

# Plywood and Plastics-I

## Resin-bonded and Impregnated Wood Veneer Heralds a Return to Wood Construction

By W. NICHOLS, A.R.Ae.S.

THE extensive use of plywood in aircraft construction during the first world war was quite general in spite of disadvantages then inherent in the material available. Later, the discarding of wood as a structural material by the industry was hastened, due to the fact that glues available at that time, mainly of animal or vegetable origin, were not durable over a period of time, and, moreover, encouraged parasitic growth, the detection of which was difficult, since nearly all glued joints affected were hidden within the structure.

Now, with the evolution of a new technique, the pendulum is again swinging back in favour of wood construction, the reason being two-fold. First, the development during recent years of synthetic resins as adhesives and for the impregnation of wood veneer has resulted in plywood and manufactured compressed woods of vastly superior properties than hitherto. Secondly, the desirability to conserve, so far as possible, metallic materials in the prosecution of the second world war has made it advisable for the aircraft designer to once again think in terms of wood wherever it can be usefully employed.

The trend towards plywood construction is gaining some momentum in this country and the U.S.A., and there now appears vital need for fundamental design data to be disseminated. Design principles applying to metal stressed-skin structures do not fit in with wood construction. In order to obtain the maximum usefulness of plywood as an aircraft material, it is essential to design specifically to plywood characteristics at its present stage of development and workability. Therefore, full consideration must be given to these factors and new principles adopted.

The British aircraft industry has indeed made a "flying" start in the design and production of a modern first-line aircraft in wood by an outstanding achievement and masterpiece in the form of the Mosquito, designed and built by the De Havilland Aircraft Co. A full, illustrated description of this aircraft appeared in *Flight* of May 6th, 1943.

This versatile aircraft (day bomber, night bomber, and intruder) is a descendant of a long line of successful air-

craft of wood construction, and has proved in no uncertain manner, and to our enemies in particular, that operational aircraft of very superior qualities constructed of wood are once again of paramount importance in the successful prosecution of the war.

There are several advantages to be gained from wood construction wherever it becomes feasible to adopt it (for it still, of course, has limitations). These advantages are especially important in wartime. Among them may be mentioned the possibility of constructing a prototype with considerable reduction in cost and in a shorter period; also the repair and maintenance of the primary structure in the Service is greatly facilitated. From the production point of view a vast body of woodworkers from other industries are available as skilled and semi-skilled personnel, and likewise the numerous factories equipped for woodwork in various fields of industry can conveniently switch over to the production of complete assemblies or component parts. This has been amply demonstrated by the production of the Mosquito in this country and within the Empire.

### Origin of Synthetics Used

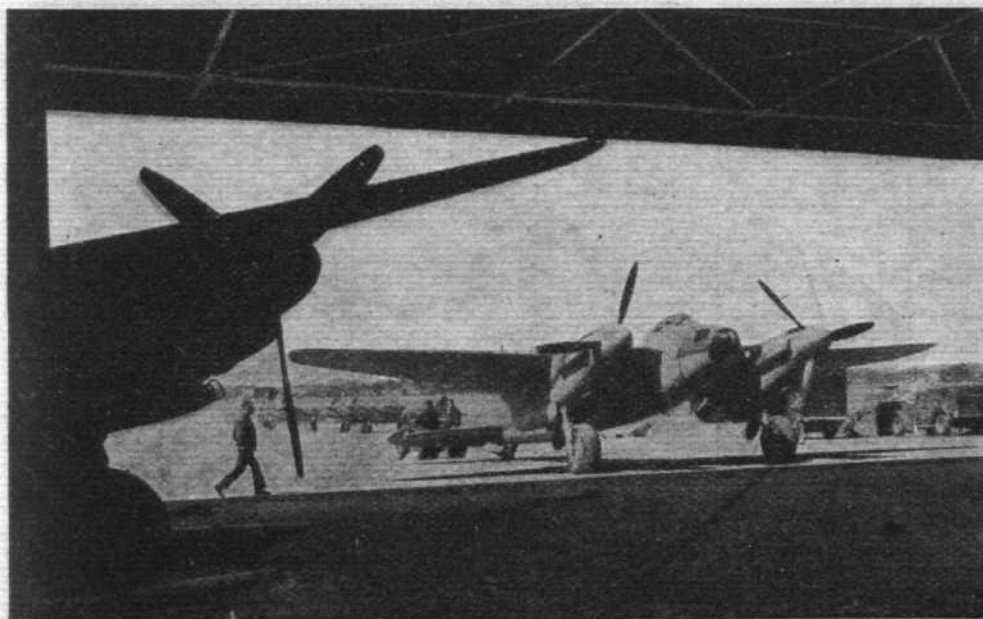
The prime factor simplifying the modern construction of aircraft and component parts in wood is the versatility of the synthetic resins used. Fully to appreciate the modern technique it is necessary to have some knowledge of the resins commonly used. It is proposed, therefore, to begin this article with such a review.

