U. S. FOREST SERVICE
RESEARCH PAPER
FPL 36
AUGUST 1965

THERMAL CONDUCTIVITY-TEMPERATURE RELATIONSHIP FOR NINE GLASS AND ASBESTOS FIBER-REINFORCED AIRCRAFT PLASTICS

FOREST PRODUCTS LABORATORY | FOREST SERVICE | U.S. DEPARTMENT OF AGRICULTURE | MADISON, WIS

This Report is One of a Series Issued in Cooperation with the
MIL-HDBK-17 WORKING GROUP ON PLASTICS FOR FLIGHT VEHICLES
of the Departments of the
AIR FORCE, NAVY, AND COMMERCE

SUMMARY

The coefficients of thermal conductivity for mean temperatures ranging from about –300° to +500° F. were determined for nine combinations of asbestos fiber or glass fiber and cloth reinforcement, with epoxy, phenolic, silicone, phenyl silane, and epoxy–novalac resins. Values of conductivity are only valid to maximum mean temperatures between +300° and 350° F. (depending on resin) because of thermal degradation of the plastic due to "hot–side" temperatures in excess of mean temperature.

Values of thermal conductivity were obtained using a "heat meter" wherein samples were placed in a stack consisting of heated plate, calibrated heat meter of fused silica, specimen, a second calibrated meter of fused silica, and a heat sink. Values of thermal conductivity (k) for a mean temperature of 0° F. ranged from 1.73 B.t.u., inch of thickness per hour, square foot, degree Fahrenheit difference in temperature for a silicone–asbestos plastic with a specific gravity of 1.52 to a conductivity of 3.60 for the DEN epoxy–novalac, glass–fabric–reinforced plastic with a specific gravity of 1.99. Approximate conductivity–specific gravity relationships are presented for mean temperatures of –200°, 0°, and +200° F. Values of thermal conductivity for each plastic are presented for mean temperatures of –250°, –200°, –100°, 0°, +100°, +200°, and +300° F. for more accurate estimates of heat flow.

THERMAL CONDUCTIVITY-TEMPERATURE RELATIONSHIP FOR NINE GLASS AND ASBESTOS FIBER-REINFORCED AIRCRAFT PLASTICS[1]

By

WAYNE LEWIS, Engineer

FOREST PRODUCTS LABORATORY[2]
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

INTRODUCTION

Thermal conductivity determinations have been made for many of the reinforced plastics used in aircraft. In some applications of use, heat dissipation is required. In others, heat insulation may be desired. The continuing development of new combinations of binder and reinforcement to satisfy other property needs of these materials has made it desirable to continue the evaluation of heat-flow characteristics of the reinforced plastics.

The Forest Products Laboratory was requested by the Military Handbook-17 Working Group to consider the evaluation of some of the newer plastics and a few of older origin that never had been evaluated. Examination of the Laboratory guarded-hot-plate equipment, which had been designed and constructed to evaluate low-conductivity materials like wood at the mean temperatures usually encountered in buildings, indicated that it could not be readily modified to accurately measure heat flow in the higher conductivity plastics nor at temperatures as high as required for high-speed aircraft applications.

---

[1] This Paper is another progress report in the series in cooperation with the Military Handbook-17 Working Group (ANC-17, Item 64-2) prepared and distributed by the Forest Products Laboratory. This work was performed under U.S. Navy Bureau of Naval Weapons Order IPR 19-65-8005 WEPS and U.S. Air Force D.O. 33(615) 65-5002. Trade names are included at the request of the Working Group. Results here reported are preliminary and may be revised as additional data become available.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Consequently, the Laboratory was requested to determine if the work could be done elsewhere under the supervision of the Forest Products Laboratory, or if additional equipment could be purchased to make such evaluations. Cost of equipment was in excess of that warranted for a study of the size contemplated, so the work was done under contract by the Dynatech Corporation, 17 Tudor Street, Cambridge, Mass.

This report describes the material included in the evaluations, the evaluation procedure used, and analyzes the results.

DESCRIPTION OF MATERIALS AND PREPARATION OF SPECIMENS

The material included in the evaluations, generally, came from material submitted to the Forest Products Laboratory for evaluation of strength and physical properties, hence can be considered as matched to that material. The only exception was that two samples, one low– and one regular–density plastic, were specially prepared by personnel in the Research and Technology Division, Air Force Systems Command, Wright–Patterson Air Force Base, so the study could be completed as planned. This plastic was the one made from parallel laminated S–glass fabric with the DEN 438 epoxy–novalac resin.

