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EFFECT OF THERMAL CYCLING ON TENSILE AND COMPRESSIVE STRENGTH OF REINFORCED PLASTIC LAMINATES

U. S. DEPARTMENT OF AGRICULTURE   FOREST SERVICE
FOREST PRODUCTS LABORATORY   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

This Paper presents the modulus of elasticity and strength values of four reinforced plastic laminates in tension and compression at room temperature and at 500° F. Prior to evaluation at these temperatures, the test specimens were exposed to thermal–shock cycling. Three of the laminates evaluated in this study were reinforced with 181-A1100 glass fabric and represented three resin systems: a phenolic resin (CTL 37–9X), an epoxy resin (ERSB–0111), and a phenyl–silane (Narmco 534). The fourth was a phenolic–asbestos laminate made of R/M Pyrotex felt style 41–RPD.

The effects of thermal–shock cycling on properties vary with the type of resin and reinforcement. In general, thermal–shock cycling had less effect on modulus of elasticity than on strength. Properties at room temperature tended to decrease after exposure to cycling, while the properties of most laminates evaluated at 500° F. were not seriously affected.

EFFECT OF THERMAL CYCLING ON TENSILE AND COMPRESSIVE STRENGTH OF REINFORCED PLASTIC LAMINATES [1]

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INTRODUCTION

The U.S. Forest Products Laboratory, in cooperation with the MIL-HDBK-17 Working Group on Plastics for Flight Vehicles of the Departments of the Air Force, Navy, and Commerce, has evaluated and reported the strength properties of various laminates of different combinations of resins and reinforcements at various elevated temperature levels and periods of exposure.[3,4,5,6] These studies furnished information on the effects of heating, for both short and long periods of time, on the strength properties of reinforced plastic laminates.

Another study[7] recently made for the Air Force Materials Laboratory presented data on the effects of repeated rapid heating and cooling (thermal-shock cycling) on the compressive strength of reinforced plastic laminates.

The purpose of the present study is to secure information concerning the effects of thermal-shock cycling on the compressive strength properties of additional reinforced plastic laminates and on the tensile properties of all the laminates.

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[1] This Paper is another in the series (ANC-17, Item 64-1) prepared and distributed by the Forest Products Laboratory under U.S. Navy Bureau of Naval Weapons Order No. 19-64-8004(WEPS) and U.S. Air Force Contract No. 33(657) 63-358. Proprietary names are given at the request of the MIL-HDBK-17 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.

[3] Boller, K.H. Strength properties of reinforced plastic laminates at elevated temperatures (CTL 37-9X resin and 181-A1100 glass fabric). ASD TR 61-482. 1962.

[4] Boiler, K.H. Strength properties of reinforced plastic laminates at elevated temperatures (Epoxy resin ERSB-0111 and 1.81-A1100 glass fabric). RTD-TDR-63-4154. 1963.

[5] Boiler, K.H. Strength properties of reinforced plastic laminates at elevated temperatures (Narmco 534 resin and 181-A1100 glass fabric). RTD-TDR-63-4091. 1963.

[6] Boiler, K.H. Strength properties of reinforced plastic laminates at elevated temperatures (Phenolic-asbestos, R/M Pyrotex felt style 41-RPD). WADD Technical Report 60-177, Part 1. 1960.

[7] Kimball, K.E. Effect of thermal shock cycling on the compressive strength of reinforced plastic laminates. AFML-TR-64-404. 1964.

MATERIALS

The laminates used in this investigation were from the same lots obtained for previous studies, and general fabrication information is included in the individual reports.[3,4,5,6] The four laminates used in the current study are:

A. CTL 37–9X phenolic resin reinforced with 181–A1100 glass fabric.[3]

B. ERSB–0111 epoxy resin reinforced with 181-A1100 glass fabric.[4]

C. Narmco 534 phenyl-silane resin reinforced with 181–A1100 glass fabric.[5]

D. Phenolic–asbestos R/M Pyrotex felt style 41-RPD.[6]

Laminates A and D are the same as those used in the previous study[7] of thermal cycling, which was limited to the evaluation of compressive strength properties after thermal cycling between room temperature and two elevated temperatures (350° and 500° F.).

TEST METHODS

In this study, tensile and compressive strength values were determined at both room temperature and 500° F. after thermal cycling between these temperature extremes. All specimens of the laminates studied were evaluated with the load applied parallel to the warp or machine direction of the reinforcement.

Tension Tests

Tensile strengths were evaluated using type II tension specimens (fig. 1) described in Test Method 1011 of Federal Test Method Standard No. 406. The rate of motion of the movable head of the loading machine was maintained at a rate of 0.04 inch per minute. Deformations were measured with a microformer equipped gage having a 2–inch–gage length (fig. 1) and both the load and deformation were recorded automatically.

