A Study of Plywood Overlays
As Applied to Douglas-fir Plywood
by
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STATEMENT OF THE PROBLEM

Faced with an ever-decreasing supply of old growth peeler logs on one side and seemingly unlimited market possibilities on the other, Douglas fir plywood manufacturers have launched an extensive program of research and experimentation on the use of various types of overlays and surfacings to be used on their product.

While the results of these studies are by no means complete, several companies have, in the past few years, manufactured commercial products of various types, progressively improving fabrication techniques and properties of the finished panels.

It is the purpose of this thesis to discuss the most important of these overlays, together with the factors influencing their use.
I HISTORY OF DOUGLAS FIR PLYWOOD

Although the science of gluing wood dates back to the days of King Tut and has been practiced in the United States since Revolutionary days, it was not until 1905 that Douglas Fir plywood, as such, was manufactured. The first panel was glued in a small plant at St. Johns, and was quickly followed by plants at McCleary, Sedro Woolley, and Tacoma, all in Washington (1). These first plants usually were limited to departments of door factories, and produced little plywood beyond that needed for their own immediate requirements.

Development was slow and it was not until 1917 that the name "plywood" was adopted for this specialized wood product. At that time, the need for a wartime construction material created a moderate increase in demand. Even then, plywood did not become too popular in the construction or industrial trades. The non-moisture resistant vegetable and animal glues together with the cold press method of gluing used at that time permitted only interior use of the product. About 1935, the waterproof synthetic resin glues were "discovered". These, together with the development of the hot press, completely changed the techniques of gluing to produce plywood which was suitable for use in all extremes of weather and climate. The demand for plywood since that time has steadily increased, and production figures have consistently climbed. In 1927, only 206 million square feet of plywood was produced in the region, but by 1942 this had risen to 1800 million square feet (this is on 3/8" basis) (2). During the war years, production dropped slightly due to labor and machinery shortages, but all indications point toward a rapid return to the higher figure.
II NEED FOR FACINGS AND OVERLAYS

A. Shortage of old growth peelers for clear face stock

One of the major problems facing Douglas-fir plywood manufacturers is the ever-decreasing supply of clear, fine-textured, smooth-grained, old-growth timber, which provides the large amount of clear stock needed for face material. Before any cutting was done in the forests of the Pacific Northwest, there were 14 million acres of old growth Douglas-fir in Oregon and Washington. By 1940, slightly more than 50% of this timber had been cut, there remaining 6.9 million acres, three-fourths of which is in Western Oregon. The following table shows the past and estimated future rates of depletion in the various areas within the region (3).

<table>
<thead>
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<th>Area</th>
<th>Estimated Acreage of Old Growth (Thousands of Acres)</th>
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<td>Puget Sound</td>
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<tr>
<td>Grays Harbor</td>
<td>1284</td>
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<tr>
<td>Columbia River</td>
<td>1433</td>
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<td>Willamette Valley</td>
<td>2001</td>
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<td>Oregon coast</td>
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<tr>
<td>Southern Oregon</td>
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<tr>
<td>Year 1933</td>
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<tr>
<td>Puget Sound</td>
<td>3186</td>
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<td>Grays Harbor</td>
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<td>Southern Oregon</td>
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<td>Year 1965 (Assumed)</td>
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<tr>
<td>Puget Sound</td>
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<tr>
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It is estimated that the supply of old growth Douglas-fir within economical transportation distance of Grays Harbor and Puget Sound will be exhausted in ten to twenty years if the present rate of cutting is continued. Most plywood producers own little, if any, timber of their own, preferring to buy logs on the open market. In the early days of the industry, the heavy concentration of factories was near the tidewater log markets of Puget Sound and Grays Harbor. Even as late as 1937, there were only 2 mills in Oregon and 19 in Washington. But with the gradual cutting out of the timber
resources in that section has come an expansion and shifting of the geographical center of the industry to the south. At the present time, there are 11 mills operating in Oregon, plus 6 veneer cutting plants, and 20 mills in Washington.

Further expansion of productive capacity is questionable. It is felt by many officials that the pre-war plant capacity is sufficient to fill the needs of all civilian markets, despite the present heavy demand, and that once the military forces have reduced their orders to normal size, the problem will be merely one of channeling the plywood products into the hands of civilian users.

Prior to 1937, only #1 peeler logs of the largest size were used in plywood manufacture. As these high grade logs become more and more scarce, operators are being forced to use inferior grades and smaller logs. This trend will, in all probability, continue in the future, possibly to the point where the use of second-growth will become a necessity. This means, of course, less clear stock for faces.

The situation can be overcome partially by the use of taped stock, thinner face veneers, and closer utilization in general. But even these measures reach a limit. Something more must be done, and it is here that plywood manufacturers turn to the obvious answer of facings and overlays.

B. A means of overcoming the limitations of conventional plywood.

While plywood has many advantages over lumber, including greater dimensional stability, non-splitting qualities, and distributed wood strength, some other characteristics of wood are retained. A more detailed study of Douglas-fir plywood would reveal the following facts:

1. The pronounced tendency toward hair line checking and grain raising of plywood faces when in service, even though well painted or otherwise protected, has prevented its use in many cases where it would otherwise be
entirely suitable. A thin surfacing, of plastic or other materials, would not only cover the surface checking, caused by changes in moisture conditions, but would also eliminate grain raising, which is due to the difference in density of the spring and summer wood in the rotary-cut face veneer. This would produce a product of more stable characteristics.