The probability now exists of the whole field of synthetic materials being dominated and expanded still further by "plastics" made from wood. More than any other raw material, wood disregards the boundaries separating substances by their functions, being chiefly composed of cellulose and lignin (about 25 per cent.) and is the prime source of both.

From a geological point of view wood is also the origin of other synthetics, for the process involved in the conversion of wood into coal results in the conversion of the lignin into the bituminous mass coal. When bituminous coal is distilled, among the chief products obtained are coal-gas and coal-tar. From the latter, when submitted to fractional distillation, are collected, among others, carbolic oil and creosote oil. These oils are for all practical purposes the only source of phenols for synthetic resins used in this country and of the group widely used for bonding and impregnation of aircraft materials. Phenol, the chemical formula of which is  $C_6H_5OH$ , is obtained in the form of large colourless crystals which melt when absolutely pure at 42.5 deg. C. and boil at 181.7 deg. C. The grade used in synthetic resin work has a melting range of 41.5 deg. C., the lower melting point being due to the presence of a trace of creosols.

Synthetic resins fall under two distinct groups, thermo-setting and thermo-plastic, the former being widely used in the fabrication of flat panels.

The use of both such adhesives involves the action of high temperatures



An outstanding example of modern British design, the De Havilland Mosquito constructed of wood—mainly plywood.

*Control Press*

## PLYWOOD AND PLASTICS

and relatively high pressures, the resulting bond being stable and permanent. Heat and pressure required with the thermo-plastic resins, however, are not of the same magnitude. Thermo-setting resins experience a chemical change under heat in which water is given off. It may be compared for analogy to cement, inasmuch as once it has set by the condensation of this water, it can never be made to liquefy or flux again. Thermo-plastic resins do

not experience any chemical change, and a plywood panel fabricated in its flat form can later be treated by a source of heat and bent to a desired shape over a form or mould, and when reset will retain its new shape.

Phenol-formaldehyde and urea-formaldehyde resins are of the thermo-setting variety. Thermo-plastic materials may be formed and then reformed many times into definite shapes by the simultaneous application of heat and pressure, providing sufficient plasticising materials be incorporated to impart the proper flow, and the material remains plastic so long as the requisite temperature is maintained. Vinylite resins belong to this class, and have been