The plastics included in the evaluations are described as follows:

Identification	Description
SC–E	Resin, Scotchply 1002; reinforcement, unwoven E–glass fiber with alternate plies oriented at ±5° to the principal axis.
SC-S	Resin, Scotchply 1002; reinforcement , unwoven S–glass fibers with alternate plies oriented at 25° to the principal axis.
EP–E	Resin, epoxy ERSB-0111; reinforcement, E–glass 181 fabric, parallel laminated.
EP–S	Resin, epoxy ERSB–0111; reinforcement, S–glass 181 fabric, parallel laminated.
PH–A	Resin, phenolic R/M Style 984 RPD; reinforcement, asbestos felt R/M Pyrotex Style 41 RPD, parallel laminated.
S1–A	Resin, silicone DC 2106; reinforcement, asbestos felt R/M Pyrotex Style 45 RPD, parallel laminated material, low density.

NA-S	Resin, Narmco 534; reinforcement, S-glass 181 fabric, parallel laminated.
DEN-S-L	Resin, Dow DEN 438; reinforcement, S-glass 181 fabric, parallel laminated, low density.
DEN-S-R	Resin, Dow DEN 438; reinforcement, S-glass 181 fabric, parallel laminated, regular density.

The S-glass fiber was all 994. Specimens were prepared in pairs, although only one was actually used for the evaluation. The extra one was a spare in case the original was damaged before the completion of the evaluation.

Specimens were each 2-1/2 inches square with a minimum nominal thickness of 1/4 inch. Two materials, the phenolic and silicone asbestos, were only available in thicknesses of 1/8 inch, so two pieces were laminated together using resins similar to those in the plastic to provide the nominal thickness of 1/4 inch.

Surfaces of each specimen were precision ground, so that variation in thickness was less than 0.002 inch and so surfaces were smooth to minimize resistance to heat flow. It is believed that these techniques minimized errors in values of heat flow that could be attributed to poor contact or temperature measurement if a thinner specimen was used.

EVALUATION PROCEDURE

The heat-flow meter apparatus used is shown in figure 1. In using this apparatus the thermal conductance of a material is obtained by placing it in a stack between two heat meters (calibrated specimens of known conductance) and passing heat through the stack. Temperatures of each of the interfaces are determined. From these interface temperatures and the fact that the heat flux is the same through each layer and the conductance of the heat meters are known, it is possible to calculate conductance of the specimen. In principle, the heat meter conformed to the requirements of ASTM C 518-63 T, Thermal Conductivity by the Heat Flow Meter.

Loss of heat laterally was minimized by a guard ring heater (shown in the lower left of fig. 1) which is maintained at the mean temperature of the specimen. The use of the two heat meters, one above and one below the specimen, permits averaging the results; this largely compensates for any heat loss or gain laterally in the meters themselves.