2. Another poor quality of conventional plywood is low resistance to abrasion. This is a troublesome problem under dry conditions but becomes greatly magnified when the plywood must be used where it is subjected to continuous soaking. In boat construction, for example, a large amount of abrasion at the waterline is caused by striking objects that are floating in the water. Also, repeated scraping to re-new paint soon wears through the thin face veneer. In many cases, this necessitates replacement of that section of the hull before the rest of the boat is affected to any degree.

3. Unprotected wood has a very high rate of moisture pickup and vapor permeability. As wood becomes wet, it swells and tends to lose much of its strength. In plywood, this swelling causes internal stresses to be set up which may, because of the weakened condition of the wood, or the softening of some of the glue lines, cause blistering or delamination. Blistering has also been noted in some of the waterproof grades, even though the glues are not affected by moisture. This may be caused by too high a veneer moisture content at the time of bonding.

4. Wood is a highly combustible material. Most of the glues used in plywood, interior grades will delaminate when exposed to combustion temperatures. Today, even fire-resistant, but some will cause delamination when subjected to extreme heat. This exposes the veneers to flames, and permits them to burn more readily. Most of the overlays now in use are extremely fire resistant than wood and thus improve the overall efficiency of the panel, and will protect the wood from charring or igniting.

5. Unless heavily painted or treated in some manner, plywood is not stainproof or readily washable. Even then, the protective coating may be but partially effective and must be renewed at regular intervals. This process is
costly. A surface which does not have the porous characteristics of wood, and which would make the panel impervious to alcohol, grease, chemicals, oils and water would be desirable.

6. For interior use, a construction or decorative material must have properties which will give stable aging characteristics. All woods change color when freshly-cut surface is exposed. Douglas-fir assumes a peculiar color - a characteristic reddish brown. To many, this coloring detracts from the natural beauty of the wood and alters its aesthetic value.

7. For exterior use, the change in wood color is accelerated by extremes, in weather conditions. A transparent overlay to preserve the natural beauty of freshly-cut wood would make it more useable for outdoor decorative purposes.

C. Offers an improved architectural material

The industrialists, the engineers, and the architects of the country are continuously engaged in a search for new and better materials with which to effect their plans. In Douglas-fir plywood, combined with a suitable type of overlay, they have found such a material. The strength and stiffness of plywood supplemented by the properties of other substances, make it adaptable for myriad purposes. These plywood and overlay combinations result in an architectural and engineering material which possesses a high degree of strength, light weight, beauty, hard surface, plus both water and heat resistance. This enables industrial manufacturers to build products that give better service and performance, at the same time allowing speedier production at lower cost.

III FACINGS IN COMMON USE

In the past few years, the number of materials that can be used for overlaying veneer or plywood have greatly increased. The design, color, and texture of surfaces now obtainable are limited only by imagination and economics. The scope of this paper, however, will be limited to those which in general have proved themselves to be economically feasible, and have been accepted for use by
industrial and construction consumers. These materials, as listed by Knauss (4), include:

a. Face veneer of wood of a species other than that used for the major portion of the plywood.
b. Paper material impregnated with resin.
c. Finely divided wood materials impregnated with resin.
d. Plastic sheets of non-wood material.
e. Metal sheet material.

The panels produced by each of these overlays are completely different in their production methods, physical properties, cost and usage. For these reasons, each type should be considered separately.

A. Face Veneer of a wood of a species other than that used for the major portion of the plywood.

The use of face veneers of a species other than that of the core stock has been practiced for years. This is done to obtain desired physical properties, to conserve rare and costly species, and for economic reasons. Exotic species are often cut into very thin veneers and used as facing material for plywood made from less costly or more readily available species in order to extend the footage of the rarer woods. For example, Douglas-fir has often been faced with Philippine mahogany, which has a more pleasing appearance, is more durable, and is comparatively free from surface checking. In the furniture industry, this practice is common, and both eastern and western hardwoods have been used.

The gluing problems involved in this type of overlay are relatively simple. Wood-to-wood joints are easier to make than most, as wood has a very high affinity for almost all of the commercial glues now used. Almost without exception, present day bonding agents are able to produce shear strength values above those of wood itself, which is the practical limit in plywood manufacture.
Wood overlays have not proved entirely satisfactory, as even the denser hardwoods still possess most of the unfavorable characteristics which limit the use of Douglas-fir plywood faces unsuitable for many construction and industrial needs.

B. Paper materials impregnated with Resin

Of all the materials now used for overlay purposes, the phenolic-resin impregnated paper and pulp sheets have been most favored by Douglas-fir plywood manufacturers. These papers can be easily adapted to the mass production methods now used to produce conventional plywood. Their wide range of physical properties enables them to be impregnated to any degree in order to produce faces of distinct texture and finish, from a soft, absorbent surface to a hard, transparent, plastic type face. They have strength properties of their own, which will contribute to the finished product. Certain types are capable of taking color, prints, lithograph, or photographic reprints, making them ideal for specialty products. The presence of many paper mills here in the Northwest will make them available in sufficient quantities and types to fill the needs of most manufacturers.

