Plywood and Plastics—II

Moulded Plywood Construction : Characteristics of Wood Veneer : Effects of Moisture Content : Glue Spread

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(Continued from page 102, July 22nd, 1943)

MORE recent developments have introduced an entirely new type of plywood, different in appearance and application and manufactured under widely different methods. This class of manufactured wood is known as laminated or impregnated wood. Whereas the grain of the plies in plywood are arranged at 90 deg. or 45 deg. to each other, in laminated wood the grain of the successive veneers run parallel to each other, or nearly so. Laminated wood is usually produced in plank form and not sheet form as with plywood.

For the structurally important parts of aircraft the British industry uses plywood of the latter variety, manufactured to B.S. Specification V3, which calls for plies of birch (European or sweet or yellow) or rock maple. Strength properties of this material are given in Table 5, compared with those for a similar plywood prior to the use of modern synthetic adhesives; the superior characteristics of the modern material should be noted.

A further specification, D.T.D.427, covers the ordinary commercial qualities of plywood made from various timber for lightly stressed aircraft parts. In addition, there is also a B.S. Specification V.34 for plywood for use on unstressed parts, much more elastic in choice of timber.

TABLE 5.—TENSILE STRENGTH OF BIRCH 3-PLY, lb./sq. in.

Material		Parallel to Grain	Normal to Grain	45 deg. to Grain
Plywood cemented with organic glues.	Ult. tensile stress Elastic modulus	10,000–12,000 1.2×10^6	6,500–7,500 0.7×10^6	4,000–4,500 0.3×10^6
Plywood cemented with Tego film glue.	Ult. tensile stress Elastic modulus	15,000–16,000 1.7×10^6	8,000–9,000 0.95×10^6	6,000–6,500 0.5×10^6

Unfortunately, three-ply wood is far from being isotropic. The pronounced grain structure of the wood precludes this. From Table V it will be noted that the tensile strength of three-ply wood at 45 deg. to the grain is less than half that parallel to the grain. Actually, in the former case failure always occurs due to shear along the grain. Modern applications to plywood structures can, to some extent, overcome this difficulty, and will be referred to later.

A plywood structure, however, distributes the fibre strength of the wood, greatly reduces swelling and shrinkage and eliminates to a large extent the possibility of the material splitting. The durability of such a material is largely dependent upon the bonding medium. Phenolic and urea resins have been applied to the veneers as dry powders, in solution or emulsion, and, more recently, in "film" form.

Laminated Compressed Wood

An important factor in obtaining maximum adhesion with synthetic resins in plywood manufacture is the control of the moisture content before hot-pressing. This point is dealt with under the characteristics of wood veneers. Developments in the use of cold-curing synthetic resins as the bonding medium are also taking place.

After plywood, the next step in improving natural wood was to minimise the effect of the grain structure on its strength properties. The compressive strength of most woods is approximately half the tensile strength, a characteristic which is due to instability of the grain fibres under compressive loads. Consequently, it was conceived that if the pores and cells in the wood could be filled with a substance having a good compressive strength/weight ratio, some degree of uniformity in strength might result. One of the many types of synthetic resins available was chosen, and much of this early research work was conducted in Germany. Impregnation of solid timber was not a success, due to the difficulty of inducing the resin to penetrate into the timber more than a few hundredths of an inch below the surface. The idea was then conceived of impregnating thin veneers with resin. These experiments eventually led to the production of laminated compressed wood, which in this country is manufactured to Specification D.T.D.370, birch veneer being the only timber allowed.

In Table 6 representative strength characteristics of natural birch wood, cresol synthetic resin and laminated birch wood compressed and impregnated are compared. It will be noticed that the natural wood has a high ratio of tensile to compressive strength, and that the cresol synthetic resin has nearly the same ratio inverted. The effect when combining the two materials is therefore to produce a third, having compressive and tensile strengths substantially equal to unity.

By thoroughly impregnating seasoned wood veneers with phenol-formaldehyde resin, drying and hot pressing together, the material produced results in both the wood and the resin losing their separate identities, and the result is a new product of interesting properties.

After preliminary seasoning, the wood veneers are processed under heat in a press to remove "free" water. A batch of dried veneers are then loaded into metal cages and placed within an impregnating vessel. The vessel is next evacuated in order to complete the removal of any free moisture left in the wood. An alcohol solution of phenolic resin is added and pressure applied to the vessel. After thorough impregnation, the veneers are removed and submitted to action of heat and vacuum in another vessel in order to remove the alcohol.