Compression Tests

Compressive strengths were evaluated using dumbbell–shaped specimens the same as used in the previous study on thermal cycling.[7] The specimens were necked down from strips 1/8 by 3/4 by 3–1/8 inches to a net section 1/2 inch wide and 1–1/4 inches long with an arc of 2–inch radius in the transition portion. The 3–1/8–inch dimension was parallel to the warp of the reinforcement. The jig for supporting the specimens during loading (figs. 2, 3) was of the type described in Test Method 1021 of Federal Test Method Standard No. 406. The motion of the movable head of the loading machine was maintained at 0.008 inch per minute. Deformations were measured with a microformer equipped gage having a 1–inch–gage length and both load and deformation data were automatically recorded.

All tension and compression specimens were conditioned for at least 2 weeks in an atmosphere maintained at 73° F. and 50 percent relative humidity prior to thermal cycling or evaluating their strength properties.

Tests at 500° F.

Tension and compression specimens evaluated at 500° F. were heated with small, automatically controlled, nichrome wire heaters––one in contact with each face of the specimen, as shown in figures 1 and 2. The small size of the heaters permitted their use without interfering with normal loading procedures. A thermocouple, placed between each heater and specimen face, was connected to a control unit for maintaining a constant, preset temperature. Operation of the heaters and control unit was checked by using dummy specimens with thermocouples on the specimen faces and also embedded midway between the faces. Loading of the specimens was started 1 minute after power was applied to the heaters.

Control Specimens

Tension and compression specimens (10 each) were selected randomly from each material as controls. Five specimens of each type (tension and compression) were evaluated at room temperature and five at 500° F.

Thermal Cycling

Tension and compression specimens were exposed to thermal-shock cycling on the same equipment used in the previous study.[7] The equipment resembled a form of "carrousel" with an endless chain from which the specimens were suspended and could be cycled between the designated elevated temperature (500° F.) and room temperature. Figure 4 shows a tension and a compression specimen suspended from the drive chain and their position relative to the heat lamps. The chain carried the specimens between two banks of high intensity, quartz-tube heating lamps and then between drilled copper-tube manifolds which directed jets of air on the specimens to cool them to room temperature. Heating elements were wired to separate powerstats and a common automatic control unit. With this arrangement, a thermocouple placed midway between the lamps and in the same plane in which the specimens pass, served as the sensitive element to actuate the control unit for any set temperature. The quartz lamps were operated with a minimum of "off" time.

Lamp control settings were established by using dummy specimens of each material with thermocouples mounted in the net section of the specimens between the gage points. One thermocouple was partially embedded in each of the facings and one embedded midway between the faces. Several cycles were run at various settings of the control and powerstat units. These cut-and-try procedures were continued until the desired 500° F. mean temperature of the specimen was approximated.

Figures 5, 6, 7, and 8 show the average time-temperature curves for tension and compression specimens of the four types of laminates studied. Similar data were recorded for temperatures measured at the specimen faces and the maximum facing temperature is indicated in the figures. The curves for facing temperatures had the same shape as those presented but were offset slightly, indicating that a temperature gradient existed between the surface and center of the specimens during a thermal cycle. For glass-fabric reinforced specimens the gradient was less than 20° F., and for asbestos-fiber reinforced specimens was about 40° F.

DISCUSSION OF RESULTS

Average compressive strength values and loss in weight for the control specimens and those exposed to thermal-shock cycling are presented in table 1, and corresponding average tensile strength values are given in table 2. Because of the length of the tension specimens in relation to the size of the heater banks, the specimens could be heated only over the net section and, therefore, weight loss measurements were not made.

Weight losses of compression specimens (table 1) ranged from less than 1 percent to about 5 percent after exposure to thermal-shock cycling.

The modulus of elasticity, tensile strength, and compressive strength of the controls (zero cycles) at 560° F. were lower than the corresponding values at room temperature. The modulus of elasticity values in compression were reduced 21 to 29 percent and in tension 12 to 26 percent. Tensile strength values were reduced 6 to 25 percent and compressive strength values 43 to 76 percent.

Effects of Cycling

After 2,000 thermal-shock cycles, the initial modulus of elasticity values at room temperature were reduced 1 to 28 percent in tension and 1 to 18 percent in compression. Tensile strength at room temperature after 2,000 thermal-shock cycles was reduced 2 to 53 percent, while the compressive strength for the epoxy laminate was reduced 72 percent. In contrast to this latter reduction, the compressive strength of the phenyl-silane laminate increased 11 percent at room temperature after 2,000 thermal-shock cycles.