Divisions of paper material overlays

Division of the paper laminate overlays are made on the basis of the degree of manufacture in the paper mill. The first is paper, the finished product of the paper company. It usually comes to the plywood manufacturer as a relatively thin, high-strength paper impregnated with phenolic resin to 30 to 50% about 50% of the dry weight of the sheet. The second is a pulp sheet, which is considered a raw material by the paper mill. It is also impregnated with phenolic resin, but usually to a lesser degree, 25 to 30% being a common resin content.
Paper - The use of paper for the resin carrier is logical on the basis that it is, in normal times, available in caliper, strength, and widths necessary to conform with the many types of overlays which may become popular (5).

The high tensile strength papers now in use are, for the most part, developed from the Kraft, Mitscherlich, or sulphite processes. The strength characteristics of the various papers may differ because of the properties developed in the beaters and dryers of the paper mill, but the final strength imparted to the finished panel will depend principally on the type and content of resin incorporated into the carrier sheet.

High strength papers have one distinct disadvantage. Because they are thin - standard thickness is usually about .015 of an inch and the run of the mill between .003 and .012 of an inch (5) - they do not have a dependable masking quality. Many deformities of the face veneer will readily show on the finished panel. This makes it necessary to use face stock that is perfectly clear or that has had all defects repaired in order to provide a smooth base for the overlay. Additional sheets may be added to increase the structural or other physical properties of the panel but these will not contribute to the masking effect, especially if the resin content of the sheet is in the higher range of 25 to 30 per cent.

In the case of very thin plywood, or veneer only, the overlaid paper adds considerably to the bending strength and stiffness factor of the panel (6). This, however, is more important in the woods used for aircraft purposes and is not of special concern to Douglas-fir plywood manufacturers.

This method of combining the desirable qualities of thermosetting resin-impregnated paper laminates with the high strength and low cost of Douglas-fir plywood produces a product of outstanding properties. These are listed by Darling (7) and include:
a. Hard, high abrasive resistance
b. Imperviousness to gas, oil or alcohol
c. Extremely low water absorption and vapor permeability
d. Fire and flame resistance
e. Resistance to temperature changes
f. Good machining, forming and fastening characteristics.

A detailed account of the properties of one commercial type of paper overlay may be found in Table I of the appendix.

Pulp - The use of an impregnated pulp type sheet as a plywood overlay presents a number of interesting possibilities. Because of its low density, this material will cover blemishes and gaps in a defective face, yet at the same time present a smooth overlay surface. This superior masking characteristic becomes more important when we consider the changing quality of veneer face stock. The fact that it may be used with a resin content as low as 15 to 25% makes it economically attractive. The reduced cost of the resin combined with the lesser expense of pulp sheets when compared to paper, allows the manufacturer to put on a much thicker overlay for an equal cost, giving the overlaid product as good or better strength characteristics.

The low resin content pulp sheet type of overlay is not intended to be used without paint or some other protective surface covering. The soft, smooth face can be readily painted and is receptive to various kinds of adhesives, making it a good base for additional overlaying with a better quality finish. It is extremely workable, lending itself readily to the forming and fastening procedures used for regular plywood.

Although pulp screenings have found little use for overlay material, chiefly because of their appearance, the small pieces of dense material cannot be screened out by any practical means, and show up as dark flecks in the sheet, and are unattractive to some people. This "oat meal" finish is unattractive. This problem is receiving attention,
as it is felt that the possibility of developing a salable product from pulp screenings is favorable.

Assembly techniques for applying paper overlays

Fabrication techniques vary between the different overlay materials of this class, and even between different mills using the same type of overlay. In general, however, three different processes are used in the Douglas-fir region to produce the finished panel (6).

The earliest method used to combine the overlay and the wood base is sometimes termed "gluing pre-formed laminates". This method, still in use by many eastern firms, consists of merely gluing the finished overlay to a completed plywood panel by means of an additional glue line. This allows all of the defects in the face of the panel to be repaired, thus presenting a surface for gluing which is free from irregularities. The many fine products turned out by eastern manufacturers testify that this method, if done correctly, will produce panels of the best appearance.

A second method, called the "two-step" assembly, was developed in 1943. Here a number of short-cuts are taken to cut down time spent in re-handling materials. Essentially, this process consists of gluing the partially cured overlay to veneers by the conventional hot press methods. These laminates are then utilized as face veneers, to be laid up and glued in the usual way. The resulting panel emerges from the press as "surfaced" plywood.

Neither of these processes, however, were well suited to the mass production schedules desired by the industry. Experimentation aimed at reducing both production time and net cost resulted in the development of a third application method, known as the "one-step" process. It consists of laying up the partially cured overlay as if it were a face veneer, then
curing and bonding the whole assembly in one operation. Often, a separate glue line is unnecessary, the flow of the impregnating agent in the overlay being used as the bonding material. A slightly longer pressing schedule is required for the simultaneous curing and bonding of the combined overlay and plywood assembly, but this is more than offset by the reduced handling of materials.

Resin -- types and content

It is recognized that the synthetic resins, used to impregnate the carrier sheets are usually more important than the sheets themselves. A detailed discussion of the resins would constitute a complete report in itself; no attempt will be made to do so in this paper. However, for the purpose of clarifying the various overlays, a brief outline of some of the more important resins will be given.