TABLE I.—PLYWOOD ADHESIVES AND CHARACTERISTICS

1	2	3	4	5	6	7	8
Adhesive	Blood Albumen	Animal	Vegetable Starch	Casein	Urea-Formaldehyde Resins	Phenol-Formaldehyde Resins	Thermoplastic Resins
Source ...	Dried beef blood.	Hides and bones of animals cooked in water, evaporated, jellied, dried.	Vegetable carbohydrate. Base mainly cassava (tapioca) also potato flour.	Precipitated from milk.	Urea-CH <sub>2</sub> O condensation.	Phenol-CH <sub>2</sub> O condensation.	Chiefly plasticised polyvinyl butyraldehyde.
Form supplied ...	Powder, flake.	Powder, pearl flake, shreds.	Flour.	Powder.	Powder and liquid.	Lumps, powder, liquid and film.	Resin solution in organic solvent.
Cold or hot press...	Hot press.	Cold.	Cold.	Mainly cold, some hot.	Mainly hot, some cold.	Mainly hot, some cold.	Hot press.
Added ingredients of mix.	Water, alkalis, para-formaldehyde, hydrated lime, albuminous adhesives, etc.	Water, some preservatives.	Water, and alkalis (sodium hydroxide).	Water, CH <sub>2</sub> O, preservatives, and alkalis (lime and sodium salt).	Water accelerators, wheat and rye flours.	Alcohol and water, flour fillers.	None, thin with solvent if necessary.
Preparations for use	Mixed cold.	Soaked in cold or warm water followed by cooking.	Generally mixed hot.	Mixed cold.	Some mixed with water only; others accelerator and flour added.	Dry film—nil. Liquid resin—nil. Solid resin dissolved in alcohol and water. Catalyst added for cold pressing, warm setting and fast hot pressing.	None.
Life of mixture ...	2 hours to several days.	Extended if preserved.	Many days.	2 hours to 2 days (preferably short).	Up to 1 day.	Extended period for hot press material. Several hours for cold press resin.	Indefinite. Not reactive.
Spreading and handling equipment.	Roller spreader.	Heater, roller spreader.	Roller spreader.	Roller spreader.	Roller spreader.	Liquids in roller spreader film used as film.	Roller spreader.
Spread, pounds per 1,000 sq. ft.—dry basis.	10-35.	25-35.	20-30.	12-35.	16-25.	25-40 for cold press resin. 10-14 for hot press liquid. 11-12 for film.	6-14.
Pressing temp. ...	180-250° F.	Cold, with warm cauls.	Ordinary room temp.	Ordinary room temp. for cold press, 180-250° F. hot press.	210-240° F.	Room temp. to 320° F.	230-300° F.
Pressing time ...	3 min. for hot press; varies with thickness of panel. Overnight cold press.	2-16 hours.	4-18 hours.	2-18 hours for cold press. 3 min. for thin panels hot press.	3 min. for thin panels hot press. 8 hours for cold press.	3-6 min. for thin panels hot press. Overnight for cold press.	Few minutes to several hours—must be cooled in press or mould.
Moisture content allowed in veneers.	2-3% for faces, 5% or less for cores and crossbands.	As Col. 2.	As Col. 2.	As Col. 2.	Wide range—2 to 100% under special conditions.	2-14% for liquid resin. For film, cores and crossbands 5-10%, faces 2-6%.	3-12%.
Dry bond strength.	Medium.	Very high.	Medium.	Medium.	High.	Medium to high.	Low to medium.
Wet bond strength.	Medium.	None.	None.	Poor to medium.	Medium to high.	Excellent in both hot and cold water.	Medium.
Water resistance ...	Medium.	Poor.	Poor.	Poor to good.	Cold water: good. Hot water: poor.	Excellent.	Medium.
Mould resistance ...	Poor to good.	Poor.	Poor.	Generally poor.	High.	Excellent.	High—not affected.
Heat and fire resistance.	Poor.	Poor.	Poor.	Poor.	Moderate.	High.	Poor.
Moisture transmission.	Marked.	Marked.	Marked.	Marked.	Medium.	Low.	Low.
Exterior durability.	Fair to good.	None.	None.	Poor.	Good.	Excellent.	Poor to good.
Relative cost ...	Medium to high.	High.	Very low.	As Col. 2.	Resin alone high, with fillers low.	High.	High.
Special features ...	Especially suitable for low temp. Hot pressing, most durable of adhesives except resins.	Relatively expensive. Easy to use.	Inexpensive adhesive.	Superior to vegetable glue for wet strength.	Very economical when mixed with flour. Provides a highly water resistant bond set hot or cold.	By far the most durable bond: resists all forms of deterioration.	Flows at elevated temp., must be cooled in press. Will reseat. Piles retain flexibility.

PLYWOOD AND PLASTICS

used with the American "Vidal" process for moulded plywood structures, to be dealt with later.

Purpose of Formaldehyde

The source of phenol having been described, it should be stated that formaldehyde is a gas  $CH_2O$ , the product of wood distillation, also obtained from coke oven or producer gas. It liquifies at  $-21$  deg. C. and solidifies at  $-2$  deg. C. It is prepared by the catalytic oxidation of methanol (synthetic methyl alcohol) at about 450 deg. By this means formaldehyde is obtained as a solution in water and methyl alcohol containing about 40 per cent.  $CH_2O$  by volume or 37 per cent. by weight is known as "Formalin." Formaldehyde is unique inasmuch as it is the only aldehyde to give rapidly thermo-setting resins with phenol and urea. The original phenol-formaldehyde resins were produced by Baekeland, a U.S. citizen of Belgian origin, in the manufacture of his "Bakelite" materials and are still frequently referred to by this term.

"Urea" is the result of heating carbon dioxide and ammonia while at high pressure, whilst Vinyl is derived from acetylene.

Casein has been used extensively in the past as a plywood adhesive, and is a product of skimmed milk. It can be toughened and rendered proof against decomposition by soaking in a formaldehyde solution.

