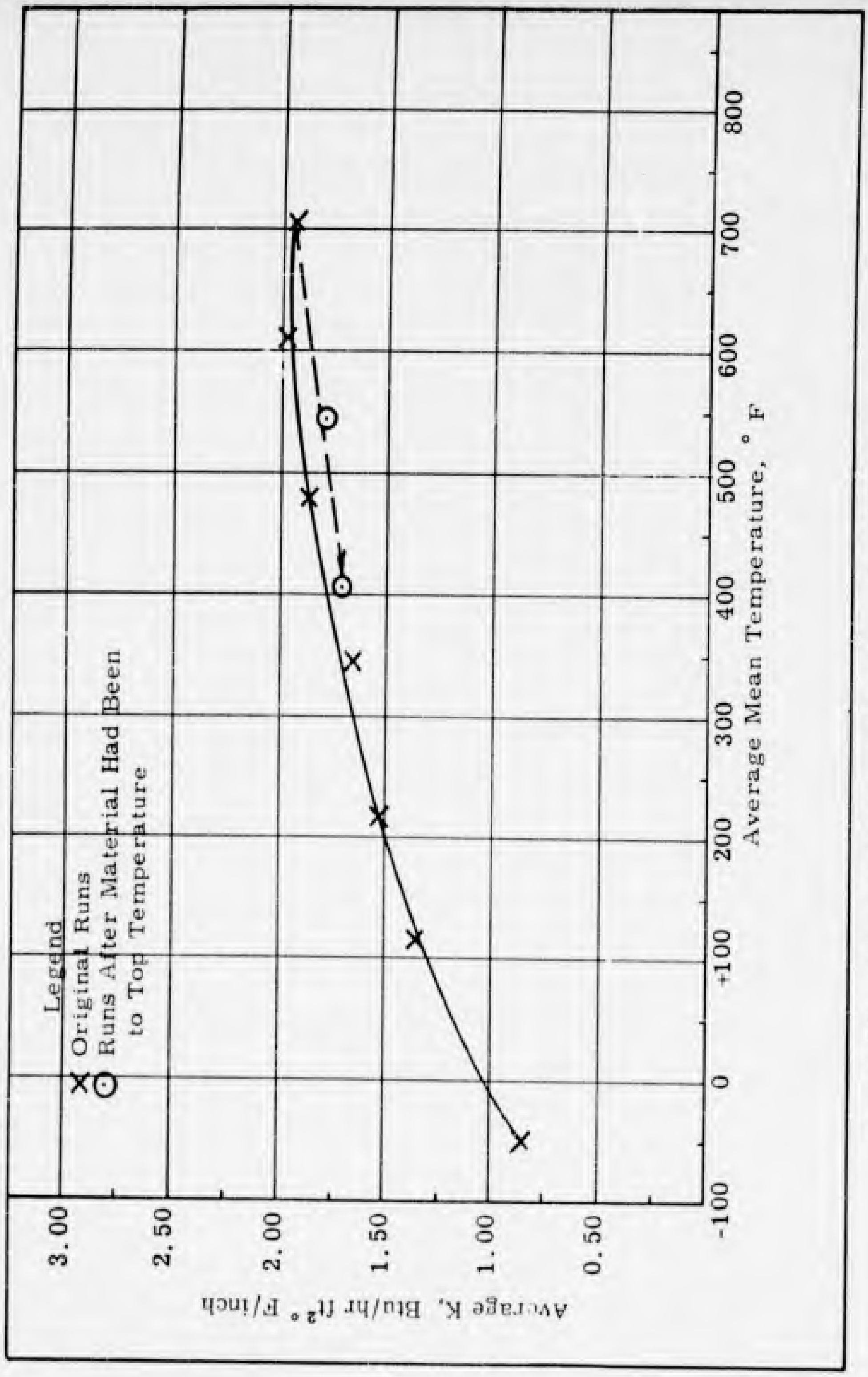

Figure 70. Thermal Conductivity Curve for Material SRI No. 13, Asbestos, Phenolic Resin.

Table 6

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Copper Calibration Specimen								
Run No.	Initial Cup Temp., ° F	Final Cup Temp., ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm.	Final Wt. of Sample, Gm.	$h = \frac{K}{W_s}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	77.455	80.610	3.155	201.600	30.40	30.40	12.5	12.0
2	74.728	77.455	2.727	204.670	30.40	30.40	10.8	10.1
3	76.044	86.348	10.304	520.000	30.40	30.40	40.9	41.0

Table 7

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Scotchply XP-125 Special Resin Content, Unidirectional Laminate SRI No. 1-1								
Run No.	Initial Cup Temp., ° F	Final Cup Temp., ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm.	Final Wt. of Sample, Gm.	$h = \frac{K}{W_S}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	77.773	74.683	- 3.090	- 64.433	16.330	16.330	- 22.7	- 24.4
2	97.304	92.044	- 5.260	- 50.934	16.330	16.330	- 38.7	- 36.8
3	155.960	149.417	- 6.543	- 49.000	16.336	16.336	- 48.0	- 32.5
4	76.826	80.348	3.522	194.667	16.407	16.398	25.8	24.7
5	80.522	88.391	7.869	315.000	16.410	16.390	57.8	58.7
6	76.956	88.609	11.653	390.333	16.415	16.365	85.6	86.6
7	87.783	103.000	15.217	491.333	16.563	16.400	111.5	116.7

Table 8

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Scotchply XP-125 Special Resin Content, Isotropic Laminate, (Adjacent Plies at 60° to Each Other) SRI No. 1-2								
Run No.	Initial Cup Temp., ° F	Final Cup Temp., ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm.	Final Wt. of Sample, Gm.	$h = \frac{K}{W_S}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	92.348	87.218	5.130	- 92.900	15.477	15.477	- 39.8	- 39.3
2	87.174	82.000	- 5.174	- 62.333	15.278	15.278	- 40.7	- 41.5
3	93.545	87.391	- 6.154	- 52.500	15.281	15.281	- 48.5	- 47.7
4	79.318	82.913	3.595	197.333	15.195	15.187	28.5	28.0
5	83.819	91.044	7.225	302.000	15.310	15.290	56.9	58.5
6	78.653	90.391	11.738	410.333	15.443	15.402	91.5	93.0
7	90.174	104.652	14.478	494.667	15.437	15.310	113.1	118.8