Synthetic resins are usually classified according to their behavior after the initial condensation or polymerization. Under this classification, there are three main groups: (5)

Thermosetting - This group consists of resins, which become infusible under heat and cannot be re-softened. They include the phenol and cresol formaldehydes, urea formaldehydes, melamine formaldehydes, aniline formaldehydes, glyceryl phthalates, polyolefine resins, the modified ester type styrene thermosetting copolymers, etc.

Thermoplastic - These resins remain thermoplastic and can be softened by the application of heat. The members of this group include the cellulose compounds (cellulose acetate, nitrate, acetate-butyrate, ethel cellulose, etc), the vinylstylene acrylic resins, the synthetic rubbers, etc.

Element-convertible resins - These become infusible through the action of certain elements such as sulphur or oxygen.
The only resins of importance and interest in the overlay field are those of the thermosetting type. Of these, the phenol-formaldehyde is the only one which, so far, has found wide use as an impregnating agent. Its good handling characteristics, comparative ease of manufacture, good physical and chemical properties, and reasonable price, all combine to make this resin acceptable to the overlay producer. It has the disadvantage however, of having a natural amber color which prevents the production of overlays of light or pastel colors. Light color phenolic resins are available, but they darken when exposed to sunlight.

Phenol-formaldehyde resin is manufactured by heating phenol and formaldehyde together in a suitable tank. During the process of development the resin goes through several distinct stages. The first stage is known as the water-soluble stage. Further progression of the reaction to the second stage, makes the resin less soluble in water but soluble in alcohol. From here, the reaction progresses through phases of toluene-xylo1 and acetone solubility and emerges into the insoluble stage.

During the stages of reaction, the molecules of the resin are arranging themselves into longer and more complex chains. Resins derived from the first and second stages, or the water-soluble and alcohol soluble stages, are sometimes distinguished as resins of low and medium molecular weight. The range extends from a molecular weight of 100 to 200 for the low, and from 400 to 1,000 for the medium. The low weight resins are best known for their high degree of penetrability. Resins of medium molecular weight have much better abrasion and moisture-resistant properties, but carrier sheets impregnated with this type resin are noted to have uneven penetration. Experiments have been carried out using a carrier sheet impregnated with both types, but this has not been successful, chiefly because of additional handling and higher costs.
Urea-formaldehyde resins, though available in quantity and produced at a slightly lower cost than the phenolics, have not become popular. This is due, for the most part, to the fact that they become brittle and check excessively when exposed to moisture. Urea has an affinity for moisture which magnifies these characteristics. It has the advantage, however, of being colorless, odorless, tasteless, and possessing a high degree of light stability. For these reasons, it may find a place for many specialty uses.

Melamine-formaldehyde resins are not widely used because of their extreme brittleness and poor machining qualities, especially when exposed to moisture. Their advantages include good abrasive resistance, excellent light stability, fair moisture and chemical resistance. They are becoming increasingly popular where light and pastel colors are desired.

Thus far, the thermoplastic resins, with the possible exception of cellulose acetate, have found very little use in the overlay field, and the element convertible resins practically none.

Once the type of resin has been selected, it is necessary to decide the amount of resin which will be put into the overlay. This is spoken of as the resin content, and is usually measured as a percentage of the dry weight of the carrier sheet. There are two general types of overlay which can be obtained by varying the resin content. Either type may be developed in a paper or a pulp carrier sheet. The first type is a low resin content - usually of 15 to 25% but sometimes as low as 10%. This produces a soft-fibered, opaque surface which has a high affinity for paint, glue, sealers, and other such materials. When the resin content is increased to 50-65%, the overlay provides a transparent, smooth, glossy finish, which, although it has a very high moisture and abrasive resistance, is quite brittle and will not accept paint or glue as readily as low content overlays.
The choice of an opaque or a transparent surface depends, of course, upon the wishes of the manufacturer and the uses for which the panel is intended. An opaque surface is used where it is desired to hide the natural defects in the base wood. Low resin content overlays have the added advantages of easy handling, low bonding pressure, and low resin cost. Such a surface may be obtained in several different ways. These include:

a. Bonding un-impregnated paper to core by means of an additional glue line. This is not very desirable, as it leaves the paper entirely unprotected.

b. Low resin-impregnation of the paper plus an additional glue line. This gives protection to the paper but not to the fibers.

c. Addition of opacifying pigment to high resin content paper. No additional glue line is required.

Paper will become translucent at about 55% resin content. Transparent overlays produced in this manner have been highly developed by manufacturers in the east. The method of obtaining this high transparency is still a commercial secret but involves:

a. Type of fiber used.

b. Treatment of stock in fiber preparation.

c. Type of resin used.

d. Method of introducing resin into the fibers.

Methods of impregnation

The carrier sheet may be impregnated with resin by one of two methods. In the first, and older, method, the resin is added to the paper as a secondary step after the paper has been completely finished. This is also known as the vat method. The carrier sheet is unrolled from its usual roll form, passed through a heated vat of resin, through squeeze rollers, and then
through a dryer, which is usually of the tunnel and chain belt type. The heat for drying may be furnished by hot air, steam coils, or infra red lamps. By varying the degree of heat and the length of time in the tunnel, any desired degree of condensation, even up to the complete curing of the sheet, may be obtained. The vat method is not completely satisfactory, however, as the resin tends to concentrate on the surface of the sheet instead of entering and surrounding the fibers, as desired. The use of pressure rollers just before paper enters the vat, plus suction cups in the bottom of the tank, partially alleviates this condition. As the paper passes over the cups, resin is drawn into the center of the sheet.