TABLE 2.—PRESSURES FOR USE WITH TEGO FILM ADHESIVE

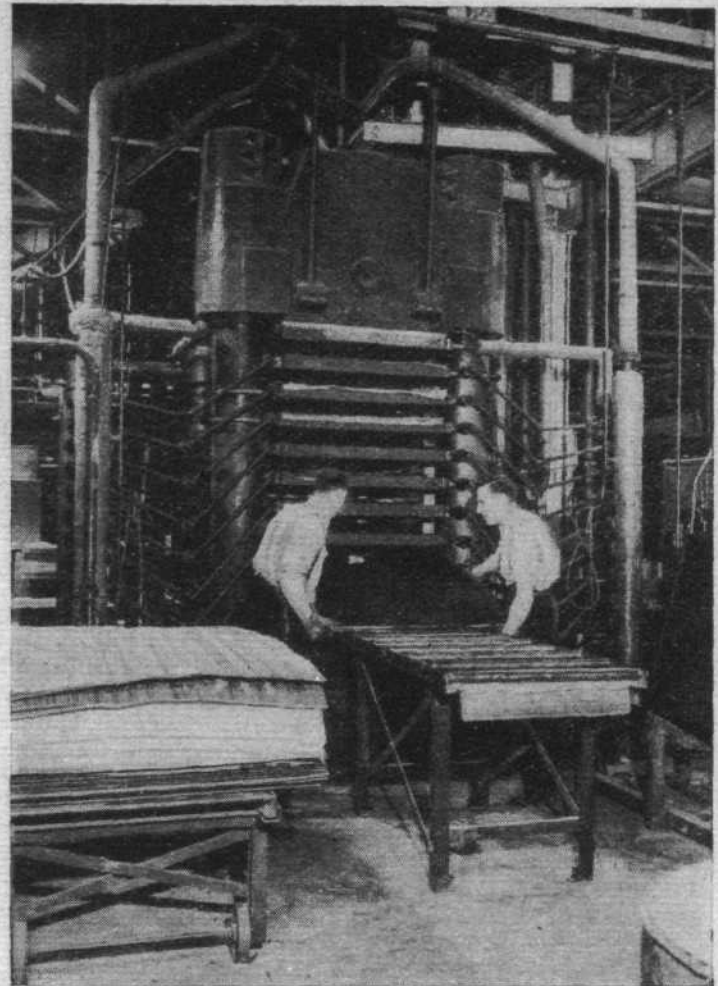
Wood	Pressure, lbs./sq. in.
Pine, Douglas Fir, and Spruce	120/140
Poplar, Basswood	140/150
High-density Woods	150/200
Thin stock of Hardwoods, such as Birch, Maple, Beech	200/300

Briefly the above resinoids are those mainly used either in bonding or impregnating aircraft plywoods, and of these the phenolic resins made from carbolic acid or cresylic acid (cresol) together with formaldehyde and the urea formaldehyde resins are the most common. Characteristics for a group of adhesives are incorporated in Table I, from which is apparent the superiority of the synthetic over those used in the past, included for comparison.

A more detailed examination of the various types under their trade name becomes necessary. Phenol-formaldehyde adhesives are supplied in two forms, as dry film and liquid glues. Of the dry film type, an example is the well-known Tego film made by British Tego Gluefilm, Ltd., a subsidiary of the Micanite and Insulators, Ltd. The successful application of this adhesive is dependent upon the moisture content of veneers—8 to 12 per cent., and a temperature range of 280-300 deg. F. is recommended, the higher value being preferable as it reduces the time necessary to effect a full cure. In the bonding operation a stack of veneers interleaved with gluefilm should be placed in the press with a thin aluminium sheet at the top and bottom of the press. Bonding processes are given in Table 2, with other characteristics shown in Fig. 1.

In general, the pressure should be kept as high as possible without danger of crushing the veneers, since the shear value of the joint increases with bonding pressure. On the other hand too high a pressure may cause warping in the panel. The time which the stack remains in the press is dependent upon the thickness and may run from five to twenty minutes.

Another type of similar film ad-



Laminated material being loaded into a multi-press.

hesive is Plybond, manufactured by Bakelite, Ltd. In this case the recommended moisture content of the veneers is 7 to 10 per cent., which from a later description dealing with the subject it will be seen is general. Pressing temperature should be controlled between 140-150 deg. C., and pressure between 250-300 lb./sq. in.

