CHAPTER - I

INTRODUCTION -

PLYWOOD & WOOD-BASED PANELS
Better taste in ornamental surface finish called for refinement and innovation in early furniture designing and thus came the craft of inlaid or superimposed patterns on articles of wood. The early craftsmen obtained ornamental appearance by inlaying or superimposing pieces of precious metals, stones, ivory, shell and timbers having different colours or decorative grains onto wooden surface. Cut manually with the help of primitive tools, thin pieces of wood of contrasting colours or decorative species were set in matching symmetrical patterns on top of solid boards. Presumably thin sheets were used to optimise the utility of scarce and costly decorative wood species. Some decorative timbers when cut into thin boards and used as such without any support tend to warp or crack and this constraint perhaps gave rise to the thought of superimposing thin pieces of decorative timber on wooden furniture.

The technique of superimposing one layer of wood on top of another is the “art of veneering” and the thin layer of wood is termed as veneer.

However, the great age Egyptian artisans were proficient in the art of veneering thousands of years ago. Among the few pieces of antiquarian remains belonging to an Egyptian Royal family of Third Dynasty period, excavated during the last century, a coffin was found having its sides made of six layers of wood securely glued together.
Some other wooden articles retrieved from the relics of an Egyptian Royal family of Twelveth Dynasty (2000 BC to 1788 BC) display the specimen of exquisite marquetry technique practised in former times. The art of marquetry is an elaborate process whereby decorative patterns are made by inserting coloured pieces of wood, shell or ivory, into a thin wood sheet which is finally affixed on a piece of furniture. The ancient Greeks used "thin sheets of fine quality woods" in wooden couches. The craftsmen during the time of Augustus (63 BC to AD) were conversant with the mastery of overlaying thin wooden sheets onto solid timber boards for aesthetic value. Over the following centuries incessant novel ideas, introduction of improved devices and progressive processing methods brought forth new reconstituted wood-based panels.

The woodworking industry in England excelled to a great height during the Sixteenth century and over that period the use of mahogany and walnut sheets gilded on articles of furniture was quite popular and thus the art of veneering was revived. Veneer sheets were glued onto cheap timbers and this form of decorative construction was practised in Holland too. In those days veneers were cut from logs with the help of pit-saws. Although it was around the middle of Seventeenth century that "mechanically operated saw cut veneers" were first used, in 1777 a patent was obtained in England for a mechanical lathe to peel thin sheets (veneers) of wood; but this did not prove to be useful.

The "Rococo" style furniture bear the testimony that in the middle Eighteenth century France the furniture makers were skillful in
veneering woodwork. However, in 1793 Sir Samuel Bentham of England erected a machine, conceived from the operation of a plane, for slicing veneers and this was regarded as the most notable invention, in that this device at a much later stage led to the designing and construction of a more efficient mechanically operated slicing machine.

However, by early 1800 a large steam-operated plane for slicing wood was introduced. This event was a big step in the evolution of plywood technology. In 1805 a circular saw was reportedly introduced in England for the first time to cut veneers as thin as 1/16 inch and, much later, in 1830 a more improved mechanical plane was used for veneer slicing. In 1840 a lathe for veneer peeling was patented in the USA and this accomplished innovation eventually made it possible for abundant supply of rotary cut veneers and for that matter mass production of plywood. It was in the USA that the fabricated panels made from veneers were initially used in 1860 for making piano. In 1865 one John Mayo in the USA first took a patent for his "invention" of a fabricated material from veneers glued together, the trade name "plywood" was yet to be conceived; but this patent was finally amended in 1868. Factually, John Mayo's invention is regarded as the pathfinder, which set into motion the evolution of present era plywood technology.

By 1867 this built-up material was being used in the USA for making sewing machine boxes. In 1871 a patent was granted to an American George Gardner for his products "chair seats" made from veneers. Yet a more perfect mechanical wood slicer was introduced in 1875. The use of built-up veneered material in the USA gaining in popularity, by 1879 this was being
used there for making organs and by 1883 for desk tops. During the period 1885-90 commercial production of plywood set about in many parts of the USA and by 1890 the people in woodworking trade in the USA got used to the application of plywood in making doors, fixtures and furniture.