In the newer method, developed in recent years, the resin is added to the pulp during the process of paper manufacture, before the paper sheet is formed. This makes the paper a homogeneous mass, and insures even penetration of the resin. The paper is then dried and processed in the regular manner. Microscopic examination reveals that the resin appears to actually enter the fibers. This method gives a much better bond, as well as producing a greatly improved overlay sheet.

Either type becomes self-bonding at about 35% resin content. With the vat method, the problem in bonding is to get enough resin through the sheet to make the bond. In the second, or newer, method, the problem is just the opposite. Here it is sometimes difficult to get enough resin out of the center of the sheet to allow the proper bond.

**Condition of materials**

The successful bonding of the resin-impregnated overlays requires constant attention to the condition of the materials. The moisture content of the base stock must be between 5 and 8% to conform with the moisture content of the overlay sheet. If the moisture content is too low, the result is inadequate bonding, while a high moisture content will cause blistering in the
panel. The paper must be of the proper resin-content to obtain the result desired. The glue used to bond the plywood must be of a type that will not be affected by the high temperatures and pressures necessary to bond the overlay. For example, urea resin will not withstand the temperature used for phenolic resin paper. The resin must have as low a volatile content as possible. Finally, the base stock used for a transparent high resin content overlay must be smoothly sanded or planed and all defects repaired.

The actual bonding operations are very similar to those used for conventional plywood. The pressures and temperatures must be kept constant. The pressures used are 100 to 200 p.s.i. for opaque, and a minimum of 250 p.s.i. for transparent overlays. The curing temperatures range from 300 to 310 degrees F. for phenolic and from 270 to 300 degrees F. for melamine resins. Curing cycles are from 5 to 20 minutes, depending on the type and per cent of resins used, the moisture content of the panel, and the rate of heat transfer.

Use of Cauls

When the overlaid panel is put into the hot press and subjected to heat, the heat causes the resin to flow and mold itself to the surface which is pressing against the panel. The surface of the finished panel will then be a reproduction of the surface which was pressed against it, much in the manner of a mold. To control this surface, thin metal sheets, known as cauls, are placed between the platen and the panel. For a glossy finish, a highly polished caul is used. A sheet of cellophane may be inserted between the caul and the panel to obtain a very high gloss finish. A low finish caul will produce a matte finish panel. A fine wire screen placed on the panel will produce a skidproof surface. A caul with a design etched upon its surface will produce a panel with the same design imprinted in the resin.
In most cases the cauls are galvanized sheet steel of 16 to 18 gauge, but other metals such as stainless steel and aluminum will be used when they become available in quantity. The cauls must receive meticulous care, for any dirt or surface irregularity will show on the panel. It usually is necessary to lubricate the cauls with zinc or aluminum stearate to prevent excess resin from sticking to them. The same result may be accomplished by placing a lubricating agent in the resin.

C. Finely divided wood material impregnated with Resin

As yet, comparatively little information is obtainable concerning this interesting overlay for it is just coming into production. Many operators believe, however, that the possibilities of this product are extremely promising, both from a market and a utilization standpoint.

The overlay is made by mixing phenolic resin with sander dust or sawdust and pressing this mixture onto a plywood panel by conventional hot-press operation at about 200 p.s.i. (8). The type of finish produced varies with the resin content, which can be from 10% up, but generally a smooth, uniform, opaque surface results. It is very receptive to paint, varnish, or further overlaying, and it is intended for this type of treatment.

Probably the most important advantage attached to this overlay is its ability to cover defects in the face veneers, being similar to the resin pulp sheets in this respect. It also has the advantage of utilizing a material which heretofore has been considered as waste, and for this reason is expected to gain popular favor among plywood manufacturing companies.

D. Plastic sheets of non-wood material

Most of the products in this field of overlays are produced by eastern manufacturing companies. Usually the companies make their own over-
layment, purchase commercial plywood, and apply the faces at their own plant. Plywood operators in the Douglas-fir region are interested in this overlay, however, as it is felt that it is entirely possible to ship the plastic to the plywood plant and complete the process there.

So far, the thermosetting plastics are the only ones that have been used commercially to any great extent. The limitations imposed by the inherent characteristics of the thermoplastic and the element convertible plastics have proved to be too stringent for all but specialty uses.

Most of the overlay sheets made are similar to one another, and a description of one typical operation should adequately outline the processes used to produce these fine panels. The overlay sheet is usually made up in three layers. The first is a phenolic resin impregnated paper or fabric. The second is the decorative layer, and can be either a melamine impregnated fabric, a veneer, a plastic of pure color, a multi-colored plastic, or a paper upon which a design has been printed. The third is a transparent melamine-impregnated paper sheet of extreme thinness. This 3-ply assembly is placed in a hot press with a highly burnished caul on the face side to produce a high glossy finish. The curing schedules are, approximately, 45 minutes time, 1100 p.s.i. pressure, and 350 degrees F temperature. The overlay is then in its finished form, a completely cured sheet 1/16" thick, which is later glued to plywood. (9). Because of the variety of materials and colors which can be used for the decorative layer, almost any imaginable design can be obtained.