At 500° F. the mechanical propertics of the laminates, with the exception of the epoxy laminate, increased somewhat as thermal-shock cycling progressed. The maximum increase in modulus of elasticity in compression was 18 percent for the phenolic-asbestos laminate after 2,000 thermal-shock cycles. The maximum increase in strength was 73 percent for the compression specimen of the phenyl-silane laminate (Narmco 534) after 1,200 thermal-shock cycles. The change in mechanical properties at 500° F. with number of cycles, which may be considered as time at temperature, follows the trend shown in the data presented in previous studies.[3], [4], [5], [6]

CONCLUSIONS

Effects of thermal-shock cycling on the mechanical properties of reinforced plastic laminates depend upon the type of resin and reinforcement used. In general, the effects of cycling increase as the number of cycles increases. From the results of this study the following conclusions are drawn concerning the behavior of reinforced plastic laminates:

1. Thermal-shock cycling has less effect on the modulus of elasticity than on the tensile or compressive strength at both room temperature and at 500° F.
2. Continued thermal-shock cycling to 500° F. does not seriously affect the properties of most of the laminates at 500° F.
3. The reduction in tensile strength at room temperature is larger for the phenol-asbestos laminate than for the glass-fabric reinforced phenolic laminate.

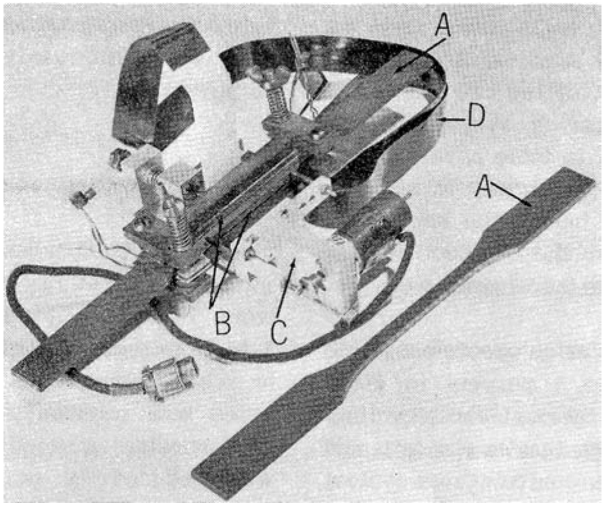


Figure 1.--Tension specimen with plate heaters and extensometer in place. A, tension specimen: B, plate heaters: C, extensometer assembly: and D, thermocouple leads. (M 124 602)

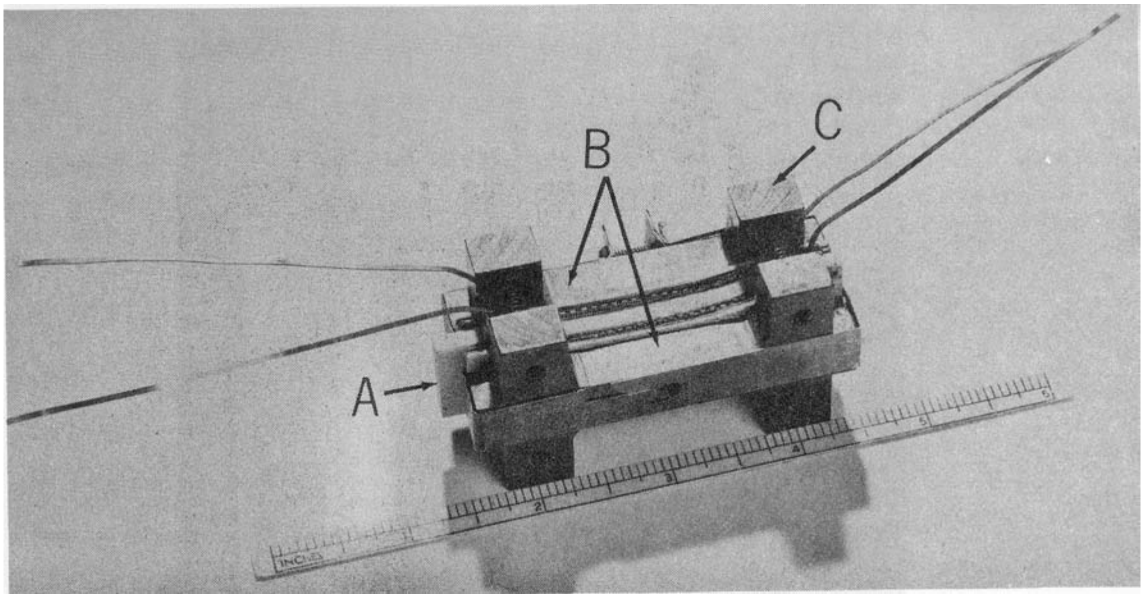


Figure 2.––Compression specimen and plate heaters in supporting jig. A, specimen; B, plate heaters; and C, supporting jig. (M 117 833)