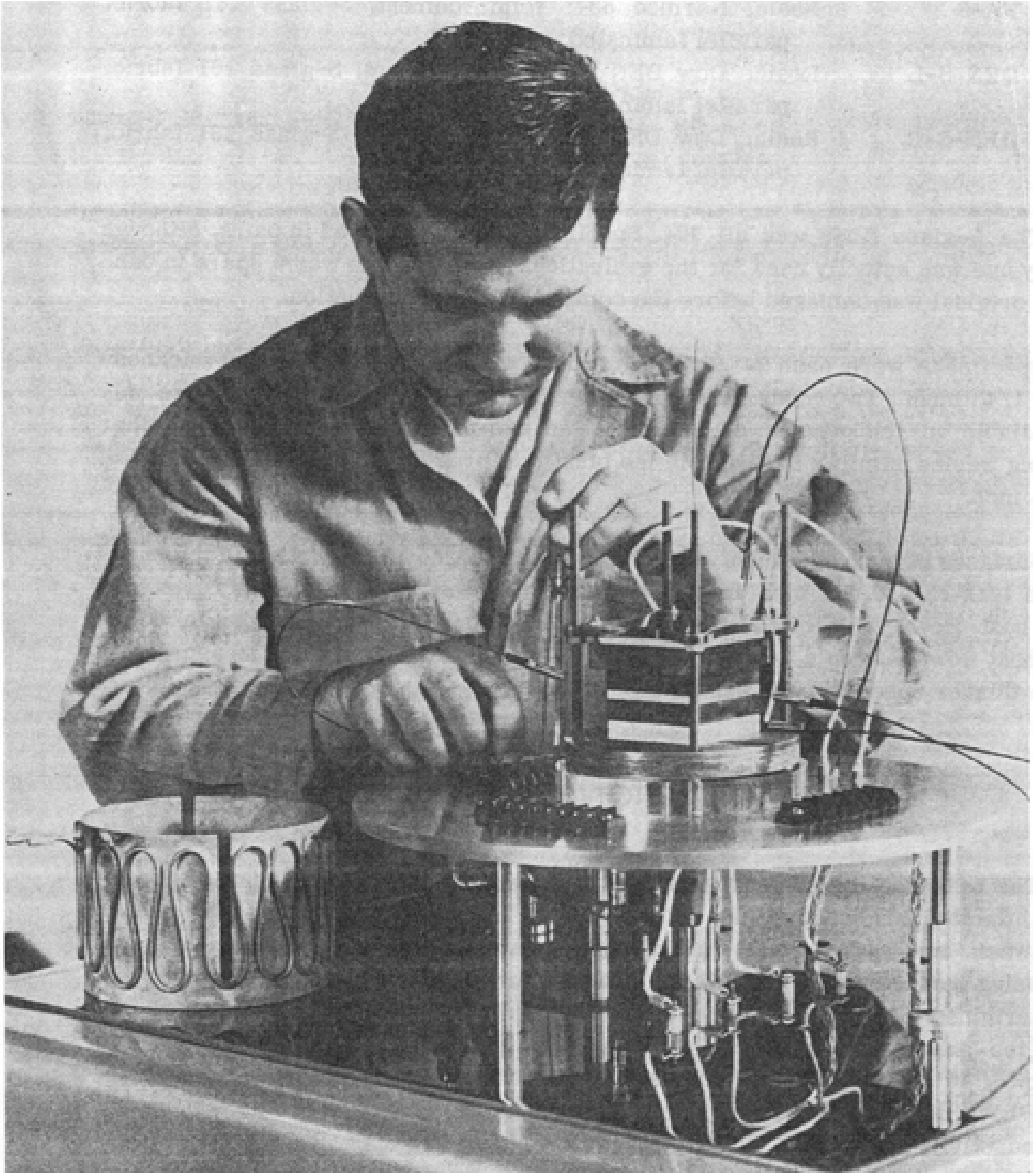


Figure 1.––Heat meter apparatus for determining thermal conductivity of aircraft plastics.

ZM 128 442

Photo courtesy of Dynatech Corp.

The actual stack arrangement used is shown schematically in figure 2. The aluminum plates were used to improve lateral heat distribution from the heaters. The auxiliary heater was used for fine temperature control. The heat meters were constructed of fused silica and were checked against calibration specimens of (1) Inconel 702 for temperatures below room temperature and (2) pyroceram above room temperature. Values for these materials were supplied by the National Bureau of Standards.

Values for each material were obtained at six mean temperatures. They were nominally –250°, –100°, +100°, +300°, +400°, and +500° F. Liquid nitrogen was used as the coolant to obtain values below 100° F. and water was used for those of 100° F. and above. In each instance, the auxiliary heater was used to adjust the temperature on the cold side of the specimen.

It was the practice to start determinations of each specimen at the lowest temperature and to raise the temperatures as the test progressed. Deterioration of the materials at temperatures above about 400° F. was evident from values obtained and the discoloration (darkening) of specimens at the end of the evaluation. Determinations at each set of conditions were made after steady–state conditions were attained.

PRESENTATION AND DISCUSSION OF RESULTS

The results of the evaluation of the nine materials are tabulated in table 1. Included are material identification, resin content as determined by crucible burnout in an electric furnace, specific gravity and the values of thermal conductivity for each of the actual mean temperatures. These results are plotted in figures 3 and 4. Examination of the figures will show the increasing function of conductivity with the increase in mean temperature, to a temperature where thermal breakdown of the resin in the plastic causes an improvement in insulating factor. Usually a smooth curve is drawn through the points in that range. Because thermal degradation is a function related to duration of exposture, this portion of each curve is shown as a dotted straight line projected back to where it intersects the smooth curve indicated by the ascending points.

Values of thermal conducticvity at even units of mean temperature were "picked off" the smooth curves drawn through the plotted points in figures 3 and 4. values for mean temperatures of –250°, –200°, –100°, 0°, +200°, and +300° F. are presented in table 2. Examination of the thermal conductivity–mean temperature curves and the values in tables 1 and 2 indicates that conductivity is a

