

Supplement to

INTERLAMINAR SHEAR STRENGTH OF GLASS-FIBER-REINFORCED PLASTIC LAMINATES

No. 1848-A

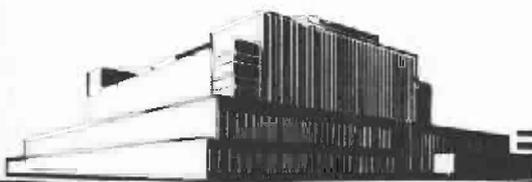
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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

Supplement to
INTERLAMINAR SHEAR STRENGTH OF GLASS-
FIBER-REINFORCED PLASTIC LAMINATES¹

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Summary

This report presents the results of tests to determine the interlaminar shear strength of 3 epoxy laminates reinforced with 112, 120, or 143 Volan A glass fabric. The data supplement those of Forest Products Laboratory Report No. 1848, in which results of tests of 11 types of glass-fiber-reinforced plastic laminates are presented.

Interlaminar shear strength was significantly higher at 45° loading than at 0° loading for the 112 laminate in both the wet and the dry condition and for the 143 laminate in the wet condition, but not for the 143 laminate in the dry condition or the 120 laminate in either the wet or dry condition. Wet conditioning produced little or no reduction in interlaminar shear strength, except in the 143 laminate at 0° loading. The 112 epoxy laminate tested in this study was somewhat higher in interlaminar shear strength than a comparable polyester laminate tested in the basic study.

¹This progress report is one of a series (ANC-17, Item 55-3) prepared and distributed by the Forest Products Laboratory under U. S. Navy, Bureau of Aeronautics Order NAer 01683 and U. S. Air Force Order DO 33(616) 56-9. Results here reported are preliminary and may be revised as additional data become available.

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

Introduction

The basic report in this series³ presents data on the interlaminar shear strength of several types of reinforced plastic laminates, particularly polyester laminates. Data on interlaminar shear strength of two 181 Volan A epoxy laminates from another study⁴ that were included for purposes of comparison showed higher interlaminar shear strength values for a laminate made with Epon 1001 resin than for laminates made of similar fabric with polyester, phenolic, or silicone resin. The comparable data on an Epon 828 laminate with Curing Agent A showed interlaminar shear strength values somewhat similar to those of polyester and phenolic laminates. The purpose of the present study, therefore, was to determine the interlaminar shear strength of three additional epoxy laminates made with fabrics with different types of weave. The study was undertaken at the Forest Products Laboratory at the request of and in cooperation with the ANC-17 Panel on Plastics for Aircraft.

Parallel laminates were made of 112, 120, and 143 glass fabric with Volan A finish, and Epon 828 containing Curing Agent CL. Laminates made with Epon 828 resin and Curing Agent CL generally have higher mechanical strength than comparable laminates made with Epon 828 and Curing Agent A. Epon 828 is an epoxy laminating resin of the type required by Military Specification MIL-R-9300A. It is a commercially available resin that is used for low-pressure laminates.

Description of Material

Two panels of 143 Volan A laminate and 1 panel each of 120 and 112 Volan A laminate were fabricated at the Forest Products Laboratory to supply the test material for this study and for a study of mechanical properties of epoxy laminates.² It was necessary to fabricate two panels of 143 Volan A laminate to provide sufficient void-free material for the specimens required. These two panels were well matched, as is shown in table 6,⁶ and may be considered as essentially a single panel for the purposes of the study.

³Werren, Fred, and Heebink, B. G., Interlaminar Shear Strength of Glass-Fiber-Reinforced Plastic Laminates. Forest Products Laboratory Report No. 1848, Sept. 1955.

⁴Werren, Fred. Supplement to Mechanical Properties of Plastic Laminates. Forest Products Laboratory Report No. 1820-B, Sept. 1955.

⁵Youngs, R. L. Supplement to Mechanical Properties of Plastic Laminates. Forest Products Laboratory Report No. 1820-C, Oct. 1956.

⁶Tables and figures in this report are numbered consecutively after those in the basic report.

All panels were nominally $1/8$ inch thick and 3 feet square. They were parallel laminated by wet lay-up procedures with Epon 828 epoxy resin containing 14 percent by weight of Curing Agent CL.