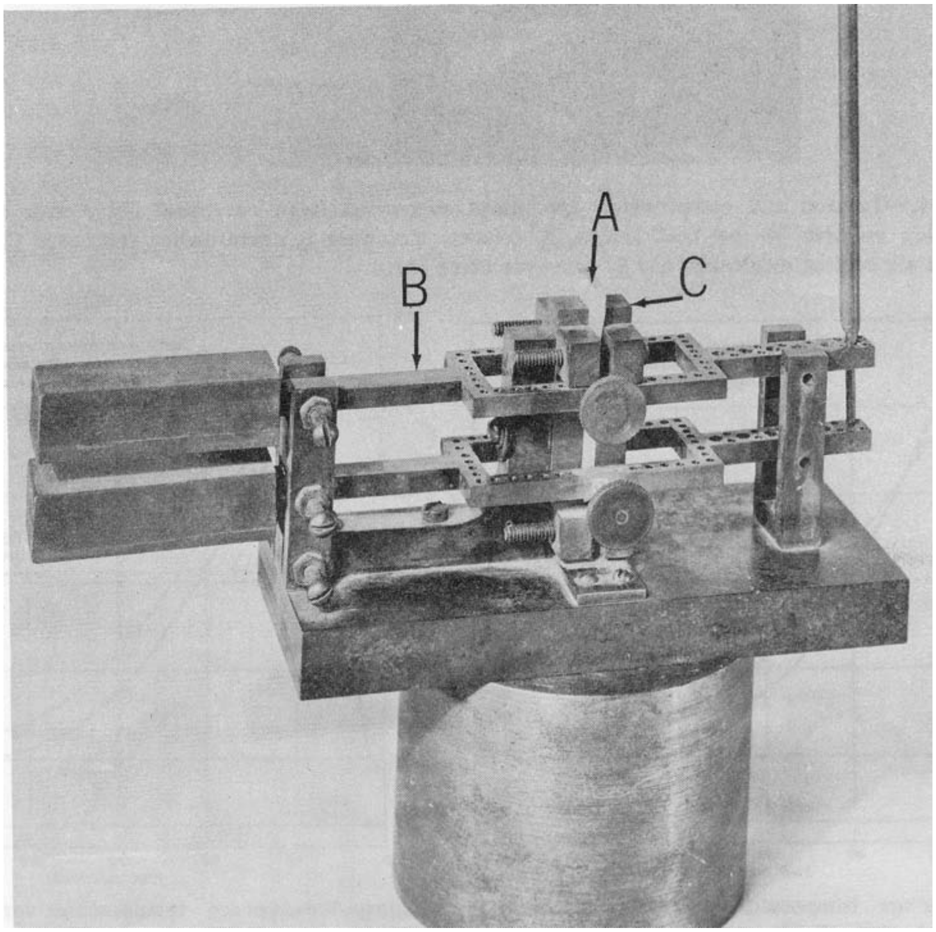


Figure 3.––Compression specimen supporting jig with lever arms of compressometer attached. A, specimen; B, compressometer assembly; and C, supporting jig. (M 114 365)

