POTENTIALITIES OF PAPER-BASE LAMINATES AS COMPARED WITH OTHER LAMINATES

February 1944

No. R1452

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison, Wisconsin
In Cooperation with the University of Wisconsin

POTENTIALITIES OF PAPER-BASE LAMINATES AS COMPARED WITH OTHER LAMINATES[1]

By

ALFRED J. STAMM, Principal Chemist

Plastics are becoming increasingly important for the fabrication of a vast variety of articles ranging from the most insignificant gadget to moderately stressed and even highly stressed parts of airplanes. Prior to the war, plastic uses and production increased largely because of their corrosion resistance, electrical properties, appearance, and ease of fabrication. Low fabrication costs have helped to put many plastic articles on the counters of the five- and ten-cent stores.

Since the beginning of the war, more emphasis has been placed on the strength properties of plastics, because of the increasing substitution of plastics for metals. Although most of the military applications are still nonstructural or semistructural, there is a definite trend to use plastics more and more in strength requiring ways. These new requirements have been met better by laminates, in both panel and molded form, than by other forms of plastics. As a result, laminates have increased in importance and production at a remarkable rate. Paper-base laminates are high in importance among laminates. Although the amount of paper going into paper-base plastics is only a fraction of a percent of the total production it is significant that the amount going into plastics increased several fold during the past year.

It should be of importance to analyze the reasons for the increased use of paper-base laminates, and compare their properties with those of other laminates.

By far the most important laminate from a production and utilization standpoint is plywood. Plywood is not generally classed as a plastic laminate because only relatively small amounts of glue or resin are used for assembling the plies, and because the glue or resin is almost entirely concentrated at the glue line. The term plastic airplane has, however, been applied quite frequently during the last few years when referring to one of the molded plywood airplanes. Resin treated laminated woods in both the uncompressed and compressed forms, however, should be truly considered as laminated plastics.

---

[1]Presented at the Annual Meeting of the Technical Association of the Pulp & Paper Industry, Hotel Commodore, New York, N. Y., Feb. 14-17, 1944 and published in the Paper Trade Journal, Vol. 118, No. 21, May 25, 1944.

Up to the present time, fabric-base laminates have perhaps more varied military applications than have paper-base laminates. Asbestos-base laminates, in the forms of both asbestos paper and fabrics, have found only special applications. Plastic laminates made from glass fabric, and a combination fabric with glass in one direction and merely enough cotton thread in the other to hold the glass fiber in place have recently created considerable interest because of their excellent strength properties. Their use so far, however, is quite limited. The glass laminates have been made with both phenolic resins and the newer contact resins, such as Columbia CR39, Laminac, and Plaskon 900.

Costs

Table I gives a comparison between the costs of the different base materials, the average amount of phenolic resin used in making the laminates, and the cost of the raw materials per pound of laminate. It is of interest that paper is considerably cheaper than most of the base materials and is as cheap as the cheapest species of veneer. Further, paper requires less resin than any of the other laminates with the exception of wood. The face that paper is as cheap as veneer on a weight basis may be surprising to many because of the relatively simple processing which veneer undergoes. This is primarily because veneer must be cut from large, quality logs that are both expensive to procure and expensive to ship and handle. Even though wood pulp represents only about a 45 percent yield of the original wood, the veneer yield of quality material is rarely much better than this. It is thus obvious that paper-base laminates have an appreciable advantage over all other laminates with the exception of wood on a cost basis per unit weight of raw materials. The slight advantage of wood, however, can be expected to decrease with time as quality logs for cutting veneer become more difficult to obtain.

Fabrication Factors

Fabrication of the various laminates involves impregnation, drying, cutting, assembling, and pressing. Paper normally used in laminates can be impregnated and dried more rapidly per unit length than the other laminating materials, but a greater length must be impregnated and dried per unit weight. Impregnating costs hence should not vary appreciably between the different laminates. Assembly costs may be slightly greater for the paper than for the other laminates because more sheets are involved per unit weight. If this is done mechanically, however, the difference should not be great.