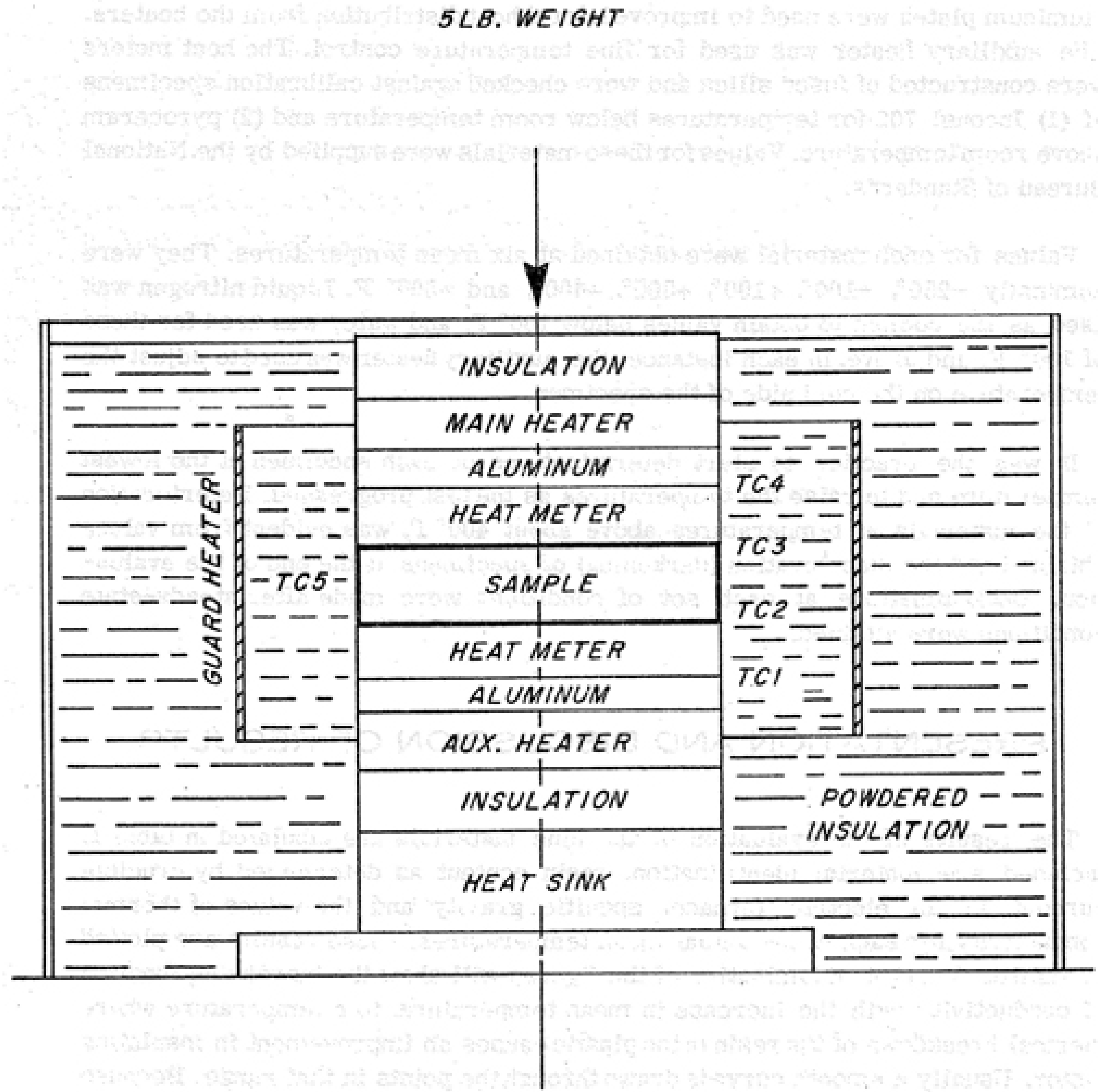


Figure 1.––Schemtic diagram of assembly for determining thermal conductivity.

Table 1. --Results of thermal conductivity determinations for various reinforced plastics at different mean temperatures

Specimen	Resin		Reinforcement		Thickness	Specific gravity[1]	Mean temperature	Thermal conductivity "k"
	Kind	Content	Kind	Orientation				
		Percent			In.		°F.	B.t.u. in. per hr., sq. ft., °F.
SC-E	Scotch-ply 1002	32.4	Unwoven E-glass	±5°	0.267	1.82	-267	1.20
							- 95	2.03
							+102	2.66
							+304	3.12
							+401	2.62
							+498	1.98
SC-S	Scotch-ply 1002	34.1	Unwoven S-glass	±5°	.253	1.81	-250	1.68
							-127	2.18
							+102	3.14
							+306	3.50
							+398	3.18
							+508	2.45
EP-E	Epoxy ERSB-0111	36.0	E-glass 181 fabric	Parallel	.201	1.92	-284	1.90
							-100	2.59
							+100	3.00
							+304	3.28
							+399	3.24
							+490	2.86
EP-S	Epoxy ERSB-0111	35.0	S-glass 181 fabric	Parallel	.231	1.82	-279	1.61
							-118	2.14
							+112	2.98
							+305	3.24
							+407	3.25
							+491	2.78

Table 1.--Results of thermal conductivity determinations for various reinforced plastics at different mean temperatures (Cont.)