Table 9

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Molded Panel, Chopped 181 Glass Fabric, A-1100 Finish with CTL-91 LD Phenolic Resin Resin Content 35 ± 5% SRI No. 2								
Run No.	Initial Cup Temp., ° F	Final Cup Temp., ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm.	Final Wt. of Sample, Gm.	$h = \frac{K}{W_S}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	75.000	78.695	3.695	194.000	17.103	17.080	26.0	24.6
2	72.910	80.609	7.699	296.167	16.740	16.616	55.6	54.5
3	79.819	92.652	12.833	411.000	17.350	17.201	89.6	91.7
4	76.304	90.914	14.610	500.167	16.665	16.066	109.5	111.1
5	88.653	107.541	18.888	614.500	16.785	16.130	140.5	146.7

Table 10

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Foam Core, Dow-Corning Silicone R-7002, Fully Cured SRI No. 3								
Run No.	Initial Cup Temp., ° F	Final Cup Temp., ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample Gm.	Final Wt. of Sample, Gm.	$h = \frac{K}{W_S}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	75.304	77.227	1.923	195.333	5.275	5.270	43.7	40.8
2	75.913	78.956	3.043	302.000	5.300	5.275	69.3	67.4
3	78.521	83.318	4.797	399.333	5.535	5.500	104.5	103.9
4	75.435	80.653	5.218	501.000	4.770	4.710	132.8	131.4
5	75.478	79.174	3.696	588.167	4.540	*2.370	187.0	184.8
6	78.217	85.087	6.870	697.000	4.420	4.165	198.0	198.0

* Sample broke in half and only half fell in cup.

Table 11

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Molded Panel Fiberite 4030-190, Glass Fiber, Phenolic Resin SRI No. 4								
Run No.	Initial Cup Temp., ° F	Final Cup Temp., ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm.	Final Wt. of Sample, Gm.	$h = \frac{K}{W_s}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	74.410	70.727	- 3.683	- 50.167	13.040	13.040	- 33.9	- 37.9
2	93.565	90.043	- 3.522	- 28.667	13.040	13.040	- 32.4	- 31.0
3	77.318	81.826	4.508	207.900	12.950	12.936	41.9	40.8
4	77.091	83.000	5.909	294.500	12.050	11.950	59.4	58.8
5	81.478	90.956	9.478	408.167	12.800	12.400	91.6	93.3
6	75.478	87.653	12.175	499.500	12.866	12.300	118.6	119.4
7	84.956	100.913	15.957	619.167	13.050	12.335	155.0	160.9
8	80.218	98.261	18.043	704.833	12.700	11.610	186.1	190.2

Table 12

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Molded Panel, Coast F-130 Chopped Glass Fiber, Silicone Resin SRI No. 5								
Run No.	Initial Cup Temp., ° F	Final Cup Temp., ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm.	Final Wt. of Sample, Gm.	$h = \frac{K}{W_s}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	129.083	121.375	- 7.708	- 24.150	17.750	17.750	- 52.1	- 39.1
2	122.125	114.416	- 7.769	- 50.000	17.250	17.250	- 53.6	- 44.0
3	78.087	82.610	4.523	210.434	16.900	16.900	32.1	31.5
4	77.864	84.956	7.092	307.000	17.250	17.250	49.4	49.4
5	83.545	94.304	10.759	404.833	17.750	17.750	72.8	70.6
6	72.864	87.479	14.615	494.000	17.506	17.491	100.7	101.3
7	73.174	91.914	18.740	591.333	17.795	17.774	126.9	128.7
8	89.174	111.042	21.868	699.667	17.790	17.666	148.8	155.4

Table 13

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Astrolite, Random Reinforcement, ½" Squares of 1201V Cloth, SC-1008 Phenolic Resin SRI No. 6								
Run No.	Initial Cup Temp., ° F	Final Cup Temp., F	Change in Cup Temp. F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm.	Final Wt. of Sample, Gm.	$h = \frac{K}{W_S}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	91.044	87.348	- 3.696	- 52.467	13.495	13.495	- 32.9	- 32.4
2	72.273	76.522	4.249	210.634	14.115	13.835	36.8	34.5
3	80.130	85.826	5.696	303.333	---	12.660	54.0	54.2
4	73.869	83.136	9.267	396.000	14.460	13.898	80.4	80.9
5	69.261	81.348	12.087	494.667	13.375	12.740	113.9	112.9
6	73.696	88.174	14.478	590.667	13.495	12.755	136.0	136.9
7	82.218	99.913	17.695	702.000	14.055	12.650	168.0	172.2

Table 14

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Astrolite, Laminar Construction, Refrasil 184 Weave, SC-1008 Phenolic Resin SRI No. 7-1								
Run No.	Initial Cup Temp., ° F	Final Cup Temp. ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm	Final Wt. of Sample, Gm.	$h = \frac{K}{W_S}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	64.591	61.565	- 3.026	- 58.500	13.380	13.355	- 27.2	- 32.5
2	75.174	78.870	3.696	204.767	13.230	13.100	33.9	35.5
3	77.955	84.565	6.610	295.333	13.265	12.805	62.0	62.1
4	73.652	83.273	9.621	422.500	13.280	12.630	91.4	90.9
5	81.609	95.087	13.478	555.625	13.180	12.470	129.8	132.6
6	66.182	83.318	17.136	682.000	13.355	12.160	169.2	169.7

Table 15

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Molded Panel, SN-19 Nylon Chopped Fabric Construction, CTL-91 LD Phenolic Resin
SRI No. 9

Run No.	Initial Cup Temp., ° F	Final Cup Temp., ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm.	Final Wt. of Sample, Gm.	$h = \frac{K}{W_s}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	72.591	69.218	- 3.373	- 49.450	9.385	9.385	- 43.1	- 48.8
2	76.478	74.045	- 2.433	- 49.850	8.969	8.969	- 32.6	- 35.5
3	71.131	75.500	4.369	218.667	9.365	9.325	56.4	52.7
4	74.682	82.609	7.927	319.333	8.905	8.837	108.0	106.9
5	73.826	85.261	11.435	414.333	8.720	8.405	163.5	163.5
*6	74.727	89.870	15.143	498.833	9.485	8.902	204.0	206.0

* Black, gummy mass came out of cut edges of specimen at this temperature.