In 1885 one Christian Luther began manufacturing plywood seats in a small factory in Reval, Estonia (a Constituent Republic of the USSR; the Tsars annexed Estonia in the late 18th century). Production of rectangular plywood pieces for tea chests began at this factory by 1895. Unfortunately enough, this factory was destroyed during the Second World War conflicts.

It was during the first decade of this century that plywood technology embarked in France, Germany, Italy, Japan and the USSR. During the First World War years the emergent need for aircraft and lightboats as also light packing boxes for despatch of armaments and war-time supplies gave rise to enormous demands for this built-up material. It was during those war years (1914-18) that this veneered panel came to be popularly distinguished as "plywood" and was decisively accepted the world over as the inevitable substitute for lumber. Thus the First World War contributed to the explosive growth of plywood industry and helped the plywood factories in the USA, Japan and elsewhere in Europe flourish to a great height. During that period many plywood plants came into existence in Australia, Norway, the Netherlands, India and many other countries. Plywood production on a commercial scale had already begun in Japan in 1908 and in Finland as also in Sweden in 1912.
Vegetable, animal and casein glues were originally used for bonding plywood panels until the late 1920s. But such glues were neither moisture-resistant nor free from the attack by micro-organisms. Owing to the problems of delamination and borer attack the plywood was still considered unsuitable for durable constructional applications. The development of hot-pressed water-proof synthetic resin in 1930 in the USA was yet another most important stepping-stone in the evolution of present day plywood technology. Introduction of synthetic resins helped fabrication of much improved and durable products like aircraft plywood, marine plywood and various types of water-proof panels. Since 1930 series of progressive developments in synthetic resins have not only aided to the utilization of wood as an engineering material and exploration of different types of fabricated wood-based panels but also revolutionized the 20th century woodworking industry as well.

Noteworthy among the most recent innovations is the centreless peeling lathe. As the name implies, it does not have the chuck attachments at the centre as does a conventional peeling machine. Instead, the new centreless peeler has three steel rollers - one fixed near the knife acts as nosebar and the other two advance the log into the knife as the log becomes diametrically smaller while veneer sheets are peeled from it. A conventional peeler lathe has at the centre chuck attachments on either side that are pierced into both ends of a log so as to hold it firmly while the log rotates and the veneer is peeled till the horizontal knife could reach the chucks. Thus a substantial volume of the log is left unpeelable and this cylindrical residual portion is known as peeler log.
In a centreless peeler a log can be peeled off to less than a 2-inch diameter and consequently the yield of veneers is much higher. Besides, the initial investment and maintenance expenses on this new centreless lathe are reportedly far less than those on a conventional peeler lathe.

During the good many years since the USA took the lead in having the plywood industry on the move, plywood technology has been immensely enriched and diversified with much refinements and innovations, and this industry has undergone a sea change all over the world. The USA, Finland, Japan, West Germany, Italy and the UK have made quite significant contributions in the growth and technological development as also in the advancement in the design and manufacture of wood-based panel-making machinery and equipment.

The largest (per capita) consumers of plywood now (1986) are the USA, Canada, Japan, Holland, Denmark, Britain, Belgium-Luxembourg, Sweden, West Germany, France, Italy, Spain and the oil-rich Arab countries. The USA, Japan, Indonesia, the USSR, Canada, South Korea, Finland and Taiwan are the world leaders in plywood production today. The top ten exporters (1986) of plywood boards are Indonesia, Finland, Singapore, the USA, Malaysia, Canada, Brazil, the Philippines, South Korea, Japan and Taiwan in that order.

PLYWOOD PANELS

Description:

Plywood is a built-up board consisting of thin sheets of wood, called veneers, arranged cross-wise successively into several layers.
and bonded together with suitable adhesive under pressure with or with­
out heat, as required.

Features and Varieties:

Plywood is almost invariably constructed with odd number of
plies like 3, 5, 7, 9, or 11 layers of veneers that are placed cross­
wise with grain directions of the successive plies at right angles to
each other. Those made of more than three layers of veneers are tech­
nically termed as "multi-ply" panels. Plywood can also be built with
an even number of veneers, the two innermost plies arranged with the
grain running in the same direction. But veneered plywood with an
even number of plies is rarely made. In a four-ply panel, two inner
(core) plies are bonded with the grain running parallel to each other.