The procedure for preparing the laminates was somewhat different from the usual wet lay-up procedures. The resin -- curing agent mixture was poured over a warm assembly of fabric on a vacuum box and allowed to stand for 5 minutes, after which a light vacuum was applied to complete the impregnation and withdraw excess resin. The impregnated fabric assembly was placed between cellophane sheets and cured in a hot press at 215° F. under contact pressure for 11 minutes and a pressure of 25 pounds per square inch for 49 minutes. Additional fabrication details are given in the report dealing with the mechanical properties of these laminates.² General information on the laminates is given in table 6. After about 2 weeks of conditioning in a room controlled at 73° F. and 50 percent relative humidity, panels were postcured for 1 hour in an oven at 400° F.

Testing

The interlaminar shear specimens were similar to those used in the basic study, except that each specimen was made from three thicknesses of laminate glued together, as shown in figure 4B. The bearing edges of the specimens were carefully ground to insure flat and parallel loading surfaces. The specimens were loaded as shown in figure 4A by means of the glue-line shear apparatus, shown in figure 2 of the basic report, at a head speed of 0.01 inch per minute. All the laminates were tested at 0° and 45° to the warp direction, and the 143 laminate was also tested at 90° to the warp direction.

For each direction of each laminate, 8 specimens were tested while dry and 8 were tested while wet. Dry specimens were conditioned for at least 2 weeks under controlled conditions of 73° F. and 50 percent relative humidity. Wet specimens were boiled for 2 hours in distilled water. Failure was generally a delamination of the specimen between two adjacent layers of glass fabric. Values from specimens that showed abnormal failure were rejected.

Presentation of Data

Table 7 presents interlaminar shear strength values for laminates tested in this study. Also included are tensile and compressive strength data for the same laminates from Report 1820-C.² Compressive strength values for wet specimens are based on tests of specimens immersed for 30 days in water at 73° F., and are thus not strictly comparable to interlaminar shear strength values for wet specimens, which are based on tests of specimens that had been boiled in water for 2 hours.

Discussion of Results

The limitations of the block-shear test for interlaminar shear strength are discussed in the basic report. The stress applied to the specimens is not a pure shearing stress, and may not give true values of interlaminar shear strength. When reasonable precautions are taken in sample preparation and testing, however, the results may be expected to show the relative shear strength values of the various materials tested. Most of the data presented in the basic report are based on tests of specimens made from a 1/4-inch-thick laminate, rather than on three 1/8-inch-thick layers glued together as in the present study. This difference should have no appreciable effect on the test results, however, because in each case the failure occurred along a plane located approximately in the center of the specimen. The two outer laminations of the specimens used in this study served merely to provide adequate thickness for satisfactory testing, and were in no way involved in the failure of the specimens.

A tensile interlaminar shear test is used by many activities to evaluate interlaminar shear strength. It is reported that such a test is more representative of the interlaminar shear stresses imposed in structural elements under service conditions than is the block-shear test. Consequently, it has been claimed that a tensile test is of more practical significance when comparing different laminates. Experience with a tensile shear test for laminates at the Forest Products Laboratory has indicated that substantial changes in shear values may occur by varying factors such as type of notch, distance between notches, thickness of laminate, and lateral restraint. It is believed that a tensile shear test imposes a combination of peeling and interlaminar shear stresses, while those imposed by the block-shear test are more nearly interlaminar shear alone. In any event, it appears that considerable development is required before a satisfactory standard tensile test of this type can be established. The use of a tensile interlaminar shear test for comparison with the block-shear test in the present study was considered, but was not possible because of insufficient test material.

In the present study, several statistical comparisons have been made to evaluate the effects of conditioning, angle of loading, and type of resin somewhat more closely than is possible by observation of averages and standard deviations alone. These comparisons were made by means of ranking methods that are as suitable, under the conditions of this study, as the more rigorous and time-consuming analysis of variance.

Effect of Wet Conditioning

Wet conditioning by boiling in water for 2 hours did not have any significant effect on the interlaminar shear strength of 112 Volan A and 120 Volan A

⁷Wilcoxon, Frank. Some Rapid Approximate Statistical Procedures. American Cyanamid Company, New York. 1949.

epoxy laminates at either 0° or 45° loading. The data in table 7 for the 120 laminate indicate an apparent increase in interlaminar shear strength at 0° loading as a result of wet conditioning. This increase is probably not significant, however, in view of the scatter of the individual test values indicated by the high standard deviation for 0° loading.

Wet conditioning produced a significant reduction in interlaminar shear strength of the 143 laminate at 0° and 90° loading, but not at 45° loading. The reason for the extremely low strength at 0° loading after wet conditioning is not clear. Since most of the fibers of 143 fabric are parallel to the warp direction (0°), and there are relatively few cross (fill) fibers, it may be that the resistance to slippage in the 0° direction of a parallel-laminated 143 laminate is substantially reduced by wet conditioning. The strength reduction at 90° loading was statistically significant, but amounted only to about 4 percent of the dry value, which is comparable to that observed in compression and bending tests of the same laminate.