Specimen	Resin		Reinforcement		Thickness	Specific gravity[1]	Mean temperature	Thermal conductivity "k"
	Kind	Content	Kind	Orientation				
		Percent			In.		°F.	B.t.u. in. per hr., sq. ft., °F.
SI-A	Silicone	20.0[2]	Asbestos	Parallel	.271	1.52	-268	1.00
							-128	1.42
							+101	1.90
							+303	2.16
							+400	2.09
							+498	2.03
NA-S	Narmco 534 phenylsilane	29.6	S-glass 181 fabric	Parallel	.252	1.81	-229	1.97
							- 99	2.45
							+105	3.10
							+300	3.42
							+402	3.43
							+500	3.22
DEN-S-R	DEN 438 Epoxy Novalac	19.3	S-glass 181 fabric	Parallel	.245	1.99	-245	2.33
							- 99	3.16
							+ 99	4.01
							+300	4.86
							+400	4.85
							+500	4.46
DEN-S-L	DEN 438 Epoxy Novalac	32.0	S-glass 181 fabric	Parallel	.277	1.65	-251	1.26
							-108	1.98
							+ 95	2.50
							+299	2.52
							+398	2.47
							+495	2.21

---

[1] Based on weight and volume at prevailing laboratory conditions.

[2] Volatile component only.

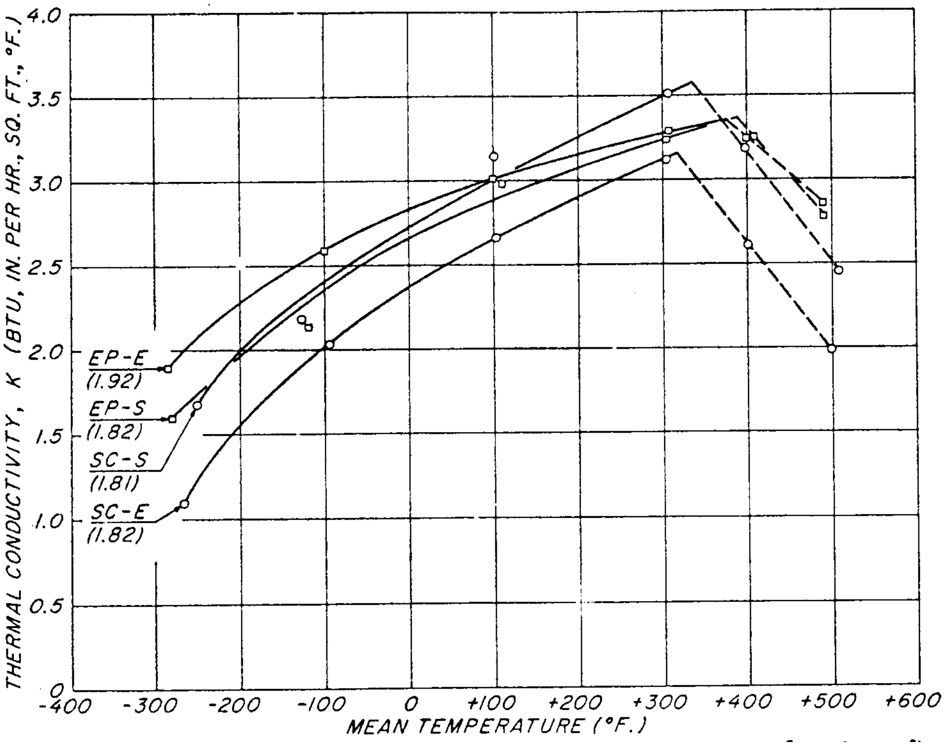


Figure 3.--Thermal conductivity-mean temperature curves for aircraft plastics SC-E, SC-S, EP-S, and EP-E. Values in parentheses are specific gravities.