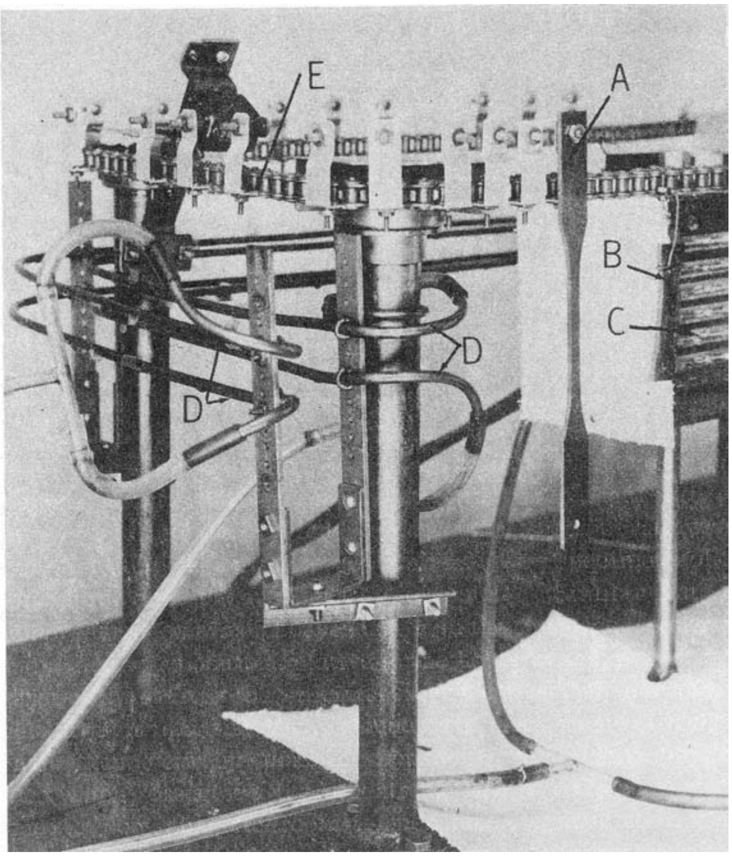


Figure 4.--Tension and compression specimens suspended from carrousel drive chain showing their position relative to the heat lamps. A, tension specimen; B, compression specimen: C, heat lamps; D, jet air cooling manifolds; and E, conveyor drive chain. (M 124 600)

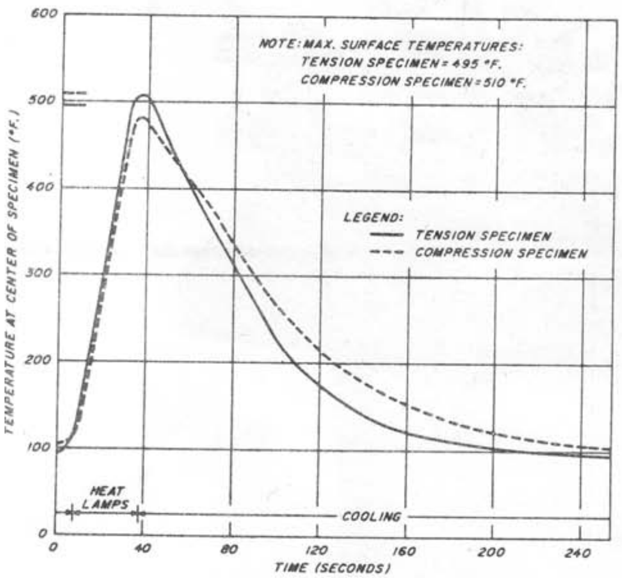


Figure 5.--Average temperature variation curves for specimens of CLT 37-9X phenolic resin laminates reinforced with 181-All00 glass fabric during one cycle of heating and cooling. (M 128 904)

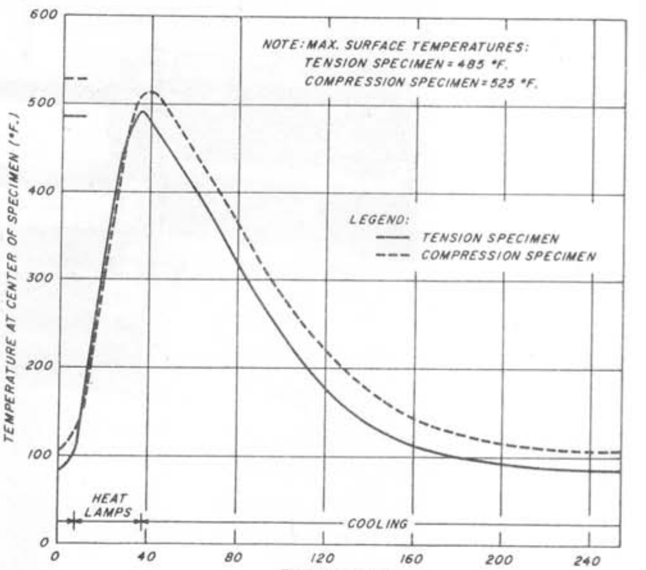


Figure 6.--Average temperature variation curves for specimens of ERSB-0111 epoxy resin laminates reinforced with 181-A1100 glass fabric during one cycle of heating and cooling. (M 128 905)

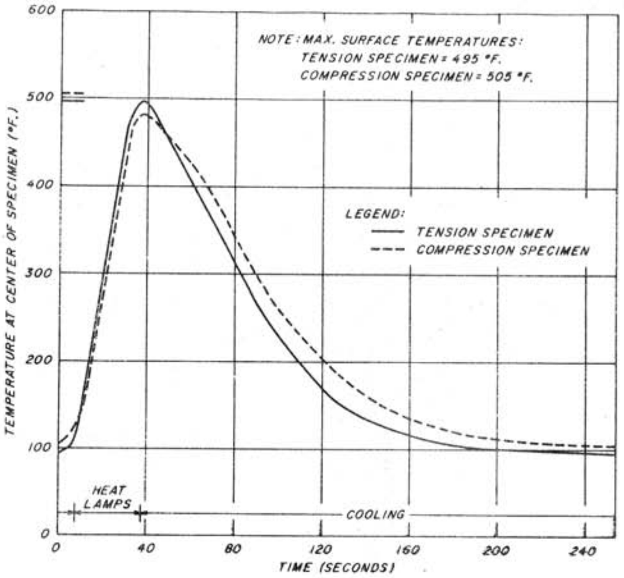


Figure 7.--Average temperature variation curves for specimens of NARMCO 534 phenyl-silane resin laminates reinforced with 181-A1100 glas fabric during one cycle of heating and cooling.