Balanced Properties Due to Resin Used

Hot pressing is carried out in multiple daylight steam-heated presses, the required number of veneers being packed between the platens. Hot-pressing reduces the thickness by about 30 per cent. or more, and the temperature and pressure used are carefully controlled in order

TABLE 6

Properties	Natural Solid Birch 15 per cent. Moisture Content		Impregnated and Compressed Laminated Birch (Synthetic Resin)			Cresol Synthetic Resin
Specific gravity	0.70		1.0			1.2
Density (lb./cu. ft.)	44		62			75
	Parallel to Grain	Normal to Grain	Parallel to Grain	Normal to Grain: Normal to Veneers	Normal to Grain: Parallel to Veneers	
Ult. tensile stress (lb./sq. in.)	21,000	—	22,000	—	2,000	5,000
Ult. compress stress (lb./sq. in.)	8,500	1,500	21,000	8,000	7,500	22,000
Ult. shear stress (lb./sq. in.)	2,500	1,500	4,000	—	2,000	—
Elastic modulus E	1.8×10^6	—	3×10^6	—	—	0.7×10^6
Modulus of rupture (lb./sq. in.)	15,000	—	25,000	—	—	—
Impact value (ft./lb.)	—	11.5	—	6.5	7.5	—
Tensile/sp. gr.	3.0×10^4	—	2.20×10^4	—	—	—
Compress/sp. gr.	1.21×10^4	—	2.10×10^4	—	—	—
E/sp. gr.	2.57×10^6	—	3.0×10^6	—	—	—

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to get uniform and consistent material. The phenol formaldehyde resin used has high compressive strength and low tensile strength, and therefore the impregnated and bonded wood has considerably improved and balanced properties. Increase in strength is accompanied by an increase in specific gravity, influenced by the percentage of resin present and the curing pressure. Increase in s.g. produced by increased pressure raises the tensile strength at a greater rate than the compressive strength, whilst the s.g. increase resulting from higher resin content raises the compressive strength at a greater rate than the tensile strength. By variations of the method of manufacture, the strength characteristics can be varied between wide limits. The graph in Fig. 3 shows the effect of higher specific pressures upon ultimate strength, and the curves in Fig. 4 show the result of varying pressures used upon original thickness.

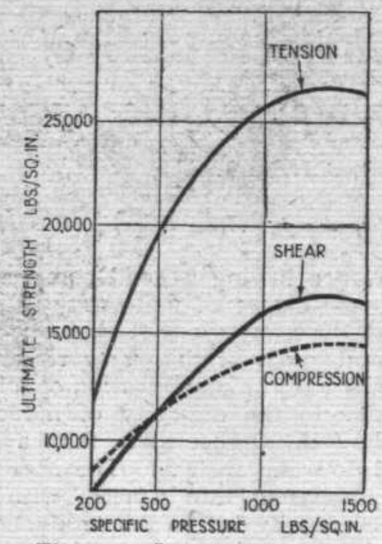

Fig. 3. Laminated compressed wood. Effect of higher pressures upon ultimate strength.

Increasing the density also serves to lock the wood fibres in the compressed condition, and prevents an elastic return to the original volume.

A material produced in a similar manner and incorporating differential pressure (that is to say, pressure between parallel platens of a pile of veneers with a pile thicker at one end than the other) is used for the manufacture of wooden airscrew blades which have to withstand high stresses at the root or hub end; such stresses taper off along the blade length to zero at tip.

Moulded Plywood Construction

Examples of wood veneer bonded and impregnated with synthetic resin in the manufacture of wood airscrew blades are to be found in the Rotol Jablo wood blade produced from a series of laminated compressed boards built up of Canadian birch veneers shown in Fig. 5. The Rotol Weybridge wood blade uses "Jicwood" material; the properties of which are given in Table 7. It is made from laminated compressed boards produced from birch veneers for the highly stressed root portion of the blade and is illustrated in Fig. 6. A more recent development in this sphere is the Hydulignum wood blade, which also uses compressed boards produced from Canadian birch veneers. The Hydulignum process differs from all others in that the planks are compressed edgewise as well as flatwise.