Time in the press is again dependent upon thickness of board being produced, and may be taken to be 3 minutes plus  $1\frac{1}{2}$  minutes for each millimetre thickness of the board. During the pressing operation moisture is forced out from the veneers, and in order to ensure the necessary joint strength it is desirable to replace this moisture. This is

usually done by treating the boards in an atmosphere of steam, or by immersing them in water and dry off under normal atmospheric conditions. The most important advantage claimed for dry gluefilm adhesives are cleanliness and economy in operation, and the convenience in handling and storage.

Of the liquid phenolic adhesives, Cellobond, manufactured by Cello-mold, Ltd., and distributed by F. A. Hughes, Ltd., is supplied in two forms for cold and hot pressing conditions. For hot pressing, conditions such as in the manufacture of plywood Cello-mold Adhesive-Rocket Resin 1840 is used. It is prepared by mixing 90 parts of this resin and 10 parts of Plasticiser R.M.9.. Immediately before use  $8\frac{1}{2}$  parts by weight of Hardener R.M.36 must be vigorously stirred into the previous mix. Life of the mixed adhesive ranges from half an hour at 80 deg. F. to two hours at 60 deg. F. Pressing should be carried

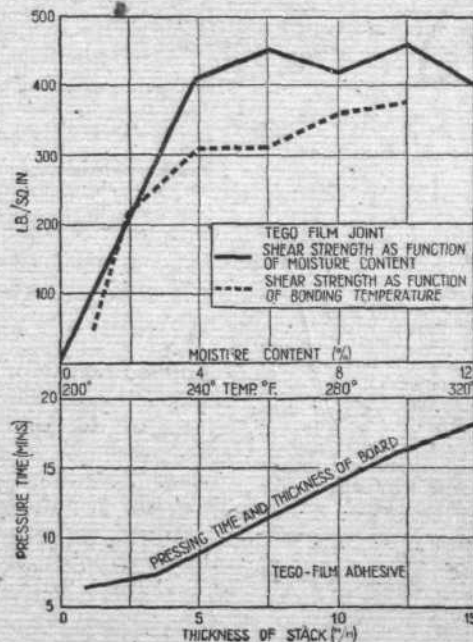


Fig. 1. "Tego" Gluefilm characteristics

PLYWOOD AND PLASTICS

put in presses with platens controlled at a temperature 194-212 deg. F. and pressure should be 100-150 lb. per sq. in. With this adhesive, 5 minutes plus 1 minute per millimetre of wood is recommended as the time required for pressing which should not be commenced until 30 minutes after the application of the adhesive. The urea-formaldehyde adhesives consist of two ingredients, the adhesive and the hardener—usually a weak acid which acts as a catalyst and promotes rapid hardening. In general, only one type of adhesive is marketed, but the use of hardeners to suit varying conditions are specified.

Widely used adhesives of this type are Aerolite and Beetle W and Beetle K for wide-gap joints, and a glue in powder form, Beetle H. Both hot and cold processes are available, and for the hot process two different hardeners are supplied, one for joints which have to be waterproof and the other for joints which must withstand the effect of boiling water.

Cold-press Process

Prior to application, the appropriate hardener is mixed with the adhesive and applied thinly to the wood, approximately 2½ lb. per 100 sq. ft. Wood surfaces should be roughened with sandpaper prior to application. Bonding is carried out in heated presses at a temperature of 90 to 100 deg. C. at a pressure of 28 lb. per sq. in. or more if necessary. With the hardener for waterproof joints the minimum time in the press is five minutes, whereas eight minutes are required for joints to withstand boiling water; one minute for each millimetre of wood being pressed should be added to the above times.

With the cold press, very strong joints can be made. The adhesive has a low water content which facilitates quick drying after pressing, and moisture content of the veneer is not so vitally important with these cements.

The procedure with the cold glue is to coat one side of the joint with the appropriate hardener using 1 lb. per 100 sq. ft., and allow to dry for a minimum period of thirty minutes. A very thin coating of glue is applied to the other joint face 2½ to 3 lb. per 100 sq. ft. After a period of about fifteen minutes the joint faces may be clamped together at room temperatures. Pressure is maintained over a period varying with the hardener used and ranging from two to twenty-four hours.

Beetle cements are manufactured by Beetle Products, Ltd., and temperatures, setting times and hardeners have been tabulated in Table 3.