(M 128 907)

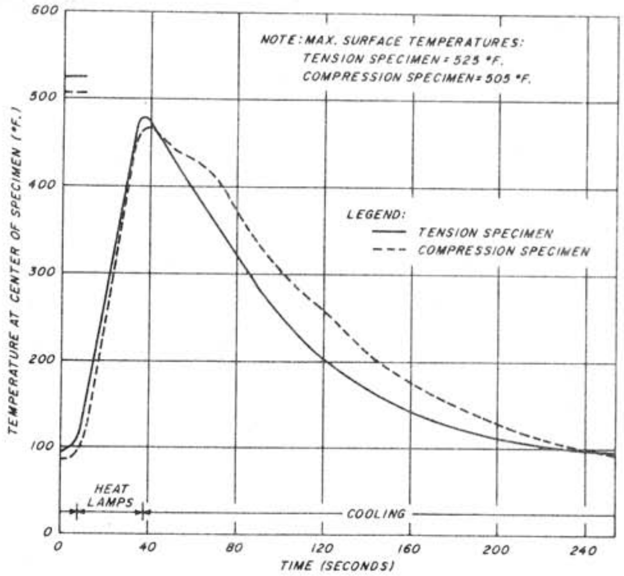


Figure 8.--Average temperature variation curves for specimens of phenolic asbestos laminates (R/M Pyrotex felt style 41-RPD) during one cycle of heating and cooling.

(M 128 906)

Table 1.--Average[1] compressive properties of controls and specimens exposed to thermal-shock cycling