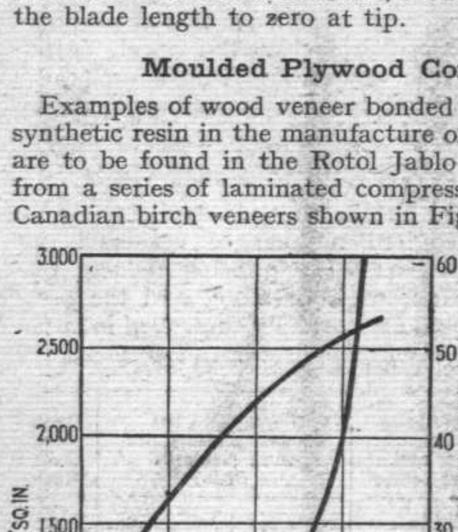

Fig. 4. Laminated compressed wood. Result of varying pressure upon original thickness.

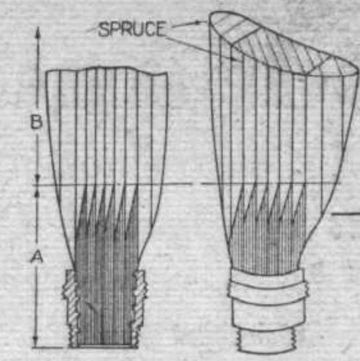

Fig. 6. Rotol Weybridge airscrew blade. Jicwood is used for the highly stressed root portion.

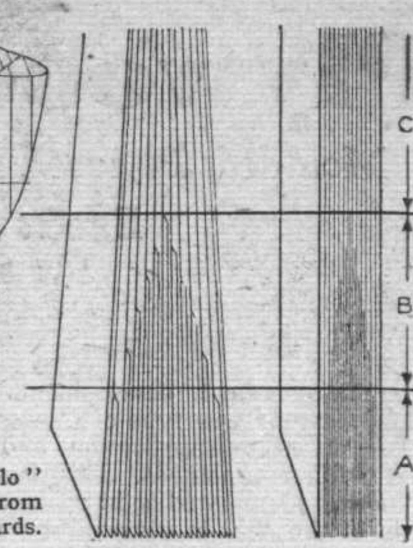

Fig. 5. The Rotol "Jablo" wood blade produced from laminated compressed boards.

TABLE 7.—PHYSICAL PROPERTIES OF COMPRESSED AND IMPREGNATED "JICWOOD"

	Tensile	Compression	Shear	"E" Modulus $\times 10^6$ lb.	Spec. Gravity
	Tons per sq. in.				
Compressed Jicwood	21.3	11.8	3.3	4.3	1.36
Impregnated Jicwood	9.0	5.5	2.25	2.0	0.9

These latest developments in manufactured wood with such a favourable change in strength characteristics through increase of density are perhaps analogous to the alloying and heat-treatment of metals to improve their qualities, and it certainly gives to woodworkers the opportunity to meet design requirements that were quite beyond the range of normal wood.

Even so, this variety of wood is strictly confined to specific purposes, and does not meet entirely the requirements of the aircraft engineer in converting from metal-stressed skin construction to wood construction upon similar lines. In this respect the disadvantages of natural wood have had to be overcome by somewhat different methods resulting in the use of wood veneer in the form of resin bonded and impregnated plywood for moulding the main component parts of a complete aircraft. This recent and most important development in aircraft engineering is dealt with in the following sections of this article, also data and characteristics relating to various species of wood veneer and the importance of moisture content control before finally dealing with some problems of design.

The tendency for a return to wood construction of aircraft has been made possible, to a great extent, by the superior qualities and durability of plywood aided by the versatility of the modern syntheic adhesives which, during recent years, have become available.

Earlier sections of this article dealt with the characteristics and application of such adhesives to wood veneer in the manufacture of plywood panels and impregnated compressed woods, leading up to the more recent and important development in the history of aviation: moulded plywood construction, aided by the plastic element.

Manufacturing Processes

Natural plywood cannot be forced into compound curvatures or sharp single curvatures in one direction without setting up initial stresses which would make it entirely unreliable for aircraft purposes.

On the other hand, the recent development of resin-bonded and impregnated plywood has all the characteristics of an ideal aircraft material. Several processes are already being used successfully for moulding complete aircraft of the trainer class and for component parts of much larger aircraft in the form of wing tips, bomb-bay doors,

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floors, seats, tanks and other units. Aerodynamic efficiency, largely dependent upon external form and finish, is achieved with marked success with this technique, which undoubtedly will be used extensively in the post-war development of civil aviation.