Table 16

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Laminate, 40 RPD Asbestos, DC-2106 Silicone Resin SRI No. 10								
Run No.	Initial Cup Temp., ° F	Final Cup Temp., ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm	Final Wt. of Sample, Gm.	$h = \frac{K}{Ws}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	88.261	83.720	- 4.541	- 48.700	14.682	14.682	- 37.2	- 37.5
2	76.652	81.013	4.361	222.000	14.423	14.348	36.6	35.6
3	80.783	88.870	8.087	326.000	14.630	14.494	67.1	68.2
4	77.091	88.000	10.909	402.333	14.400	14.262	92.1	93.0
5	81.479	94.956	13.477	498.500	14.320	14.115	114.4	117.2
6	73.131	90.348	17.217	593.333	14.230	14.000	148.0	149.6
7	88.956	109.333	20.377	702.000	14.082	13.687	178.8	186.1

Table 17

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Laminate, YM-31A Glass Fabric, CTL-91 LD Phenolic Resin SRI No. 11								
Run No.	Initial Cup Temp., ° F	Final Cup Temp., ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm.	Final Wt. of Sample, Gm.	$h = \frac{K}{W_s}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	92.913	89.261	- 3.652	- 58.033	12.185	12.202	- 35.9	- 34.9
2	88.913	86.565	- 2.348	- 29.566	12.003	12.017	- 23.4	- 23.1
3	79.000	82.783	3.783	212.167	11.960	11.947	38.1	38.8
4	82.956	88.696	5.740	310.833	11.931	11.900	58.0	59.0
5	77.591	86.261	8 670	403.667	11.528	11.642	89.5	89.9
6	86.261	96.834	10.573	512.500	11.730	11.552	141.1	145.3
7	86.435	99.913	13.478	601.333	11.699	11.490	110.0	113.1

Table 18

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Laminate, YM-31A Glass Fabric, Epon 1031 Epoxy Resin SRI No. 12								
Run No.	Initial Cup Temp., ° F	Final Cup Temp., ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm.	Final Wt. of Sample, Gm.	$h = \frac{K}{W_s}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	80.914	77.864	- 3.050	- 52.835	12.042	12.045	- 30.4	- 32.1
2	75.261	73.391	- 1.870	- 38.200	12.080	12.082	- 18.6	- 20.5
3	77.773	80.131	2.358	192.566	11.650	11.640	24.3	23.3
4	77.227	81.740	4.463	202.233	11.970	11.960	44.8	46.0
5	82.956	89.217	6.261	319.667	11.894	11.867	63.5	64.6
6	87.914	95.914	8.000	407.000	11.810	11.780	81.6	84.5
7	92.956	103.000	10.044	505.333	11.807	11.735	102.8	107.4
8	80.174	93.174	13.000	598.167	11.556	11.350	137.5	139.7

Table 19

Specific Heat Data

Calorimeter Constant K = 0.2654 Btu/° F

Test Specimen; Laminate, R/M 42 RPD Asbestos, R/M High Heat Resistant Phenolic SRI No. 13								
Run No.	Initial Cup Temp., ° F	Final Cup Temp., ° F	Change in Cup Temp., ° F	Initial Sample Temp., ° F	Initial Wt. of Sample, Gm.	Final Wt. of Sample, Gm.	$h = \frac{K}{W_S}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85° F Ref., Btu/lb
1	100.217	94.304	- 5.913	- 57.167	18.039	18.050	- 39.4	- 37.0
2	74.819	81.130	6.311	228.000	18.341	18.295	41.5	40.4
3	81.130	91.091	9.961	315.750	18.237	18.120	66.0	67.8
4	90.696	103.740	13.044	396.750	18.070	17.960	87.1	92.7
5	73.565	91.913	18.348	501.000	18.065	17.723	124.1	126.2
6	91.609	114.208	22.599	602.750	18.015	17.630	154.0	163.2
7	75.348	102.500	27.152	699.667	17.952	17.258	188.8	194.3

Table 20

Thermal Expansion Data for $\frac{3}{4}$" Diameter x 3" Long Graphite Calibration Sample

Run No. 1		Run No. 2		Run No. 3	
Avg. Temp., °F	Avg. Expansion, µin./in.	Avg. Temp., °F	Avg. Expansion, µin./in.	Avg. Temp., °F	Avg. Expansion, µin./in.
77	0	96	0	79	0
135	0	155	- 33	102	0
150	-33	202	0	151	0
203	-67	255	33	206	0
251	-67	307	33	249	0
302	-33	351	33	302	33
349	-33	413	67	353	33
368	-33	465	100	402	67
415	-33	499	133	450	67
449	-33	551	133	508	67
501	-33	604	133	549	67
561	-33	647	200	593	67
610	+33			660	67
				699	100
				759	100
				797	133

Table 21

Thermal Expansion Data for $\frac{3}{4}''$ Diameter x 3'' Long Nickel Calibration Sample

Avg. Temp., °F	Avg. Expansion, μin./in.
123	0
152	167
200	533
255	933
301	1300
363	1733
400	2033
447	2400
503	2867
569	3367

Table 22

Thermal Expansion Data for Scotchply XP-125, Special Resin Content 30% ± 1.5%
Specimens 3" Long x 1" Wide x $\frac{1}{8}$" Thick Approx.