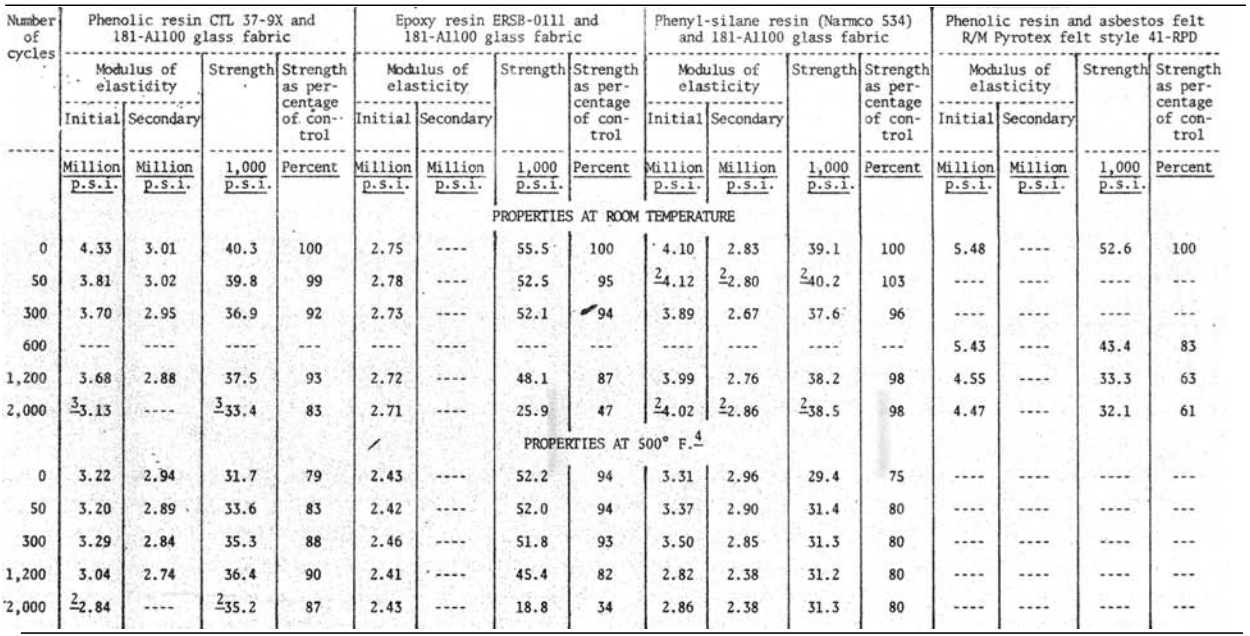
Number of cycles	Phenolic resin CTL 37-9X and 181-A1100 glass fabric[2]				Epoxy resin ERSB-0111 and 181-A1100 glass fabric				Phenyl-silane resin (Narmco 534) and 181-A1100 glass fabric				Phenolic resin and asbestos felt R/M Pyrotex felt style 41-RPD[2]			
	Modulus of elasticity	Strength	Strength as percentage of control	Loss in weight	Modulus of elasticity	Strength	Strength as percentage of control	Loss in weight	Modulus of elasticity	Strength	Strength as percentage of control	Loss in weight	Modulus of elasticity	Strength	Strength as percentage of control	Loss in weight
	Million p.s.i.	1,000 p.s.i.	Percent	Percent	Million p.s.i.	1,000 p.s.i.	Percent	Percent	Million p.s.i.	1,000 p.s.i.	Percent	Percent	Million p.s.i.	1,000 p.s.i.	Percent	Percent
PROPERTIES AT ROOM TEMPERATURE																
0	3.85	63.6	100	0.00	3.44	44.1	100	0.00	3.90	51.4	100	0.00	5.31	25.0	100	0.00
2	3.71	40.1	63	.82	----	----	---	----	----	----	---	----	----	----	---	----
5	3.59	41.3	65	.79	----	----	---	----	----	----	---	----	----	----	---	----
10	3.58	44.3	70	.76	----	----	---	----	----	----	---	----	----	----	---	----
50	3.57	38.0	60	1.18	3.35	33.0	75	.46	3.93	56.1	109	.27	5.34	26.0	104	1.58
300	3.54	32.2	51	1.20	2.84	25.5	58	.50	3.86	58.3	113	.62	5.55	28.9	116	2.00
600	----	----	---	----	----	----	---	----	----	----	---	----	5.19	25.3	101	1.89
1,200	----	----	---	----	2.65	15.3	35	3.44	3.81	59.4	116	.88	5.26	24.3	97	1.80
2,000	----	----	---	----	2.83	12.3	28	4.57	3.87	57.1	111	.84	5.28	22.9	92	1.93
PROPERTIES AT 500° F.[3]																
0	2.73	19.7	31	----	2.44	10.7	24	.35	3.08	22.8	44	.18	4.04	14.2	57	----
2	2.82	20.0	31	.77	----	----	---	----	----	----	---	----	----	----	---	----
5	2.74	20.2	32	.85	----	----	---	----	----	----	---	----	----	----	---	----
10	3.00	20.8	33	.77	----	----	---	----	----	----	---	----	----	----	---	----
50	3.06	22.3	35	1.14	2.47	12.6	29	.46	3.23	32.4	63	.27	4.49	18.1	72	1.55
300	2.90	24.2	38	1.16	2.43	14.0	32	.52	3.26	37.4	73	.65	4.60	20.2	81	2.02
600	----	----	---	----	----	----	---	----	----	----	---	----	4.58	21.4	86	1.90
1,200	----	----	---	----	2.61	12.5	28	3.85	3.50	39.5	77	.86	4.85	20.7	83	1.78
2,000	----	----	---	----	2.45	10.7	24	4.46	3.44	36.7	72	.85	4.79	18.7	75	1.85

[1] Each value is an average of 5 specimens.

[2] Data obtained from Technical Report AFML-TR-64-404.

[3] Specimens were heated for 1 minute prior to loading.

Table 2.--Average[1] tensile properties of controls and specimens exposed to thermal-shock cycling.



Number of cycles	Phenolic resin CTL 37-9X and 181-A1100 glass fabric				Epoxy resin ERSB-0111 and 181-A1100 glass fabric				Phenyl-silane resin (Narmco 534) and 181-A1100 glass fabric				Phenolic resin and asbestos felt R/M Pyrotex felt style 41-RPD			
	Modulus of elasticity: Initial	Modulus of elasticity: Secondary	Strength	Strength as percentage of control	Modulus of elasticity: Initial	Modulus of elasticity: Secondary	Strength	Strength as percentage of control	Modulus of elasticity: Initial	Modulus of elasticity: Secondary	Strength	Strength as percentage of control	Modulus of elasticity: Initial	Modulus of elasticity: Secondary	Strength	Strength as percentage of control
	Million p.s.i.	Million p.s.i.	1,000 p.s.i.	Percent	Million p.s.i.	Million p.s.i.	1,000 p.s.i.	Percent	Million p.s.i.	Million p.s.i.	1,000 p.s.i.	Percent	Million p.s.i.	Million p.s.i.	1,000 p.s.i.	Percent
PROPERTIES AT ROOM TEMPERATURE																
0	4.33	3.01	40.3	100	2.75	----	55.5	100	4.10	2.83	39.1	100	5.48	----	52.6	100
50	3.81	3.02	39.8	99	2.78	----	52.5	95	[2]4.12	[2]2.80	[2]40.2	103	----	----	----	---
300	3.70	2.95	36.9	92	2.73	----	52.1	94	3.89	2.67	37.6	96	----	----	----	---
600	----	----	----	---	----	----	----	---	----	----	----	---	5.43	----	43.4	83
1,200	3.68	2.88	37.5	93	2.72	----	48.1	87	3.99	2.76	38.2	98	4.55	----	33.3	63
2,000	[3]3.13	----	[3]33.4	83	2.71	----	25.9	47	[2]4.02	[2]2.86	[2]38.5	98	4.47	----	32.1	61
PROPERTIES AT 500° F.[4]																
0	3.22	2.94	31.7	79	2.43	----	52.2	94	3.31	2.96	29.4	75	----	----	----	---
50	3.20	2.89	33.6	83	2.42	----	52.0	94	3.37	2.90	31.4	80	----	----	----	---
300	3.29	2.84	35.3	88	2.46	----	51.8	93	3.50	2.85	31.3	80	----	----	----	---
1,200	3.04	2.74	36.4	90	2.41	----	45.4	82	2.82	2.38	31.2	80	----	----	----	---
2,000	[2]2.84	----	[2]35.2	87	2.43	----	18.8	34	2.86	2.38	31.3	80	----	----	----	---