TABLE 3

BEETLE W CEMENT COLD PROCESS: MINIMUM SETTING TIMES			
Temp., Deg. F.	Setting Time with Hardeners		
	C.H. Orange	C.H. Yellow	C.H. White
50	45 mins.	5-6 hours	30-35 hours
60	30 mins.	3 hours	12 hours
70	20 mins.	1½ hours	4 hours

BEETLE A CEMENT SETTING TIMES, RAPID AND SLOW HARDENERS		
Temp., Deg. F.	Setting Times with Hardeners	
	15 (Purple)	50 (Brown)
50	2 hours	—
60	1½ hours	20 hours
65	—	12 hours
70	1 hour	8 hours
80	½ hour	4 hours

BEETLE W CEMENT: HARDENER MIXTURES FOR HOT PRESS			
Class	Proportions by Weight		
	Beetle W Cement	H.H. Liquid	H.H.12 (Powder)
Waterproof joints	100	10	Nil
Joints to withstand boiling water ...	100	Nil	10

Aerolite cements are manufactured by Aero Research, Ltd., under the direction of Dr. N. A. de Bruyne, an authority on plywood and plastics. Further reference will be made to the work of this establishment.

TABLE 4.—AEROLITE ADHESIVES

SETTING TIME—COLD PROCESS					
Hardener	Temperature, Degrees F.				
	50°	60°	70°	80°	90°
G.B.P. ....	5-6 hours	2½ hours	1½ hours	1½ hours	1 hour
G.B.Q. ....	6-7 hours	3 hours	2 hours	1½ hours	1 hour
G.B.M. ....	10-12 hours	5 hours	3½ hours	2½ hours	2 hours

SETTING TIME: GAP FILLING GLUES AT HIGH TEMPERATURES						
Hardener	Temperature, Degrees F.					
	104°	140°	158°	176°	194°	230°
G.B.P. ...	40 mins.	10 mins.	6 mins.	3 mins.	2 mins.	1½ mins.
G.B.M. ...	60 mins.	15 mins.	8 mins.	4 mins.	2½ mins.	2 mins.

There are a variety of Aerolite adhesives, including Aerolite 300, 301 and 300 F, which differ mainly in their viscosity. Aerolite 300 F. is a stiff liquid designed to "stay put" in gaps where a glue of normal viscosity would run out from the joint. Aerolite 300 is less viscous than 300 F. and can be spread more easily. Aerolite 301 is a low-viscosity glue which is exceptionally easy to spread, but an essential point for its successful application is that it must only be used where time can be allowed for the glue to become really "tacky" before closing the joint. Hardeners for these adhesives are designated G.B.M., G.B.P. and G.B.Q., all approved for aircraft use. The method of use is somewhat similar to the previous cements described, and the period during which pressure should be applied, with the corresponding temperatures, are given in Table 4.

Digressing upon the characteristics of wood veneer and its various applications, the term "plywood," it would seem, may easily become misconstrued. Plywood properly describes the material of any wooden part built up of several thicknesses with the grain of the veneers running in different directions, and is generally used to convey the meaning of boards built up of three or more plies and

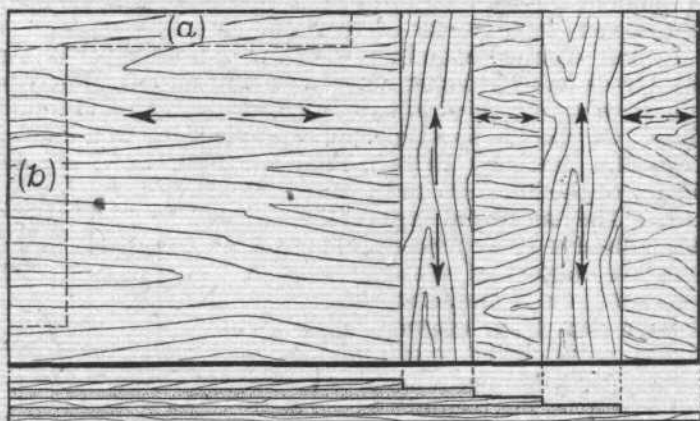


Fig. 2. Plywood specimen (a) grain of face-ply lengthwise (b) grain of face-ply crosswise. Arrows indicate direction of grain.

supplied ready for fabrication in the industry. Wood being stronger with the grain than across the grain, placing the grain of the alternate plies at right angles gives a better proportion of strength and stiffness in the two principal board directions, as shown in Fig. 2. For special purposes, the skin of a fuselage, for example, plywood is sometimes arranged with the grain of the plies at 45 deg. Though this is stronger, it is more expensive to produce.

(To be continued.)

In subsequent articles the production and characteristics of wood veneer are discussed, including moisture-content control and effect.