Unidirectional Laminate, SRI No. 1-1						Isotropic Laminate, SRI No. 1-2	
Expansion Parallel and at 0° to Major Axis		Expansion Parallel and at 45° to Major Axis		Expansion Parallel and at 90° to Major Axis		Expansion Parallel to Panel	
Avg. Temp., °F	Avg. Exp., μin./in.	Avg. Temp., °F	Avg. Exp., μin./in.	Avg. Temp., °F	Avg. Exp., μin./in.	Avg. Temp., °F	Avg. Exp., μin./in.
78	0	74	0	74	0	78	0
48	-100	-24	-767	-43	-1967	9	-300
4	-267	-46	-1100	-84	-2533	-28	-433
-35	-400	-71	-1333	-96	-2700	-69	-633
-69	-500	-89	-1467	-106	-2833	-105	-867
-84	-533	-103	-1567	-91	-2633	-59	-767
-102	-600	-82	-1467	-54	-2100	-23	-600
-69	-500	-56	-1300	-12	-1433	15	-433
-35	-400	-15	-933	-21	-900	54	-133
2	-333	-2	-767	48	-500	78	0
48	-133	28	-567	73	0	* 76	0
78	-33	46	-367	* 73	0	99	133
* 76	0	74	-133	126	1000	174	500
119	167	* 73	0	158	1933	225	567
185	233	127	533	192	2600	251	600
247	333	167	1100	274	7867	305	833
303	433	206	1533	332	11000	347	1100
367	500	294	4367	373	12367	411	1167
411	533	358	6333	424	14100	461	1267
444	367	399	6667	473	13233	501	900
502	167	457	7167	507	9333		
76	-833	512	5967	71	-13533		
		71	-5167				

* Dial gage rezeroed.

Table 23

Thermal Expansion Data for Molded Panel, Chopped 181 Glass Fabric, A-1100 Finish with CTL-91 LD Phenolic Resin, Resin Content 35% ± 5%
SRI No. 2

Expansion Parallel to Panel Specimen, 3" Long x 1" Wide x $\frac{1}{4}$" Thick Approx.		Expansion Normal to Panel Specimen, 11 - $\frac{3}{4}$" Dia. Disks Stacked to $3\frac{3}{32}$" Approx.	
Avg. Temp., °F	Avg. Expansion, μin./in.	Avg. Temp., °F	Avg. Expansion, μin./in.
73	0	73	0
109	167	109	711
166	700	162	1583
209	900	215	2718
255	1167	257	3135
303	1500	293	3655
359	1667	357	4490
398	1833	421	12900
443	2300	440	15540
503	1867	460	19890
516	1500	504	21100
540	1367	557	12100
585	1500	615	9830
635	1733	671	7950
724	2233	727	8020
69	- 833	69	- 744

Table 24

Thermal Expansion Data for Foam Core, Dow-Corning Silicone R-7002, Fully Cured SRI No. 3

Expansion Parallel to Panel ½" x ½" x 3" Long Specimen		Expansion Normal to Panel 6 - ¾" x ¾" x ½" Cubes Stacked to Form 3" Specimen	
Avg. Temp., °F	Avg. Expansion, µin./in.	Avg. Temp., °F	Avg. Expansion, µin./in.
76	0	76	0
17	- 3133	104	700
- 2	- 4233	151	2200
- 29	- 5133	215	4400
- 57	- 5800	247	5400
- 86	- 6633	294	5900
- 94	- 6833	342	5800
- 98	- 6933	367	4300
-101	- 7033	391	1800
-103	- 7100	447	- 4000
-103	- 7133	518	- 7000
- 77	- 6800	532	-11600
- 44	- 5800	611	-11500
- 15	- 4800	650	-13000
+ 2	- 4300	715	-19000
21	- 3467	75	-21800
40	- 2800		
53	- 2300		
63	- 1933		
76	- 1467		
* 78	0		
100	700		
148	3267		
197	5967		
260	8333		
304	8670		
328	8567		
345	7900		
382	2600		
395	- 1167		
447	- 5733		
492	- 6200		
547	- 8100		
554	-12467		

* Dial gage rezeroed.

Table 25

Thermal Expansion Data for Molded Panel Fiberite 4030-190, Glass Fiber, Phenolic Resin
Expansion Parallel to Panel, 1" x $\frac{1}{4}$" x 3" Long Specimen
SRI No. 4

Sample No. 1, Run No. 1		Sample No. 1, Run No. 2		Sample No. 2	
Avg. Temp., °F	Avg. Expansion, µin./in.	Avg. Temp., °F	Avg. Expansion, µin./in.	Avg. Temp., °F	Avg. Expansion, µin./in.
80	0	78	0	78	0
14	- 767	97	133	98	167
- 3	- 967	143	467	144	767
- 38	-1300	195	833	203	1567
- 50	-1433	251	1200	246	1933
- 57	-1500	312	1600	288	2333
- 70	-1667	369	2033	350	2700
- 79	-1733	434	2533	415	2133
- 83	-1767	387	1967	428	1767
- 95	-1833	428	2300	433	1433
-100	-1900	496	2800	455	733
-103	-1933	524	2900	478	467
-104	-1967	579	3000	512	533
- 88	-1800	650	3433	567	767
- 68	-1633	656	3367	638	833
- 50	-1433	683	3367	687	1033
- 27	-1267	735	3200	774	1367
12	- 767	623	1833	85	-4967
37	- 533	420	267		
51	- 367	279	- 667		
63	- 233	136	-1567		
78	- 67	78	-1900		
* 76	0				
129	700				
148	967				
213	1867				
280	2600				
306	2900				
369	3430				
414	2500				
464	1667				
518	1500				
460	833				
413	200				
340	- 267				
316	- 533				
74	-2167				

* Dial gage rezeroed.