An important feature of some grades is the incorporation of an aluminum foil directly beneath the decorative, or second, layer. The purpose of this is to produce a surface which is impervious to cigarette burns, a serious drawback for most table-top surfaces. The metal foil rapidly conducts the heat away from the point of contact and leaves the surface unmarked.
Several special problems are encountered in gluing this type of overlay on plywood. The most efficient means is by use of a heat reactive synthetic resin glue, since this reduces the setting time and makes a very good bond. Although experiments have been made using a liquid, cold-setting synthetic resin glue, most manufacturers are still using a water-resistant casein glue with satisfactory results. There are several reasons why manufacturers continue to use casein glue for this purpose. First, temperatures above 150 degrees F. cannot be used because the melamine surface tends to soften and imperfections in the overlay will result. Second, the variety of products that are manufactured involve many simple compound curvatures, which are difficult to bond in a conventional hot plate press. Third, high frequency heating methods cannot be used to glue the cigarette-proof grades as the current will follow the aluminum foil instead of the glue line and will not set the glue (10).

The plywood is first cut to size, 1/16" scant on the edge if plastic edging is to be used. The edgings are glued on using bar clamps or "c" clamps. Next, the core is run through a sander to make the edges perfectly uniform with the top surface. The glue is hand spread, the face and back overlay sheets are placed into position, and pressure is applied by means of hand screws or a hydraulic press. Assembly time is critical, 15 to 20 minutes being the maximum. After a curing period of 6 to 8 hours, the edges and corners are trimmed and sanded with specially designed tools.

Although these procedures, if carefully followed, produce a material which possesses both usefulness and beauty, the cost is extremely high, when compared to other overlaid plywoods. Until shortcuts can be found for the many progressive operations now necessary, and the slow, tedious gluing methods are replaced by faster, mass production methods, this product will remain in the high price field. Both plywood and plastic manufacturers are attempting to solve these perplexing problems.
The plastic overlays first gained wide use as table and counter tops. This is still one of the principal markets of overlays, but as more colors, designs, and patterns have become available, their uses have been broadened to include wall paneling, furniture, decorative door covering, cabinets, elevator cab interiors, phone booths, office partitions, to name only a few. Interior decorators and architects have come to recognize this fine product for its smart, modernistic appearance, durability, and adaptability for a multitude of purposes.

E. Metal Sheet Material

The bonding of plywood and metals presents a challenge to the ingenuity and resourcefulness of adhesive research men and plywood manufacturers alike. The problem of producing an overlaid product from these two unlike materials which will combine the desirable qualities, yet at the same time eliminate the poorer characteristics of each is not an easy one.

The metals are characterized by high density, surface hardness, fireproofness, and high strength, although they are heavy and, in thin sheets, lack stiffness. On the other hand, wood is light in weight, has good insulating values for heat and sound, is moderate in cost, with excellent stiffness factors and in all cases is easy to work (11).

The problems in bonding are complex. First, wood is extremely porous and has a high affinity for glue. Metal is dense, and presents a smooth, hard surface which most glues will not penetrate. A great amount of time and effort was expended in attempting to glue a surface of porous nature to a more dense layer before the phenomenon of specific adhesion was recognized.* Because of the affinity for glue by the more porous surface, the glue would make a suitable bond on that side only, the penetration on the

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* A more detailed discussion of the fundamentals of adhesion will be found in the Appendix.
denser surface being inadequate. Now the problem has resolved into that of developing a glue which will have duplex characteristics. It must have high specific adhesion for the benefit of the metal, yet at the same time possess a capacity for mechanical adhesion on the wood side.

**Glue development**

As far back as 1920, Casein-latex glue mixtures were used for wood-metal bonding for aircraft purposes (12). The initial results obtained were satisfactory, but this combination was not too effective when exposed to severe weather conditions. However, very little progress was made in developing other glues until the advent of the synthetic resins about 1935. Improved bonding techniques developed by the plywood industry were soon emulated in the wood-metal field, providing many new opportunities for the utilization of this excellent product. Another important contribution to the development of bonding processes for plymetal was the wartime demand for a metal-to-metal glue by the aircraft industry. For aircraft purposes, the conventional methods of joining light metals were impractical. Riveting added weight where every pound decreased speed and payload, and likewise produced a rough, air-resistant surface. Welding the thin metal was difficult and induced objectionable stresses at strategic points. The research was directed toward finding first, a metal-to-metal bonding agent, which could then be adapted to the gluing of metal to wood, fabric, plastics, or any other porous material. This was accomplished through the combined efforts of government agencies and private industrial research.

**Methods of gluing**

There are several procedures for metal-to-wood bonding as follows:

(11)

a. Metal adhesives on one with wood adhesive on the other mating surface, single stage process.
b. Adhesive coated metal surfaces, two stage process.

c. Film adhesive, interlaid in joint, especially for plywood.

d. Non-plywood applications, as solid wood to metal.

The first three methods are, in general, designed for gluing of relatively wide areas, as would be found in bonding plywood panels. They are not intended to be alternate procedures, but each manufacturer should select the one most suitable to his needs, basing his decision on the ultimate use of the product, equipment available, the strength and durability desired, and cost limitations. The commercial glues now on the market usually are formulated for only one particular procedure.