The various laminates are pressed at quite different pressures. Plywood assembly pressures using hot-press phenolic glues range, in general, from 150 to 250 pounds per square inch, the lower pressures being used for the softwoods (conifers), such as Douglas-fir, and the higher pressures being used for the hardwoods (broad-leaved woods), such as birch. Impreg laminates can be made at the same pressures. High-density compreg requires pressures of 1,000 to 1,200 pounds per square inch when nonadvanced water-soluble resins are used, and 2,500 to 3,000 pounds per square inch when advanced spirit-soluble resins are used. With the newer low-pressure phenolic resins, paper-base laminates can be made with practically maximum specific gravity (1.35 to 1.40) and strength properties under pressures as low as 100 pounds per square inch. Fabric-base laminates and lignin laminates, however, require considerably higher pressures to obtain maximum specific gravity and to avoid delamination. In general, fabric-phenolic laminates and lignin-plastic laminates are made at pressures of 1,000 to 2,000 pounds per square inch. The same is true for asbestos-base laminates. Glass fabric is laminated with phenolic resins at pressures of 100 pounds per square inch or less. It is laminated with the new contact-pressure resins under practically negligible pressures. Ability to lower the laminating pressure is not of great importance in making flat panels, but it is of extreme importance in molding.

Comparison of Various Fiber Bases

The specific gravity, water absorption, and strength properties of laminates made with different fiber bases are given in Table II, together with the corresponding values for aluminum alloy 24ST used extensively in airplane construction. The paper-base, cotton-fabric, lignin-sheet, and compreg laminates when compressed to practically the ultimate compression, all have about the same specific gravity -- about half that of aluminum. The glass- and asbestos-base laminates have somewhat higher specific gravity values than do the other fiber-base laminates, due to the heavier filler.

No systematic differences exist between the water-absorption values. Differences in the degree of precure of the resin and its distribution throughout the structure cause a greater difference in water absorption than do differences in the fiber base.

Table II shows that paper-base laminates compare favorably with the best of the fiber-base laminates in practically all specific strength properties. The properties given in column 1 for Mitscherlich high-strength paper represent minimum values that can be readily attained, whereas values in the other columns are the averages for specimens tested. Values 20 percent greater than those given in column 1 are frequently obtained. The only specific strength property for this paper-base laminate that is exceeded by the cotton-base laminates is ultimate compression. Where the impact strength is not of vital importance, the compressive-yield strength can be increased by about 60 percent at the expense of toughness, by impregnating with a nonadvanced water-soluble resin instead of the conventional somewhat advanced spirit-soluble resin. This will also lower the water absorption to about 1 percent.

It has been rumored that glass-fabric laminates with strength properties considerably higher than those given in the table have been attained. The high cost and, at present, small production facilities, however, seem to limit the use of this type of laminate to very special purposes. The greatest virtue of glass laminates is in their extremely high impact strength.

Impact strength is the poorest property of paper-base laminates. In this respect paper-base laminate is superior only to the lignin laminate as shown in Table II. Other forms of lignin laminates, however, are also superior to the paper-base laminate in this property. Improving the impact strength of paper-base laminates without seriously impairing other properties is the biggest research job now confronting paper and resin chemists interested in laminates. This seems to involve making a more ductile product without too serious a loss in modulus of elasticity.

On a specific strength basis the properties of aluminum alloy 24ST are, in general, not much better than the fiber laminates. The superiority of aluminum rests largely in its compressive-strength properties and in its impact strength.

Ordinary plywood ranks high on a specific strength basis with the other laminates except in ultimate compression and excels in specific flexural properties because of the low specific gravity.

Most of the other physical properties of the highly compressed laminated plastics are quite similar. The electrical properties depend more on the absence of electrolytes from the filler and resin, the degree of precure of the resin, and the distribution of resin throughout the structure of the laminate than on the choice of the laminate base. Neither the coefficients of thermal expansion nor the thermal conductivity values of the different highly compressed laminates differ appreciably. The burning rate of the laminates with inorganic bases, such as the glass and asbestos, is nil. The burning rate for all the laminates with an organic filler is slow; in fact, they are self-extinguishing. The resistance to continued heating is also higher for the laminates with inorganic fillers. Glass-fabric laminates, impregnated with phenolic resin, will stand continued heating at 480° F.; asbestos laminates will stand 250° to 300° F., while paper and cotton-fabric laminates will stand only a temperature of 212° to 250° F. When heat resistance is sought, the laminates with inorganic fillers should be used.

It appears, from the analysis of the properties of laminates made with different fiber bases, that paper-base plastics deserve the important place they are finding among laminates. Although they may have to relinquish some of their present war-time uses to metals, their excellent properties and relatively low cost will assure them many future industrial and structural uses. Further reductions in fabricating costs should assure them a place in house construction and furnishings. Even at present prices they appear promising for facing of the better grades of plywood. Because of the better dimensional stability and freedom from face checking of plywood faced with a paper-base laminate, this material should find extensive outdoor use.