Table 26

Thermal Expansion Data for Molded Panel Fiberite 4030-190, Glass Fiber, Phenolic Resin. Expansion Normal to Panel. 12 - $\frac{3}{4}$" Diameter Disks Stacked Up, Total Height Approximately $2\frac{15}{16}$" SRI No 4

Avg. Temp., °F	Avg. Expansion, μin./in.
76	0
57	- 306
42	- 511
- 10	- 1261
- 24	- 1465
- 37	- 1670
- 50	- 1875
- 65	- 2145
- 77	- 2319
- 92	- 2620
- 96	- 2690
-105	- 2827
- 78	- 2420
- 44	- 1910
- 15	- 1500
41	- 750
59	- 545
76	- 170
* 75	0
103	400
155	1100
194	2300
248	4000
261	4600
318	7900
357	13900
381	20400
423	17600
480	11300
539	9000
576	7200
622	4400
680	5800
714	9800

* Dial gage rezeroed.

Table 27

Thermal Expansion Data for Molded Panel,
Coast F-130 Chopped Glass Fiber, Silicone Resin
SRI No. 5

Expansion Parallel to Panel, Specimen, 3" Long x 1" Wide x $\frac{1}{4}$" Thick Approx.		Expansion Normal to Panel, Specimen, 11 - $\frac{3}{4}$" Dia. Disks Stacked to 3" Approx.	
Avg. Temp., °F	Avg. Expansion, μin./in.	Avg. Temp., °F	Avg. Expansion, μin./in.
76	0	76	0
61	0	57	- 366
27	- 233	14	- 767
3	- 333	- 17	- 867
- 28	- 467	- 50	- 1133
- 52	- 600	- 77	- 1200
- 76	- 733	-105	- 2333
-102	- 833	- 5	- 1267
- 39	- 633	49	- 700
- 10	- 467	68	- 467
13	- 367	76	- 333
46	- 333	* 76	0
60	- 300	113	300
76	- 200	150	600
* 76	0	220	2267
108	100	285	4267
157	300	317	5600
202	467	364	7600
263	733	422	9633
311	967	481	12067
352	1100	538	15433
437	1500	589	19733
464	1667	613	23067
513	2000	663	28500
569	2400	715	32933
608	2700	76	9700
662	3000		
720	3300		
76	200		

* Dial gage rezeroed.

Table 28

Thermal Expansion Data for Laminate, Astrolite, Random Reinforcement $\frac{1}{2}$" Squares of 1201 V Cloth, SC-1008 Phenolic Resin. Resin Content 30-35% by Weight
SRI No. 6

Expansion Parallel to Panel Specimen, 2 Pieces 3" Long x 1" Wide x $\frac{1}{8}$" Thick Approx. Clamped Together		Expansion Normal to Panel Specimen, 22 - $\frac{3}{4}$" Dia. Disks Stacked to 3" Approx.	
Avg. Temp., °F	Avg. Expansion, μin./in.	Avg. Temp., °F	Avg. Expansion, μin./in.
76	0	76	0
23	- 233	50	- 500
- 16	- 400	14	- 967
- 46	- 500	- 24	-1233
- 79	- 633	- 55	-1500
-102	- 700	- 72	-1700
- 73	- 633	- 99	-2000
- 28	- 467	- 51	-1567
36	- 267	4	- 933
76	- 33	30	- 333
* 76	0	57	400
146	167	76	833
207	367	* 76	0
294	33	145	2367
405	- 333	189	3733
413	- 400	257	2700
448	- 600	297	1700
482	- 533	353	933
567	- 567	386	333
604	- 633	504	- 133
638	- 867	572	0
720	-1033	599	33
69	-1600	668	67
		723	- 300
		69	-3467

* Dial gage rezeroed.

Table 29

Thermal Expansion Data for Laminate, Astrolite, Refrasil 184 Weave, SC-1008 Phenolic Resin
SRI No. 7-1

Expansion Parallel to Panel Specimen, 2 Pieces 3" Long x 1" Wide x $\frac{1}{8}$" Thick Approx. Clamped Together		Expansion Normal to Panel Specimen, $\frac{3}{4}$" Dia. Disks Stacked to 3" Approx.	
Avg. Temp., °F	Avg. Expansion, μin./in.	Avg. Temp., °F	Avg. Expansion, μin./in.
75	0	73	0
25	- 167	51	0
- 19	- 267	14	- 233
- 51	- 400	- 12	- 533
- 73	- 467	- 45	- 1000
- 89	- 500	- 81	- 1667
-100	- 567	-104	- 2100
- 43	- 467	- 22	- 967
- 10	- 333	15	- 300
29	- 167	73	+ 167
63	- 67	* 72	0
72	0	107	600
108	133	139	1167
151	333	204	2167
222	567	259	1233
280	433	300	33
313	433	343	- 600
356	267	410	- 1033
386	67	461	- 1500
440	67	512	- 2033
534	- 133	584	- 1900
544	- 267	635	- 1900
593	- 267	696	- 1900
709	- 467	752	- 3467
752	- 600	831	- 7800
860	-1067	74	-11333
74	-1700		

* Dial gage rezeroed.

Table 30

Thermal Expansion Data for Molded Panel,
SN-19 Nylon Chopped Fabric Construction, CTL-91 LD Phenolic Resin
SRI No. 9

Expansion Normal to Panel Specimen, 11 - $\frac{3}{4}$" Dia. Disks Stacked to a Height of 3"	
Avg. Temp., °F	Avg. Expansion, μin./in.
74	0
33	- 800
8	- 1433
- 19	- 2033
- 55	- 2733
- 73	- 3033
-101	- 3667
- 70	- 3367
- 11	- 3067
26	- 2800
59	- 2000
75	- 1433
† 75	0
104	1166
144	3333
286	18900
205	10333
295	19500
320	31233
327	32900
356	57833
407	*125833
76	98700

* Limit of dial gage reached so run was stopped. Bubbles were produced in the material, and the dial gage would show a great expansion as the bubble formed and then a contraction when the bubble burst.

† Dial gage rezeroed.