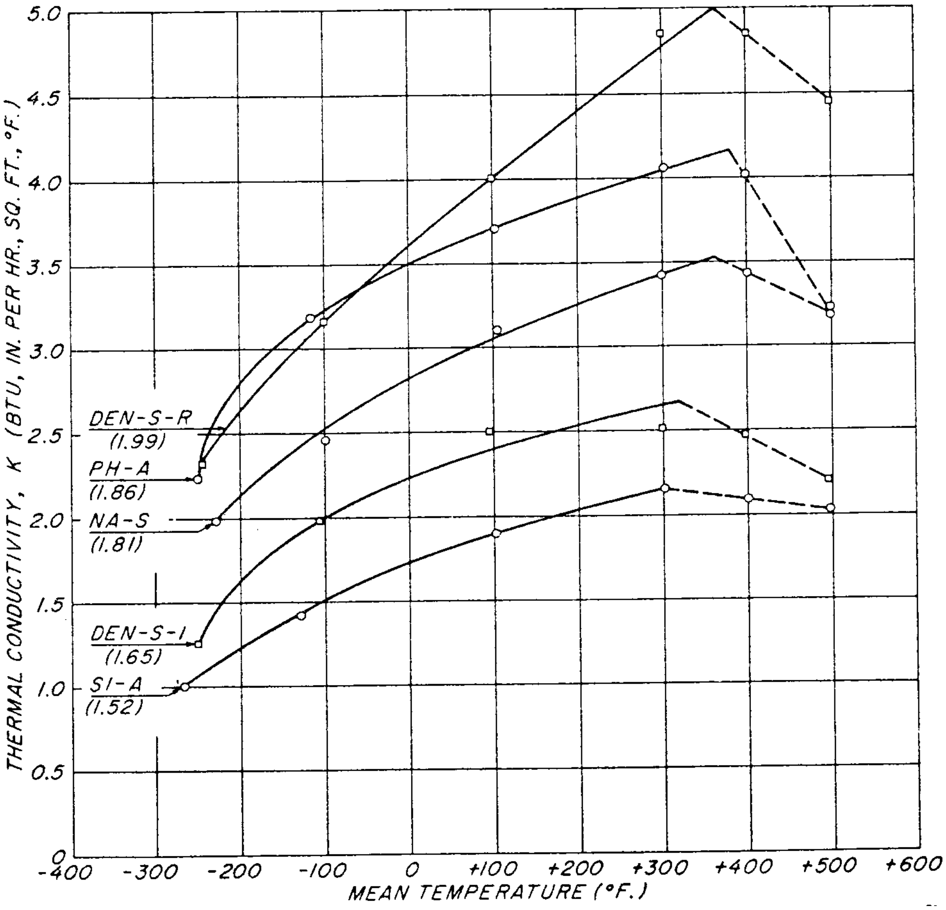


Figure 4.--Thermal conductivity-mean temperature curves for aircraft plastics SI-A, DEN-S-L, NA-S, PH-A, and DEN-S-R Values in parentheses are specific gravities.

Table 2.--Values of thermal conductivity at selected mean temperatures for various reinforced plastics

Material	Specific gravity	"k" at a mean temperature of -250°	-200°	-100°	0°	+100°	+200°	+300°
		B.t.u. in. per hr., sq. ft., °F.						
Scotchply, unwoven E-glass	1.82	1.24	1.56	2.01	2.37	2.65	2.89	3.12
Scotchply, unwoven S-glass	1.81	1.68	1.99	2.41	2.72	3.00	3.26	3.49
Epoxy, E-glass fabric	1.92	2.08	2.28	2.59	2.83	3.01	3.15	3.27
Epoxy, S-glass fabric	1.82	1.74	1.96	2.36	2.66	2.88	3.07	3.23
Phenolic, asbestos	1.86	2.25	2.80	3.22	3.49	3.70	3.88	4.04
Silicone, asbestos	1.52	1.07	1.23	1.51	1.73	1.90	2.03	2.15
Narmco 534, S-glass fabric	1.81	1.87	2.14	2.53	2.82	3.05	3.25	3.42
DEN 438, S-glass fabric	1.99	2.30	2.63	3.15	3.60	4.01	4.40	4.28
DEN 438, S-glass fabric	1.65	1.25	1.62	2.00	2.23	2.40	2.53	2.65

function of density as well as formulation. The two materials, silicone–asbestos and the low–density DEN–glass plastics, with specific gravity values of 1.52 and 1.65 respectively, have substantially lower values of thermal conductivity at most mean temperatures than the others with specific gravity values of 1.8 to 2.0.

For some purposes of design where absolute values of conductivity are not required, an approximate value of conductivity based on the mean temperature and the density of an aircraft plastic may be useful. Such relationships for the range of plastics included in this evaluation are presented in figure 5.

Combinations of resin and reinforcement were selected for the evaluations so some comparisons could be made of thermal conductivity where only one variable of composition was different. The analyses of such possible combinations follow, but they are only valid when densities and resin contents are approximately the same.