Effect of Angle of Loading

It was observed in the basic report that the average interlaminar shear strength of laminates tested was, in most cases, higher at 45° than at 0° loading. Statistical analysis of the results of the present study indicate that strength at 45° loading is significantly higher than at 0° loading for the 112 epoxy laminate and the wet 143 laminate, but not for the 120 or the dry 143 epoxy laminates.

Test results for the 112 laminate show a significantly higher interlaminar shear strength at 45° than at 0° loading for both the wet and dry specimens. The interlaminar shear strength at 45° loading exceeded that at 0° loading by about 17 percent in dry material and by 14 percent in wet material.

Test results for the 120 laminate show no significant difference between values of interlaminar shear strength at 0° and 45° loading when tested while either wet or dry, although the difference approached significance at the 5 percent level of probability for the dry laminates. The apparent difference indicated for the dry specimens in the data of table 7 loses its significance because of the wide scatter of individual test values, particularly values for tests at 0° to the warp.

The effect of angle of loading on the interlaminar shear strength values for the 143 laminate varied considerably with the conditioning to which the specimens were exposed before they were tested. Results of tests on dry specimens indicate significantly lower values of interlaminar shear strength at 45° loading than at either 0° or 90° loading. The average for the 90° values was slightly lower than the average for the 0° values, but the difference is not statistically significant. Results of tests on wet specimens from the same laminate, however, indicate significantly

lower interlaminar shear strength at 0° loading than at either 45° or 90° loading, and no significant difference between results at 45° and 90° loading, although the average for the 90° values was slightly higher than the average for the 45° values.

The "nesting" of threads in adjacent laminations, which was suggested in the basic report as a possible explanation for the generally higher values of interlaminar shear strength at 45° than at 0° to the warp, does not seem to explain the directional behavior observed in the present study. The only laminate showing a pronounced increase in interlaminar strength at 45° loading over that at 0° loading was the laminate reinforced with 112 fabric, a thinner fabric than the 120 and 143 fabrics used in the other laminates. The thinner fabric would be expected to show the least "nesting" of threads.

Effect of Resin

The 112 laminate made with Epon 828 epoxy resin, which was tested in the present study, may be compared with the 112 laminate made with Selectron 5003 polyester resin, data on which is presented in the basic report, to determine possible effects of type of resin on interlaminar shear strength. A comparison of the individual test values indicates that the interlaminar shear strength of dry specimens loaded at 0° to the warp direction is not significantly different for the 2 laminates, but that the epoxy laminate gave significantly higher values of interlaminar shear strength at 45° loading in the dry condition and at both 0° and 45° loading in the wet condition. This retention of high strength under wet conditions is typical of epoxy laminates.

Similar comparisons are not possible for the other 2 fabrics used as reinforcements in this study, because (1) no data are available on interlaminar shear strength of a 120 polyester laminate, and (2) the 143 laminate tested in the basic study was cross laminated, while the laminate used in the present study was parallel laminated.

It was shown in the basic report that a 181 Volan A laminate made with Epon 1001 resin was consistently higher in interlaminar shear strength than other laminates made with the same fabric and Epon 828, polyester, or phenolic resin. The interlaminar shear strength of the 181 laminate made with Epon 828 was very close to that of the laminates made with polyester or phenolic resin. Epon 828 with Curing Agent A was used in fabricating the 181 laminate tested in the basic study, while Epon 828 with Curing Agent CL was used in the 112 laminate of the present study. In general, higher strength values are obtained with Curing Agent CL than with Curing Agent A.

Conclusions

1. Wet conditioning by boiling in water for 2 hours had no significant effect on the interlaminar shear strength of epoxy laminates reinforced with 112 Volan A or 120 Volan A fabric. Similar conditioning produced a statistically significant reduction in interlaminar shear strength of the 143 Volan A laminate when loaded at 0° or 90° to the warp direction, but not when loaded at 45° to the warp direction. The strength reduction of the 143 laminate was large at 0° loading, but was very small at 90° loading.
2. The interlaminar shear strength of the 112 laminate was significantly higher when loaded at 45° than at 0° to the warp direction under both dry and wet conditions. This was not the case with either the 120 or the 143 laminates.
3. The interlaminar shear strength of the 112 epoxy laminate tested in the present study was significantly higher than that of the 112 polyester laminate tested in the basic study at 45° loading under both dry and wet conditions and at 0° loading under wet conditions. It was not significantly different from that of the polyester laminate at 0° loading under dry conditions, however.