Table 31

Thermal Expansion Data for Laminate, 40 RPD Asbestos, DC-2106 Silicone Resin
SRI No. 10

Expansion Parallel to Panel Specimen, 2 Pieces 3" Long x 1" Wide x $\frac{1}{8}$" Thick Approx. Clamped Together		Expansion Normal to Panel Specimen, 24 - $\frac{3}{4}$" Dia. Disks Stacked to 3" Approx.	
Avg. Temp., °F	Avg. Expansion, μin./in.	Avg. Temp., °F	Avg. Expansion, μin./in.
78	0	79	0
32	- 167	41	- 1000
- 4	- 267	2	- 1867
- 39	- 400	- 32	- 2367
- 69	- 533	- 54	- 2633
-102	- 600	- 74	- 2900
- 69	- 533	-102	- 3233
- 33	- 433	- 51	- 2633
10	- 267	- 13	- 2267
50	- 133	20	- 1567
81	0	39	- 1000
* 76	0	79	+ 267
111	100	* 76	0
150	167	110	1533
199	400	153	4500
249	533	203	7833
301	800	255	10433
342	900	295	11967
409	1133	349	14133
438	1200	394	16533
442	1167	455	19533
489	1367	503	22667
539	1567	552	26267
587	1700	608	30333
660	1867	649	34333
711	1867	698	36867
770	1833	739	38367
506	700	65	4200
65	- 267		

* Dial gage rezeroed.

Table 32

Thermal Expansion Data for Laminate, YM-31A Glass Fabric, CTL-91 LD Phenolic Resin, Resin Content 31% by Weight
SRI No. 11

Expansion Parallel to Panel Specimen, 2 Pieces 3" Long x $\frac{7}{8}$" Wide x $\frac{1}{8}$" Thick Approx. Clamped Together		Expansion Normal to Panel Specimen, $\frac{7}{8}$" Squares Stacked to 3" Approx.	
Avg. Temp., °F	Avg. Expansion, µin./in.	Avg. Temp., °F	Avg. Expansion, µin./in.
76	0	77	0
33	- 67	54	- 433
- 1	- 300	33	- 733
- 44	- 633	12	- 967
- 85	- 933	- 17	-1300
-103	-1067	- 46	-1633
- 68	- 967	- 75	-1967
- 38	- 833	-101	-2267
- 7	- 667	- 85	-2000
19	- 533	- 53	-1677
71	- 133	- 25	-1400
74	- 133	12	-1033
* 74	0	37	- 677
111	133	76	- 200
158	400	* 74	0
224	733	107	300
248	967	162	1000
299	1300	213	1633
391	1633	276	1933
437	1800	334	1933
502	2067	368	2100
543	2133	391	2000
592	2167	443	2867
642	2100	491	5467
712	2067	529	8167
523	2100	559	9000
75	-2700	605	6967
		643	5633
		78	-1033

* Dial gage rezeroed.

Table 33

Thermal Expansion Data for Laminate, YM-31A Glass Fabric, Epon 1031 Epoxy Resin
Resin Content 22% by Weight
SRI No. 12

Expansion Parallel to Panel Specimen, 2 Pieces 3" Long x 7/8" Wide x 1/8" Thick Approx. Clamped Together		Expansion Normal to Panel Specimen, 7/8" Squares Stacked to 3" Approx.	
Avg. Temp., °F	Avg. Expansion, µin./in.	Avg. Temp., °F	Avg. Expansion, µin./in.
78	0	77	0
43	- 167	24	- 233
8	- 367	- 5	- 433
- 34	- 633	- 46	- 633
- 64	- 833	- 76	- 767
- 93	-1000	-103	- 900
-103	-1033	- 70	- 1567
- 65	- 967	-103	- 1700
- 26	- 667	- 54	- 1467
18	- 367	- 3	- 1067
77	+ 67	26	- 767
* 67	0	77	- 100
97	133	* 67	0
156	467	112	367
211	700	157	833
258	800	213	1100
303	833	270	733
364	1000	313	1033
402	1100	351	1567
452	1267	416	3567
500	1433	444	4700
551	1633	495	6800
601	1667	546	9900
666	1600	601	20500
692	1533	670	43567
		366	24133
		281	23000
		170	21567
		81	21133

* Dial gage rezeroed.

Table 34

Thermal Expansion Data for Laminate, R/M 42 RPD Asbestos, R/M High Heat Resistant Phenolic Resin. Resin Content 25-30% by Weight
SRI No. 13

Expansion Parallel to Panel Specimen, 2 Pieces 3" Long x 1" Wide x $\frac{1}{8}$" Thick Approx. Clamped Together		Expansion Normal to Panel Specimen, 20 - $\frac{3}{4}$" Dia. Disks Stacked to 3" Approx.	
Avg. Temp., °F	Avg. Expansion, µin./in.	Avg. Temp., °F	Avg. Expansion, µin./in.
74	0	74	0
34	- 133	57	- 200
- 27	- 333	18	- 767
- 63	- 433	- 15	-1233
- 79	- 500	- 44	-1600
-102	- 567	- 63	-1833
- 75	- 500	- 80	-2067
- 38	- 400	-100	-2300
16	- 233	- 77	-2167
41	- 167	- 30	-1767
73	- 33	29	-1038
* 70	0	60	- 500
100	33	73	- 333
176	267	* 70	0
208	333	113	667
255	467	170	1733
307	567	198	2233
368	733	247	2467
405	833	304	2700
461	933	348	2500
510	1033	404	3200
546	1100	446	4100
599	1200	499	5000
651	1367	535	4933
700	1533	595	3433
496	767	649	3700
306	100	699	7733
73	- 500	511	- 66
		322	-4267
		79	-8167

* Dial gage rezeroed.