The first method, which is comparable to the "one-step" process used in bonding paper laminates, is accomplished by placing a suitable metal adhesive on the metal surface and a compatible wood adhesive on the wood side. For all metal bonding, the metal must be thoroughly cleaned by a degreasing solvent, treated by acid etching, or scoured with soap. It must be clean enough to carry a continuous water film. In some cases, the metal may have to be slightly roughened to present a better gluing surface. The assembly time in this process is not critical, and in case liquid resin is used for the metal adhesive, sufficient time must be allowed for the solvents to evaporate. If this is not done, blistering will result when heat is applied. The two surfaces are brought together and placed in a hot press. Curing conditions vary for each type of assembly and between operations, but generally the ranges are from 250 to 300° F. for temperature, 50 to 250 p.s.i. for pressure, and 10 to 30 minutes for time. For thicker metals, the heat may be reduced to 175 to 200° F. before the pressure is released to prevent excessive internal stresses. The main disadvantage to this process is the fact that the bond is cured while the metal is in a heated, or expanded state.
As the assembly cools, the undesirable internal stresses are set up by the contraction of the metal. However, the glues now used are designed to take care of this situation and still maintain a bond of great strength and durability.

The second, or two-stage process, may be compared to the "two-step" procedure in resin paper bonding. In this case, the adhesive is placed on the metal, after suitable cleaning, and completely cured by the hot press method. At an indefinite later time, after the metal has cooled, it is then bonded to the wood, using a resorcinol formaldehyde resin at room temperature. The metal adhesive may also be cured without pressure by placing the sheet in an oven and baking. This leaves a comparatively rough glue surface which is sanded or planed to present a smooth face for subsequent bonding. Many advantages are claimed for the process, the principle one being that the final bonding of metal to wood may be accomplished at room temperatures. In this way, the panel is not subjected to the opposing internal stress set up by the cooling metal, and the joint is not weakened. Douglas-fir plywood manufacturers are giving particular attention to this process because they feel that it is adaptable to present production methods. The metal sheets, with the primer adhesive already cured on its surface, can be delivered to the plywood mill. The final bonding of the veneer and metal assembly to form the finished panel can be completed in one step by the plywood operator.

The third method of bonding metal-wood combinations involves the use of a film glue, much on the order of the phenolic film resin developed for plywood. The adhesive in the one and two stage methods are composed of two components, but the use of the film makes it possible to lay up and bond the whole assembly in one operation. This method is recognized to be the cheapest and simplest of the three, but requires special equipment, including annealing ovens to de-grease the metal, as the regular cleaning methods are
not sufficient. So far, the use of the film has been confined to the bonding of very thin aluminum, from 0.010 inches on up (11). The heat-cured bond has excellent durability and shear strength almost equal to that of wood. For the most part, the aluminum foil has been bonded to each side of 1/16" veneer to form a 3-ply panel that is extremely pliable, and can be stamped and punched to fit a variety of forms and uses. Further experiments are being carried out to make the film glue suitable for the bonding of metal and conventional plywood.

**Strength data**

The strength/weight ratios and the stiffness factors developed by the various combinations of wood and metal are phenomenal, and are far above other materials of similar weight and thicknesses. Table II of the appendix shows stiffness factors for various types of plymetal.

The principle metals used so far include galvanized steel, aluminum, stainless steel, and to a lesser extent, copper. Steel was the first to be used, but gave way to the superior lightness and rustproof qualities of aluminum. Stainless steel became popular for much the same reasons. The bonding of copper as yet has not been too successful, but it is hoped that further research will correct this situation.

**Uses**

Plymetal first gained wide use in the transportation field. The trailer house boom of 1936 and 1937 gave impetus to development of a practical product. The builders of the first streamlined trains used quantities of this material where abrasive and weather resistance had to be combined with light weight. Truck bodies and cabs have been made from plymetal for years. In the construction field, plymetal is now used for office partitions, elevator cabs, stair wells, and in many other places where zoning ordinances require a combustion-proof material. Industrial users are turning out tabletops, cabinets, hospital equipment, counters, refrigerators, and drainboards.
Aircraft uses include floors, cockpits, bulkheads. An interesting wartime development was the weather-tight powder cases which replaced heavier, bulkier, two part containers. Other service uses included tool and equipment chests. It is felt by many that the surface of market possibilities has only been slightly scratched and that further refinements of the products will produce a host of new and better uses.

IV ECONOMIC ASPECTS OF SURFACED PLYWOOD

It is readily apparent that there are numerous physical advantages to be realized by overlaying Douglas-fir plywood. The economic advantages, however, are not so easily discernible. At the present time, plywood operators are able to sell almost any panel that comes from the press. Even the trimmings and the defective panels are marketable, as many uses are found in the industrial trades for small pieces of plywood, both surfaced and unsurfaced. With the return of a more normal market, plywood is not likely to be in such great demand.

Even before the war, there were a multitude of paneling materials on the market which could be considered as competitors of surfaced plywood. They vary from inexpensive fiberboards to costly plastics. The fact that most of these same materials may be reduced to a fraction of their thickness and then used as an overlay reduces the competitive factor.