Table 6.--Average thickness, resin content, specific gravity, and Barcol hardness of laminated panels before postcuring. All panels were parallel-laminated with Epon 828 resin containing Curing Agent CL.

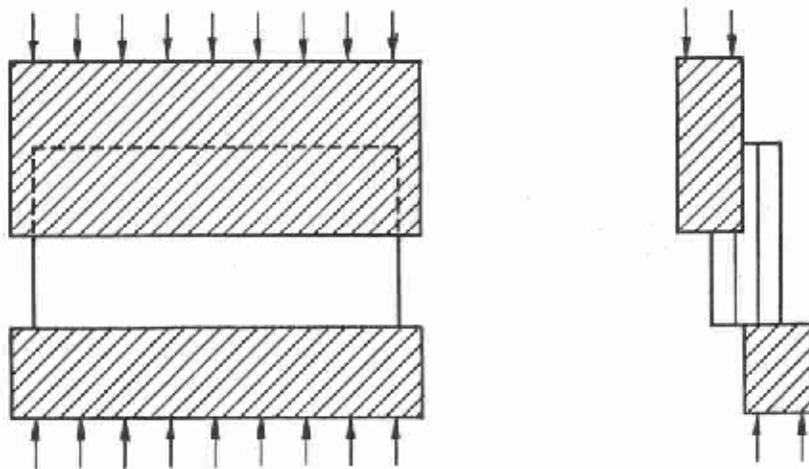
Panel No.	Fabric	Number of plies	Thickness	Resin content	Specific gravity	Barcol hardness
			<u>In.</u>	<u>Percent</u>		
548	143 Volan A	14	0.119	27.5	1.89	69
549	143 Volan A	14	.117	27.2	1.93	70
550	112 Volan A	46	.119	36.4	1.74	70
551	120 Volan A	33	.121	36.5	1.81	71

Table 7.--Results of interlaminar shear tests of parallel laminates made with Epon 828 resin and different types of glass fabric reinforcement. Tension and compression test values are from Forest Products Laboratory Report No. 1820-C.

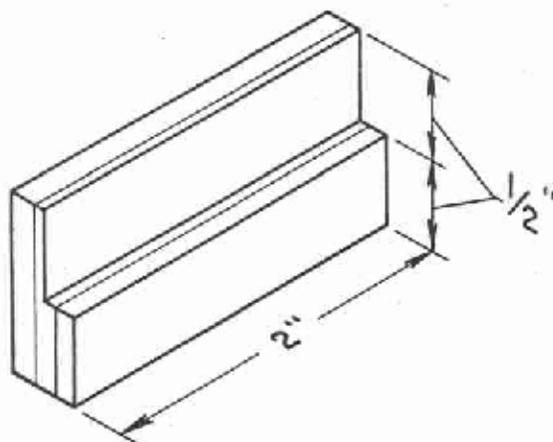
Panel No.	Fabric	Angle of loading	Condition	No. of specimens	Interlaminar shear strength		Tensile strength		Compressive strength		Average increase in weight ²
					Average	Std. dev.	Average	Std. dev.	Average	Std. dev.	
		Degrees			P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	Percent
548, 549	143 Volan A	0	Dry	8	6,310	780	104,800	2,670	73,900	3,400	0.16
			Wet	8	3,690	1,091			68,700	3,700	
		45	Dry	6	5,290	483	15,700	300			
			Wet	8	5,400	470					
		90	Dry	4	6,150	525	12,600	280	32,400	400	.19
			Wet	8	5,890	162			30,900	1,160	
550	112 Volan A	0	Dry	8	5,420	296	52,000	1,410	57,800	5,550	.26
			Wet	8	5,540	293			51,200	2,240	
		45	Dry	7	6,320	384	25,100	340			
			Wet	8	6,300	378					
551	120 Volan A	0	Dry	8	4,480	1,142	52,200	1,290	61,700	1,260	.25
			Wet	8	5,310	867			56,500	1,980	
		45	Dry	8	5,330	571	26,400	390			
			Wet	8	5,240	294					

¹ Within-plot standard deviation based on highest and lowest values in group.

² Increase in weight during immersion as a percentage of weight before immersion.



(A.) METHOD OF LOADING SPECIMEN



(B.) ISOMETRIC SKETCH OF SPECIMEN

Figure 4. --Method of loading and type of specimen used to determine interlaminar shear strength. Three plies of 1/8-inch laminate were glued together and sheared through the center of the middle ply.