[1] Average value for 5 specimens except as noted.
[2] Average value for 4 specimens except as noted.
[3] Average value for 3 specimens except as noted.
[4] Specimens were heated for 1 minute prior to loading.

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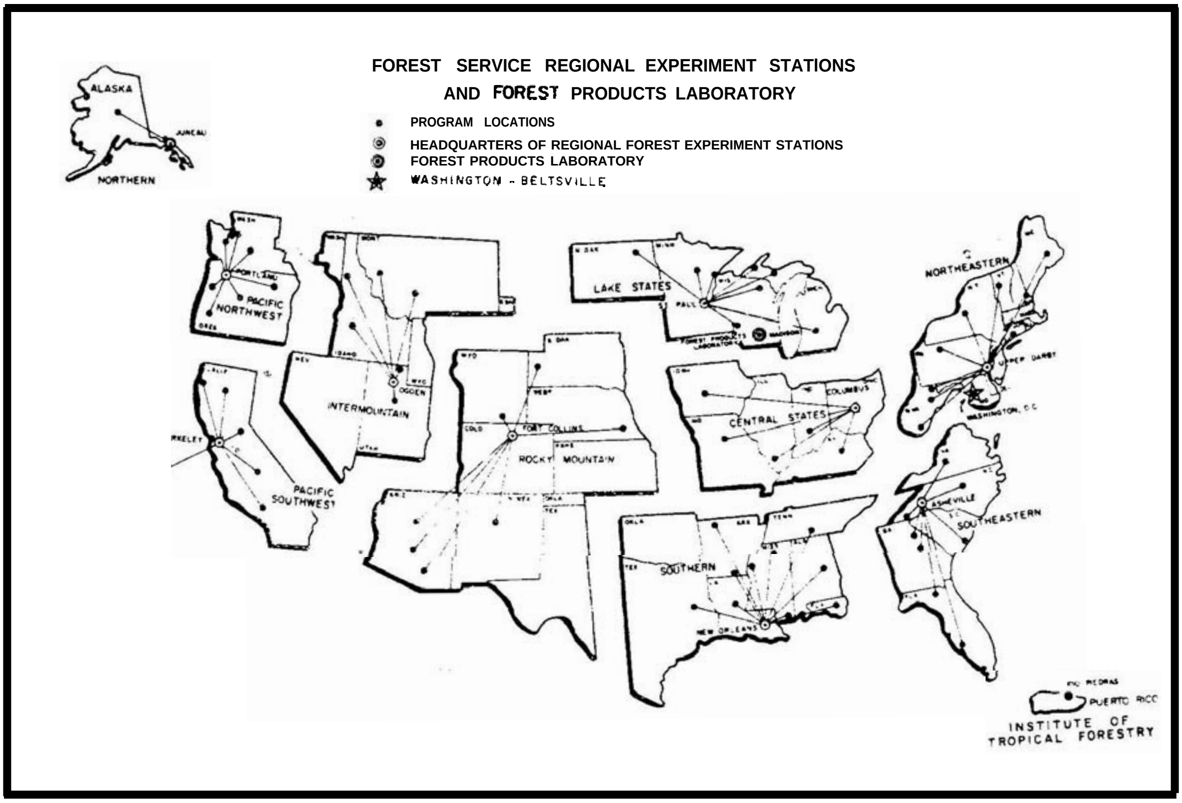

Forest Service regional experiment stations and Forest Products Laboratory

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In Cooperation with the University of Wisconsin