Table 35

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Unidirectional Laminate, Scotchply XP-125 Special Resin Content 30% ± 1% by Weight, 14" x 14" Specimen, Average Thickness = 0.122" SRI No. 1-1			
Average Mean Temp., ° F	Average Δt ° F	Total Heat Input Watts	K Btu/hr ft² ° F/in.
- 55	22.0	32.7	0.714
94	28.0	52.6	0.906
196	86.0	198.5	1.107
281	128.5	331.0	1.238
357	166.5	463.0	1.335
436	74.5	185.8	1.197
527	107.5	221.7	0.989

Table 36

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Isotropic Laminate, Scotchply XP-125 Special Resin Content 30% ± 1% by Weight, 14" x 14" Specimen, Average Thickness = 0.122" SRI No. 1-2			
Average Mean Temp., °F	Average Δt °F	Total Heat Input Watts	K Btu/hr ft² °F/in.
- 45	27.5	41.7	0.713
108	35.0	65.0	0.872
119	39.5	87.0	1.035
197	75.5	176.6	1.095
214	90.5	218.2	1.130
300	128.5	373.0	1.361
445	76.0	217.9	1.345
527	100.5	274.0	1.276
*337	58.0	147.8	1.193

* Run made after material had been to top temperature.

Table 37

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Molded Panel, Chopped 181 Glass Fabric, A-1100 Finish, CTL-91 LD Phenolic Resin, 8" x 8" Specimen in 14" x 14" Asbestos Board, Specimen Thickness = 0.281" SRI No. 2			
Average Mean Temp., °F	Average Δt °F	Total Heat Input Watts	K Btu/hr ft^2 °F/in.
101	41.0	48.8	1.280
232	167.5	223.0	1.435
414	141.5	218.5	1.661
541	185.0	274.2	1.602
554	192.5	286.2	1.602
*421	144.0	183.6	1.375
*593	208.0	275.3	1.422
*167	46.5	50.6	1.172

* These values were obtained after material had been to highest temperature.

Table 38

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Foam Core, Dow-Corning Silicone R-7002, Fully Cured, 14" x 14" Specimen, Average Thickness = 0.688" SRI No. 3			
Average Mean Temp., ° F	Average Δt ° F	Total Heat Input Watts	K Btu/hr ft² ° F/in.
122	79.5	11.2	0.371
237	256.5	55.1	0.568
311	311.5	84.7	0.718
510	428.5	167.4	1.031
553	439.0	182.0	1.094
704	475.0	266.0	1.478

Table 39

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Molded Panel, Fiberite 4030-190, Glass Fiber, Phenolic Resin, 8" x 8" Specimen in 14" x 14" Asbestos Board, Specimen Thickness = 0.230" SRI No. 4			
Average Mean Temp., ° F	Average Δt ° F	Total Heat Input Watts	K Btu/hr ft² ° F/in.
- 54	26.0	15.5	0.585
- 54	24.0	15.7	0.636
107	35.5	41.9	1.137
206	88.5	113.1	1.231
214	90.0	115.5	1.231
303	77.0	117.7	1.465
407	108.0	160.6	1.427
512	143.0	230.0	1.548
613	169.5	284.5	1.613
780	241.0	419.0	1.670

Table 40

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Molded Panel, Coast F-130 Chopped Glass Fiber, Silicone Resin, 8" x 8" Specimen in 14" x 14" Asbestos Board, Specimen Thickness = 0.273" SRI No. 5			
Average Mean Temp., ° F	Average Δt ° F	Total Heat Input Watts	K Btu/hr ft² ° F/in.
- 73	23.0	14.4	0.657
104	35.0	41.6	1.372
262	193.0	230.0	1.310
454	161.0	215.5	1.402
633	215.5	337.0	1.635
*320	107.0	127.0	1.242
*183	49.5	58.5	1.020

* These values were obtained after material had been to highest temperature.

Table 41

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Laminate, Astrolite, Random Reinforcement $\frac{1}{2}$" Squares of 1201V Cloth, SC-1008 Phenolic Resin, 8" x 8" Specimen in 14" x 14" Asbestos Board, Specimen Thickness = 0.132" SRI No. 6			
Average Mean Temp., °F	Average Δt °F	Total Heat Input Watts	K Btu/hr ft² °F/in.
- 61	18.0	26.5	0.745
105	33.0	69.3	1.061
218	99.0	239.2	1.222
333	164.5	439.0	1.351
481	105.0	264.0	1.276
627	138.0	361.5	1.328
725	162.5	439.0	1.369
*563	130.0	306.0	1.191
*454	105.5	242.0	1.165

* These values were obtained after material had been to highest temperature.

Table 42

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Laminate, Astrolite, Refrasil 184 Weave, SC-1008 Phenolic Resin, 14" x 14" Specimens x 0.126" Thick SRI No. 7-1			
Average Mean Temp., ° F	Average Δt ° F	Total Heat Input Watts	K Btu/hr ft² ° F/in.
- 61	18.5	27.4	0.716
111	29.5	65.0	1.065
193	70.0	172.0	1.189
313	140.5	372.0	1.280
447	78.5	206.2	1.271
551	94.5	273.0	1.396
730	127.0	377.0	1.435
*656	118.5	335.0	1.369
*465	85.0	219.5	1.249

* These values were obtained after material had been to highest temperature.

Table 43

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Laminate, Edgewise Layup with Thickness in Warp Direction, Astrolite, Refrasil 184 Weave, SC-1008 Phenolic Resin, 8" x 8" Specimen in 14" x 14" Asbestos Board, Specimen Thickness = 0.132" SRI No. 7-2			
Average Mean Temp., ° F	Average Δt ° F	Total Heat Input Watts	K Btu/hr ft² ° F/in.
- 65	18.0	27.4	0.731
105	29.5	71.1	1.158
204	90.0	255.5	1.361
308	161.5	464.7	1.380
400	81.0	255.0	1.510
521	100.0	344.0	1.651
733	148.0	481.0	1.560
*625	131.0	400.0	1.466
*465	99.5	286.1	1.380

* These values were obtained after material had been to highest temperature.

Table 44

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Laminate, CTL 37-9X Phenolic Resin, 181 "E" Glass Fabric, Regular Layup, 14" x 14" Specimens x 0.132" Thick SRI No. 8-1			
Average Mean Temp., ° F	Average Δt ° F	Total Heat Input Watts	K Btu/hr ft² ° F/in.
- 57	19.5	27.7	0.719
103	30.0	64.1	1.081
183	71.0	168.8	1.203
317	139.0	372.5	1.360
450	73.5	210.9	1.455
586	97.0	296.0	1.545
730	127.5	377.0	1.500
*614	112.5	309.5	1.392
*468	86.5	221.5	1.295

* These values were obtained after material had been to highest temperature.