Thus, we see that plywood is no longer to be considered as a substitute or as a competitor of other materials, but an integral part of an entirely new product. As such, overlaid plywood is expected to find its own economic level in the future. The enthusiastic reception that the surfaced products are receiving is a favorable indication that this level will be profitable to both the producer and the customer.
BIBLIOGRAPHY


**TABLE I**

**PROPERTIES OF PHENOLIC-RESIN IMPREGNATED SURFACING* (13)**

- **General colors**...Olive drab, black, red
- **Surface finish**...Glossy, satin, matte
- **Aging Characteristics**...Stable on interior use
- **Weatherability**...Slight fading on prolonged use, when phenolic resin used
- **Flammability**...Moderate ignition
- **Weight**...Standard grade, 60#/1000 sq. ft., .009" thick
- **Effect of wet steam**...None
- **Effect of cold temperatures**...None
- **Abrasion**...Highly resistant, wet or dry

**Chemical stability, resistance to**
- Weak inorganic acids...Excellent
- Weak inorganic alkalies..." "
- Weak organic acids..." "
- Alcohols..." "
- Hydrocarbons..." "
- Mineral oils..." "
- Vegetable oils..." "
- Acetones...Good
- Ketones..." "
- Esters..." "

**Physical Properties of Grade 200°**

- **Tensile Strength**
  - Parallel...18,000 p.s.i.
  - Cross...14,000 p.s.i.

- **Elastic modulus (tensile)**
  - parallel, p.s.i...1,650,000
  - cross, p.s.i...1,200,000

* This is Kimpreg, manufactured by the Kimberly-Clark Corporation.
TABLE I
(Continued)

<table>
<thead>
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<th>Property</th>
<th>Value</th>
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<td>Flexural strength, parallel, laminated,</td>
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<td>machine direction, p.s.i.</td>
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<td>Izod impact, flatwise, Ft-lb/in notch.</td>
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<td>Flexural modulus, parallel, laminated</td>
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<td>Water absorption, 24 hr, A.S.T.M., %</td>
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<td>Water permeability, 30 MPH wind, %</td>
<td>0.94-1.26 (on exposed area)</td>
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<td>Vapor permeability, gr/sq.in/hr</td>
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<tr>
<td>Abrasion (K.C. Tester) dry</td>
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<tr>
<td>Wet, gr/sq.ft/hr</td>
<td>No measurable loss</td>
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**TABLE II**

**STIFFNESS FACTORS FOR PLYMETAL (11)**

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<td>SHEET STEEL Without Plywood</td>
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<td>20</td>
<td></td>
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<td>.12</td>
<td></td>
<td>1.46</td>
<td>.19</td>
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<td>2.50</td>
<td>.56</td>
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<td>2.50</td>
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<td>11</td>
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| SHEET ALUMINUM Without Plywood | .047" | 16 |  | .71 | .11 |  | .84 | 1.2 | 2.3 |
|  | .078 | 12 |  | 1.14 | .42 |  | 1.00 | 2.3 | 4.5 |
|  | .102 | 10 |  | 1.44 | .87 |  | 1.45 | 10.1 | 13.2 |
|  | .125 | 8 |  | 1.81 | 1.3 |  | 1.52 | 14.5 | 19 |
|  | .156 | 6 |  | 2.89 | 3.6 |  | 1.65 | 20 | 26 |
|  | .250 | 1/2 | 3.52 | 14 | 1/2 | 1.48 | 9.4 | 16 |
|  | .313 | 5/16 | 4.41 | 26 | 5/16 | 1.00 | 2.3 | 4.5 |
|  | .375 | 3/8 | 5.29 | 43 | 3/8 | 1.15 | 3.2 | 7.7 |
|  | .438 | 7/16 | 6.17 | 69 | 7/16 | 1.34 | 5.6 | 12 |
|  | .500 | 1/2 | 7.06 | 110 | 1/2 | 1.48 | 9.4 | 16 |
|  | .625 | 5/8 | 8.82 | 200 | 5/8 | 1.80 | 17.2 | 28 |
|  | .750 | 3/4 | 10.58 | 380 | 3/4 | 2.13 | 29.4 | 46 |
|  | .875 | 7/8 | 10.58 | 380 | 7/8 | 2.46 | 48.6 | 68 |
|  | 1.000 | 1 | 2.78 | 72 | 1 | 2.78 | 72 | 94 |

* With transverse grain face (crosswise) next to the metal.

** With longitudinal grain face (lengthwise) next to the metal.
Until very recent years, little thought was given to this subject, and even yet, many of the principles involved are not thoroughly understood. The U. S. Bureau of Standards has published a review of the present knowledge of adhesion (14), and others are conducting research programs to learn more of the facts. The bonding of any materials, especially hard surface materials such as metal, require a brief consideration of the fundamentals of adhesion.

In general, two principal types of adhesion have been recognized:

(15)

**Mechanical adhesion** is found effective chiefly between relatively porous surfaces, such as wood, paper, cloth, etc. It is the mechanical interlocking of the hardened adhesive in the voids of the material, into which it has been forced by pressure, while the adhesive is still in the flow stage. Recent investigations conclude that its effect, while still recognized, is not as important as it was formerly considered to be.

**Specific adhesion.** It now appears that adhesion, even to a porous surface, is not primarily a mechanical phenomenon. It is, rather, an expression of molecular attractive forces, in which electrostatic, or polarity, factors have a bearing, covalences exhibit important adhesive qualities, and the Van der Waals forces exert definite influences. Therefore, a knowledge of the chemical nature of the surfaces is necessary to establish the type of bond formation that may be expected.