The manufacturing processes involved have already been reviewed at intervals in past issues of *Flight*, so that only a brief description need by given here. In moulding aircraft and component parts in plywood the fundamental principle is the use of heat and fluid pressure applied simultaneously. During the moulding process the wood veneers become impregnated with synthetic resin, which fluxes under the application of heat and is forced by pressure into the wood fibres. The operation is performed with the plywood in contact with a suitable mould. When, after the curing period, the resin has set, a plywood unit of the required shape is obtained.

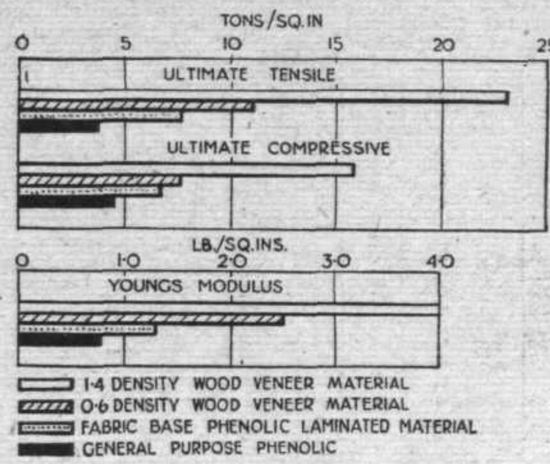

Fig. 7. Comparison showing the superior characteristics of wood veneers with other plastic materials.

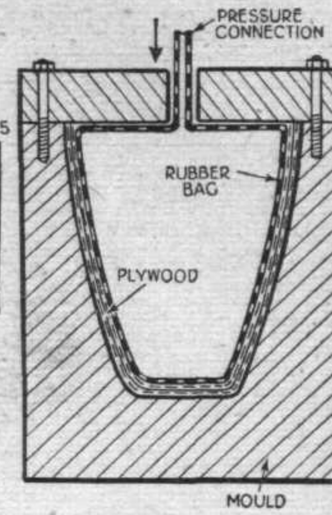

Fig. 8. Completely enclosed forms may be moulded by the internal moulding process shown above.

In most cases fluid pressure is obtained by means of an inflated or deflated rubber bag which is used either as the male or female member of the mould. Pressure supplied by this means develops in a direction everywhere normal to the surface of the work, irrespective of curvature. For certain complex forms veneer sheet is not always practicable. In such cases narrow strips are sometimes used, cut to tapered, trapezoidal or triangular form where necessary to facilitate the forming of the final shape.

Use of Hot- and Cold-setting Adhesives

More recently veneers have been impregnated prior to "laying-on" the mould, a practice associated with the manufacture of laminated plastic materials. In either case the veneers are bonded by the hot process with a thermosetting adhesive. This, it is claimed, gives improved durability and has greater moisture resistance. In contrast to this, however, the Langley Aircraft Corporation, in the construction of their twin-engined plywood aircraft by the Vidal process, selected Vinyl thermo-plastic resins for the bonding agents as being the most satisfactory over the required temperature range of 40 deg. C. to +160 deg. C. Due to the fact that thermo-plastic resins can be reworked it would appear that their use will facilitate repairs and more convenient servicing.

In general, the use of hot-setting adhesives is advocated for panels and the cold-setting type for the production of heavier frames or final assemblies. This is recommended because of the danger of damaging the outer wood by over-heating when the hot-setting type is used, the cure time being proportional to the thickness of the members. The necessary steam heat and pressure for moulding the plywood are obtained by using autoclaves, which are relatively easy and cheap to construct.

In America such autoclaves are some 8ft. in diameter and up to 35ft. in length. It is understood that larger equipment is in course of construction, so that limitations of the process which at present confine its application to complete light aircraft and trainer types may be removed.

The use of moulded plywood offers all the advantages of moulded plastics, and many of the difficulties which accompany the use of the latter material disappear. Its superior qualities in comparison with other plastic materials are grouped in the chart, Fig. 7. The weight of plywood is even lower than that of plastics, and the vibration-damping properties of this material are well known. The application and future development of this modern technique to aircraft engineering is indeed promising, and for that reason will be approached later from the design point of view.

In this country Merron, Ltd., and Renn's Shaped Ply, Ltd., are engaged in this class of work and employ both the external mould and the internal rubber bag method. By the internal method it is possible to produce completely enclosed forms, such as the cylindrical or conical units, shown in Fig. 8, as the bag is collapsible and can be withdrawn after releasing internal pressure.