Table 45

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Laminate, 181 "E" Glass Fabric, CTL 37-9X Phenolic Resin, Edgewise Layup with Thickness in Warp Direction, 8" x 8" Specimen in 14" x 14" Asbestos Board, Average Thickness = 0.699" SRI No. 8-2			
Average Mean Temp., ° F	Average Δt ° F	Total Heat Input Watts	K Btu/hr ft^2 ° F/in.
- 64	24.5	16.2	1.770
102	23.0	18.5	2.155
215	95.5	96.1	2.700
316	152.0	174.2	3.075
459	233.5	299.6	3.440
554	209.5	271.5	3.460
701	270.5	356.0	3.535
*561	209.5	257.0	3.290
*377	139.5	157.0	3.015

* These values were obtained after material had been to highest temperature.

Table 46

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Laminate, 181 "E" Glass Fabric, CTL 37-9X Phenolic Resin, Edgewise Layup with Thickness at 45° of Warp Direction, 10" x 10" Specimen in 14" x 14" Asbestos Board, Average Thickness = 0.708" SRI No. 8-3			
Average Mean Temp., °F	Average Δt °F	Total Heat Input Watts	K Btu/hr ft² °F/in.
- 58	35.0	18.8	1.455
116	40.5	24.3	1.628
223	113.0	76.9	1.845
330	135.8	135.8	2.245
458	167.5	171.1	2.770
572	209.0	221.5	2.870
702	255.0	283.0	3.010
*547	193.5	197.7	2.770
*396	139.5	131.5	2.560

* These values were obtained after material had been to highest temperature.

Table 47

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Molded Panel, SN-19 Nylon, CTL-91 LD Phenolic Resin, 8" x 8" Specimen Made of Four 4" x 4" Pieces in 14" x 14" Asbestos Board, Average Thickness = 0.265" SRI No. 9			
Average Mean Temp., °F	Average Δt °F	Total Heat Input Watts	K Btu/hr ft² °F/in.
- 68	26.0	203.0	0.794
101	43.0	54.9	1.295
201	136.0	189.0	1.411
298	235.5	314.0	1.360
451	178.5	228.5	1.302
556	241.5	295.0	1.245
732	307.0	349.0	1.159
*559	242.0	188.5	0.791
*362	160.5	102.0	0.646

* These values were obtained after material had been to highest temperature.

Table 48

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Laminate, 40 RPD, DC-2106 Silicone Asbestos Laminate, 12" x 12" Specimen in 14" x 14" Asbestos Board, Specimen Thickness = 0.121" SRI No. 10			
Average Mean Temp., ° F	Average Δt ° F	Total Heat Input Watts	K Btu/hr ft² ° F/in.
- 65	16.0	25.7	0.746
102	26.0	73.9	1.320
193	74.5	230.5	1.438
298	129.5	430.0	1.542
437	70.0	233.5	1.549
569	93.5	330.0	1.640
721	126.0	430.0	1.585
*547	96.0	306.0	1.480
*340	59.0	175.5	1.380

* These values were obtained after material had been to highest temperature.

Table 49

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Laminate, YM-31A Glass Fabric, CTL-91 LD Phenolic Resin, 14" x 14" Specimen, Average Thickness = 0.116" SRI No. 11			
Average Mean Temp., °F	Average Δt °F	Total Heat Input Watts	K Btu/hr ft² °F/in.
- 57	19.0	35.4	0.828
104	16.0	49.0	1.361
222	83.0	288.0	1.545
325	142.0	542.0	1.695
485	55.0	236.0	1.910
586	72.0	288.5	1.785
*487	58.5	216.0	1.640
*370	47.5	171.0	1.600

* These values were obtained after material had been to highest temperature.

Table 50

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Laminate, YM-31A Glass Fabric, CTL-91 LD Phenolic Resin, 14" x 14" Specimen, Average Thickness = 0.110" SRI No. 12			
Average Mean Temp., °F	Average Δt °F	Total Heat Input Watts	K Btu/hr ft² °F/in.
- 51	15.5	36.3	0.988
103	14.5	49.9	1.450
231	71.0	274.0	1.630
347	115.0	496.0	1.825
510	57.0	233.8	1.730
599	80.0	288.5	1.521
*479	64.5	222.3	1.455
*374	47.0	148.8	1.335

* These values were obtained after material had been to highest temperature.

Table 51

Thermal Conductivity Data 8" x 8" Area (64 sq. in.)

Laminate, R/M Style 42 RPD Asbestos Mat, R/M High Heat Resistant Phenolic, 14" x 14" Specimen x 0.147" Thick SRI No. 13			
Average Mean Temp., ° F	Average Δt ° F	Total Heat Input Watts	K Btu/hr ft² ° F/in.
- 51	17.0	25.7	0.854
115	29.5	70.8	1.351
218	76.5	206.0	1.520
345	136.0	399.8	1.659
477	76.5	255.5	1.881
608	95.0	332.5	1.975
706	114.0	394.0	1.950
*546	91.0	290.0	1.800
*406	67.0	204.5	1.723

* These values were obtained after material had been to highest temperature.

SOUTHERN RESEARCH INSTITUTE, Birmingham, Alabama, THE THERMAL PROPERTIES OF SOME PLASTIC PANELS, by Paul T. Howse, Jr., C. D. Pears and Sabert Oglesby, Jr., January 1961. 137p. incl. figs. and tables. (Project 7360; Task 73603) (WADD TR 60-657) (Contract AF 33(616)-6073)

Unclassified report

The thermal expansion, specific heat, and thermal conductivity were measured for twelve different resin-reinforcement combinations, some of which had variations in reinforcement orientations. These properties were also determined for one foam core. The

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