Materials SC–E and SC–S, Scotchply resin and unwoven glass fiber with either E– or S–glass fiber. Specific gravity and resin content was essentially the same for the two materials. The two curves (fig. 3) are essentially parallel, with the S–glass–reinforced plastic having a higher conductivity factor (poorer heat insulator) at all mean temperatures of about 0.4 B.t.u. in. per hr., sq. ft., °F. difference than the E–glass. This suggests that E–glass fiber in combination with resins will have lower values of thermal conductivity, other variables being equal.

Materials EP–E and EP–S, Epoxy ERSB–0111 resin and parallel–laminated 181–weave glass with either E– or S–glass fiber. Resin contents were essentially the same, but specific gravity values were substantially different, 1.82 for the plastic with S–glass and 1.92 for the one with E–glass. The slope of the curve for the S–glass–fabric–reinforced plastic was steeper than the one for the E–glass–fabric–reinforced plastic. Values of thermal conductivity were lower for the S–glass between –300° and +300° F. where the curves crossed, and higher for temperatures in excess of 300° F. Because the density of the plastic with E–glass reinforcement was substantially greater than for the one with S–glass cloth reinforcement, it is entirely possible that at the same density the “S–glass” curve would have been above the “E–glass” one for the entire range of temperatures. If so, the difference between the conductivity values observed for the “SC” specimens would be substantiated.

Materials EP–S and NA–S were nearly the same except for kind of resin. Both had S–glass fabric reinforcing, although amounts of resin differed more than would be considered ideal for comparisons. The epoxy (EP) material had 35 percent resin while the phenyl–silane material (NA) had about 30 percent