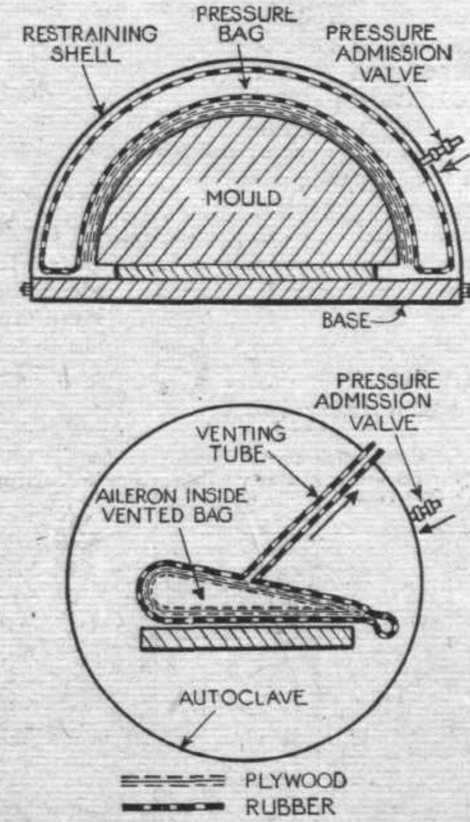

Fig. 9. Moulded plywood construction. Top: The inflated bag method, positive pressure. Bottom: The deflated bag method, vacuum pressure.

Among the successful processes operating in America are Duramold, Vidal and the Timm Aeromold process. Moulding the supporting structure integrally with the plywood skin is a characteristic feature in certain of these processes, in which the following are among the advantages claimed: Fire resistance (since the thickness of the plywood skin will resist the effects of heat longer than a thin light-alloy skin), freedom from pulsation; external rivet heads and overlapping joints, combined with a superior finish which improves aerodynamic efficiency. Typical examples of the process are illustrated in Fig. 9. It is conceivable that a high-speed aircraft of this construction could be quite a good deal faster than a similar aircraft of metal construction.

From what has been written it will be noticed that apart from the plastic element the use of wood veneer predominates throughout in these latest applications of wood to aircraft engineering, and it becomes equally essential to study the characteristics of such material.

The production of veneer offers several distinct advantages to the manufacturer in addition to the engineer. For example, thin planks and veneers can be seasoned much more rapidly and economically than ordinary timber; sliced or rotary-cut veneer gives greater yield per log, as there

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TABLE 8
A COMPARISON OF IMPORTANT WOODS USED IN THE MANUFACTURE OF PLYWOOD

Species	Average Value Spec. Grav.	Per cent. Walnut
Group 1. High Density Woods:		
Beech	0.64	116
Birch	0.62	113
Maple	0.63	115
Group 2. Medium Density Woods:		
American (Black) Walnut	0.55	100
Douglas Fir (Coast Type)	0.48	87
Douglas Fir (Mountain Type)	0.43	78
African Mahogany	0.45	82
Cuban Mahogany	0.59	107
Mexican Mahogany	0.45	82
Nicaraguan Mahogany	0.48	87
Peruvian Mahogany	0.55	100
Group 3. Low Density Woods:		
Yellow Poplar	0.40	73
Spruce—Sitka	0.40	73
Spruce—Eastern Red and White	0.41	75

TABLE 9
EQUAL THICKNESS

Group No.	Thickness	Wt.	Bending Strength	Stiffness	Shock Resistance	Wt. lb./cu. ft.
1	1.00	100	100	100	100	44
2	1.00	82	82	83	76	36
3	1.00	64	66	80	45	28
EQUAL WEIGHT						
1	1.00	100	100	100	100	—
2	1.22	100	122	152	93	—
3	1.57	100	164	311	71	—

A comparison of the strength of wood on a thickness and weight basis. All values in these tables are relative.

is no saw-waste and it can be handled and transported faster and cheaper. The strength properties of most importance can be emphasised in laminating, and likewise a combination of several species of wood can be arranged in one pre-fabricated unit.

The veneer used in all forms of plywood is generally sliced off a log revolving in a lathe, and may well be regarded as a circumferential plank. Due to the fact that the stem of a tree generally has a taper and is not accurately circular, the veneers are not cut truly parallel to grain. The want of parallelism between length of grain and length of veneer can reduce the strength wherever it occurs. Recent experiments in riving off veneers that are exactly parallel to the grain have met with success, except for the fact that cutting can be wasteful, due to irregularities in the grain producing a proportion of spoiled sheets. Veneer produced in this manner is referred to as "rotary-cut," and is almost exclusively employed in this country in the manufacture of plywood. The B.S.