Hydrolyzed-wood laminates and combined lignin-and-paper laminates also show great promise as competitive building materials. Although their properties are, in general, somewhat inferior to paper-base phenolic laminates, their potentially lower cost will make them desirable for many uses. Plastic laminates made from paper mill products thus appear to have real future in store for them. This future, however, will be attained only by continual research and improvement and cheapening of products, for those sponsoring other forms of laminate and the metals will extend themselves to the utmost to place their products ahead of laminates produced from wood and wood products in all industrial applications.

Table 1.--Comparative material cost of different types of phenolic-resin laminates

Base material	Cost of base material per pound	Resin[1] content of laminate	Total material cost[2] of laminate per pound
		Percent	
Douglas-fir veneer[3]	$0.07	[4]13	$0.10
Do	.07	[5]23	.11
Yellow birch veneer[3]	.12	[4]10	.13
Do	.12	[5]23	.15
Kraft paper	.06	35	.13
Mitscherlich sulfite paper	.07	35	.14
Cotton fabric (coarse weave)	.30	45	.28
Cotton fabric (fine weave)	.40	45	.33
Asbestos paper	.30	50	.28
Asbestos fabric	.80	50	.52
Glass fabric	2.00	50	1.12

[1]On the basis of the total weight.

[2]On the basis of the phenolic-resin costing $0.25 per pound (100 percent solids).

[3]Select, rotary cut, 1/16-inch.

[4]Plywood.

[5]Impreg or compreg.

Table 2.--Properties of cross-banded, phenolic-resin laminates with different fiber bases

Property	Mitscherlich high-strength paper[1]	Kraft[2] paper NEMA Grade XX	Cotton[2] fabric NEMA Grade C	Cotton[2] fabric NEMA Grade L	Asbestos[3] paper NEMA Grade A	Asbestos[3] fabric NEMA Grade AA	Glass[4] fabric and cotton alternate laminates	Lignin[5] plastic sheet	Birch[3] plywood	Birch[6] compreg	Aluminum[4] alloy 24ST
	Base material										
Specific gravity	1.38	1.34	1.34	1.34	1.8	1.8	1.68	1.38	0.8	1.33	2.8
Water absorption (24 hours, 1/8 inch thick), percent	2 to 4	1.3	1.9	.8	1.0	1.0	....	0.7-4.5	....	1.0	0.0
Tension (specific)[7]:											
Ultimate, psi	18,200	11,400	9,000	10,800	6,400	6,400	21,300	8,700	16,400	11,000	22,100
Modulus of elasticity, 1000 psi	1,600	1,100	840	880	500	720	[8]1,200	1,100	1,750	1,660	[8]2,400
Compression (edge, specific)[7]:											
Yield strength, psi	....	6,600	5,100	4,800	....	....	9,100	....	....	5,900	14,300
Ultimate, psi	13,100	17,500	20,600	18,800	5,500	11,700	13,900	14,500	7,100	16,300	22,100
Modulus of elasticity, 1000 psi	1,400	1,400	1,050	1,130	280	280	[8]1,270	....	1,750	1,660	[8]2,400
Flexure (specific):											
Modulus of rupture,[9] psi	13,700	9,500	10,300	10,900	6,600	7,500	12,600	9,400	....	11,000	7,900
Modulus of elasticity,[10] 1000 psi	770	650	500	500	....	....	560	....	2,700	880	470
Impact (notched Izod):											
Face, ft.-lb./in. notch	4.0	2.1	[11]2.8	4.1	4.5	....	13.5	0.8	....	....	22
Edge, ft.-lb./in. notch	.7	.6	[11]1.9	1.9	2.0	....	6.0	....	....	....	22

[1]Data of Consolidated Water Power and Paper Company, March 17, 1943.

[2]Data of Oberg, T. P., Schwartz, R. T., and Shinn, D. A., Army Air Forces, Modern Plastics, April, 87 (1943).

[3]Data of Caldwell, L. E., Westinghouse Electric Manufacturing Company, Modern Plastics, August, 82 (1943).

[4]Data of Sang, H., and Fields, P. M., Naval Aircraft Factory, Modern Plastics, October, 107 (1943).

[5]Plastics catalog (1943).

[6]Data of Forest Products Laboratory, Wood Aircraft Fabrication Manual, July 1942.

[7]Strength expressed on specific basis; that is, strength divided by the specific gravity.

[8]Secant modulus which is somewhat lower than the normal tangent modulus.

[9]Modulus of rupture divided by the square of the specific gravity as this property varies with the square of thickness when comparison is on equal weight and width basis.

[10]Modulus of elasticity in bending divided by the cube of the specific gravity as this property varies with the cube of the thickness when comparison is on equal weight and width basis.

[11]Values more than twice as great have in some instances been reported.

Z M 52523 F