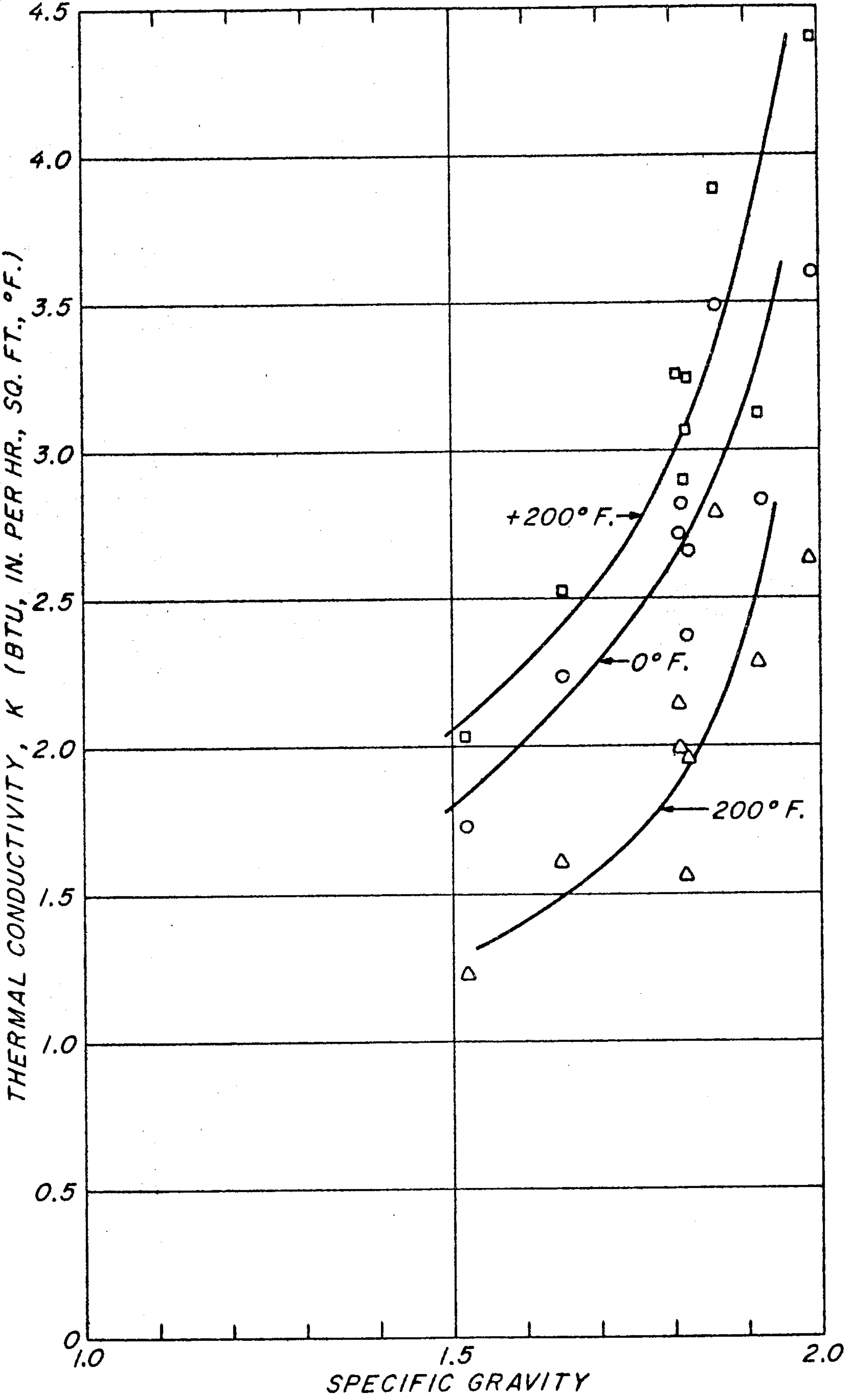


Figure 5.--Thermal conductivity-specific gravity relationship for mean temperatures of -200°, 0°, and +200° F.

resin. At 0° F. mean temperature the material with epoxy resin had a conductivity value of 2.66 as compared to 2.82 for the phenyl-silane. At other mean temperatures similar differences (6 to 9 percent) existed. Some of this difference can at least be attributed to percentages of difference in resin.

No other comparisons between materials appear to be advisable because of differences in density and amounts of resin.

HIGH-TEMPERATURE LIMITATIONS

Each of the curves presented in figures 3 and 4 show a reduction in conductivity at mean temperatures between 300° and 400° F. Temperatures on the hot surface of the specimens were about 15° F. higher than the mean values as is shown in table 3.

Degradation of plastics at high temperature as measured by thermal conductivity appears to begin at lower temperatures than when the index is measurable loss of weight or strength. This difference is plausible when the various forms of heat transfer that influence conductivity are considered. Conduction, and to a lesser extent convection and radiation, all influence the factor measured. Emissivity at contacting surfaces changes with discoloration. Since the degradation is in the resin it is interesting to note in figures 3 and 4 that similar or the same resins showed nearly equal “drop-off” points.

Table 3.--Hot-surface temperatures for mean temperatures that indicated thermal breakdown during conductivity determinations

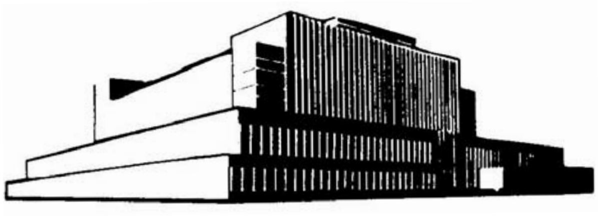
Material	Mean temperature	Hot-surface temperature
	°F.	°F.
SC-E	304	320
	401	420
	498	518
SC-S	306	320
	398	413
	508	526
EP-E	304	319
	399	413
	490	503
EP-S	305	320
	407	421
	491	504
PH-A	302	315
	399	413
	500	515
SI-A	303	326
	400	421
	498	519
NA-S	300	314
	402	416
	500	516
DEN-S-R	300	322
	400	423
	500	523
DEN-S-L	299	318
	398	418
	495	517

PUBLICATION LISTS ISSUED BY THE FOREST PRODUCTS LABORATORY

The following lists of publications deal with investigative projects of the Forest Products Laboratory or relate to special interest groups and are available upon request:

- Architects, Builders, Engineers, and Retail Lumbermen
- Box, Crate, and Packaging Data
- Chemistry of Wood
- Drying of Wood
- Fire Protection
- Fungus and Insect Defects in Forest Products
- Furniture Manufacturers, Woodworkers, and Teachers of Woodshop Practice
- Glue and Plywood
- Growth, Structure, and identification of Wood
- Logging, Milling, and Utilization of Timber Products
- Mechanical Properties of Timber
- Structural Sandwich, Plastic Laminates, and Wood-Base Components
- Thermal Properties of Wood
- Wood Fiber Products
- Wood Finishing Subjects
- Wood Preservation

Notes: Since Forest Products Laboratory publications are so varied in subject matter, no single catalog of titles is issued. Instead, a listing is made for each area of Laboratory research. Twice a year, December 31 and June 30, a list is compiled showing new reports for the previous 6 months. This is the only item sent regularly to the Laboratory's nailing roster, and it serves to keep current the various subject matter listings. Names may be added to the mailing roster upon request.



FOREST PRODUCTS LABORATORY
U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE --- MADISON, WIS.

In cooperation with the University of Wisconsin