TABLE 10
STRENGTH PROPERTIES AIRCRAFT STRUCTURAL PLYWOOD

Species Name	Spec. Grav.		Column Bending Modulus Parallel to Grain of Face Plies		Mod. of Elasticity Parallel Grain Face Plies		Tension Parallel Grain of Face Plies		Splitting Resistance
Group II. Medium Density Woods:		Per cent. Walnut	lb. sq. in.	Per cent. Walnut	lb. sq. in.	Per cent. Walnut	lb. sq. in.	Per cent. Walnut	
American Walnut	0.59	100	12,660	100	1,740	100	8,250	100	100
Douglas Fir	0.48	82	9,340	74	1,530	88	6,188	75	121
African Mahogany	0.52	88	8,070	64	1,260	72	5,370	65	No data
"True" Mahogany	0.48	82	8,500	67	1,250	72	6,390	77	No data
Group I. High Density Woods:									
Beech	0.67	114	15,390	121	2,150	123	13,000	157	122
Birch	0.67	114	16,000	126	2,260	130	13,210	160	130
Maple	0.68	115	15,600	123	2,110	121	10,190	123	148
Group III. Low Density Woods:									
Poplar	0.50	85	8,860	70	1,540	89	7,390	89	66
Sitka Spruce	0.42	71	7,710	61	1,370	79	5,650	68	100

A comparison of strength properties of three-ply panels (Data based on tests of plywood, all plies being one species). As the number of plies per panel is increased there is a little change in the strength relationship between species.

TABLE 11

Wood	Bending Strength per cent.	Stiffness per cent.
Grain lengthwise	100	100
Grain crosswise	6	5
3-ply Plywood:		
(a) Grain outerplies lengthwise	82	96
(b) " " crosswise	17	9
5-ply Plywood:		
(a) Grain outerplies lengthwise	67	81
(b) " " crosswise	30	25
7-ply Plywood:		
(a) Grain outerplies lengthwise	60	73
(b) " " crosswise	34	33

Above values based on material (plywood) in which all plies are same thickness and same kind of wood.

Specification for plywood also permits veneers to be sliced or sawn from the log, providing the samples from stock of the finished plywood can pass the test laid down.

The thickness of veneers may vary from extremely thin sheets of 0.01in. thick, but with most species of timber it is difficult to obtain rotary-cut veneers of less than 0.05in. thick.

Very little information is available to the designer on the characteristics of the numerous species of wood veneers. As a result the American Walnut Manufacturers' Association recently prepared and distributed a compilation and analysis of important data on each of the woods in considerable use. Abstracts from this publication are of particular interest. The species of timber are divided into three groups: high, medium and low-density, and the characteristics are compared as a percentage of those for walnut.

In Table 8 a comparison of the important woods used in plywood construction has been tabulated. A comparison of the strength of wood on a thickness and weight basis for the three groups are given in Table 9. Table 10 gives a comparison of strength properties of three-ply panels, the data having been based upon plywood tests in which all plies were of the same species. It is stated that as a number of plies per panel are increased there is little change in the strength relationship between species.

The data in Table 11 are especially interesting, and show the effect of the run of the grain of the outer plies on bending strength and stiffness. These values are based on plywood in which all plies are of the same thickness and same species. The values quoted in these tables should receive consideration in the design of components, particularly where the properties of stiffness and shock resistance are important.

Tangential and Radial Shrinkage

It should be noted that the less dense, Group 3, woods are far more stiff on a weight basis, but they have a much lower rating in shock resistance compared with other woods. By a well-thought-out combination of the several woods upon this basis, the best and most consistent results may be obtained.

Before dealing with that most important aspect, moisture content, some observations on the shrinkage of wood are worth attention. All woods shrink more tangentially parallel to the growth rings than radially (perpendicular to the growth rings). An ideal wood for aircraft purposes would be one in which a low percentage was combined with a low ratio between the amount of shrinkage in either direction. The optimum ratio would be 1.0 indicating that the wood shrinks an equal amount in both directions, a condition never found in any species.

In the subsequent issue the question of radial and tangential shrinkage is continued. Moisture content, its effect upon the modulus of elasticity and the effect of grain angle upon this latter property is also dealt with prior to finally concluding with some fundamental design data.