Plywood could be uniformly strong, stable and durable provided
its face and back veneers are of equal thicknesses and of same or com­
perable timber species. To make a stronger board, the thickness of the
core layer is increased. Basically two types of plywood are made, one
for interior use and the other for exterior use exposed to humid con­
ditions. Glued veneered panels are called plywood as a generic term;
but those intended for general purpose carpentry, joinery and furniture
jobs are called by the tradesmen as commercial plywood and those for
decorative use as decorative plywood. Keeping in view their suitability
to different weather conditions and perfunctory requirements for inte­
rior or exterior applications, general purpose commercial plywood panels
are manufactured in various moisture-resistant grades, viz. cold water
resistant (CWR), warm water resistant (WWR), boiled water resistant (BWR) and boiled water proof (BWP) etc. There are speciality products made with appropriate standard components for specific practical uses. The items under this category include tea chest plywood, marine plywood, shuttering plywood, medium and high strength aircraft plywood, fire-retardant and flame-proof plywood etc. Other than the cheap disposable variety for tea chest and small packaging purposes, plywood panels are mostly constructed in large sheets.

General purpose moderate quality plywood panels for interior uses are normally bonded with urea-formaldehyde glue. For durable moisture-resistant interior type plywood and warm/boiled water-proof exterior type plywood boards, phenol-formaldehyde, phenol-resorcinol or melamine-urea-formaldehyde synthetic adhesives are generally applied. Plywood pre-finished with ornamental timber species or coated with decorative paper, foil, or vinyl etc. are used in making fixtures and furniture items bearing artistic appearance. There are metal laminated speciality products that have specific utilities. Lead-cored plywood, formed with a centre layer of 1 to 9 mm of thick lead, is used as partition panels in a room where an X-ray machine is installed. This lead-cored board helps keep the rays confined within the panelled space. Fibre glass laminated plywood boards are used in boats and rafts.

Vegetable or animal glue is commonly used for bonding cheap quality non-durable plywood. Other than flat panels, plywood is also fabricated in curved form, known as moulded plywood, and it differs from flat panel in grain orientation, shape, size, processing and application.
Moulded plywood is produced by simultaneous process of gluing, bonding and pressing with or without heat. Cylindrical containers, tubes, fruit baskets, trays, reels for electrical cables and wires, bobbins etc. are also made from 3-ply or multi-ply veneers.

Advantages:

Wood, even if it is seasoned, may shrink, expand or warp in adverse weather conditions. The successive veneer layers assembled cross-wise with the grain of each ply at right angles to that of the adjacent ply or plies and then bonded together with suitable adhesive prevents expansion or shrinkage of each ply. The glue applied in each ply penetrates into wood fibres, and the fibres in adjoining sheets are affixed together and this fastening process imparts strength and rigidity in both directions of each veneer layer and affords greater resistance to shrinkage, expansion, swelling, stress and moisture. Built-up plywood has greater dimensional stability, uniformity of strength and better splitting resistance than wood of same thickness in natural form. Veneers properly seasoned, chemically treated and bonded with suitable synthetic adhesive make superior quality plywood panels that are durable, weather-proof and resistant to micro-organisms. Light weight, flexibility and minimal wastage are some of the major characteristics that contribute to its ready-to-use adaptability. The cross-grain sandwich construction has numerous advantages over sawn timber and thus plywood is more ideally suited to a variety of applications. The ornamental appearance of plywood panels treated with decorative face veneers or coated with decorative paper (DAP) or vinyl pre-
sents a much better aesthetic value than the natural wood. The use of thin sliced decorative veneers helps optimise utilisation of scarce and costly ornamental timber species.

Uses:

Plywood has revolutionized the woodworking industry, and its utility in industrial, household and other multi-use purposes has assumed worldwide importance. It has wide ranging applications in packaging, containers, domestic and office furniture, showroom fixtures, walls, ceilings, floors, partitions, windows, doors, radio and TV cabinets, sewing machine boxes, toys, trays, table tops, make-shift camps, automobiles, train and tram compartments, aircraft, ships, rafts, boats, sports goods, concrete shuttering and a host of other purposes. Currently some of the Western countries (particularly Finland) produce a variety of speciality technical products including thick plywood whose main applications are in pattern making for foundry work and in the manufacture of cores for skies used for gliding over snow.

Types of Plywood:

Plywood is a generic term for different types of built-up veneered board. Similar built-up materials having almost common characteristics and properties as that of three- or multi-layer veneered panels are also classified as types of plywood. These are stoutheart, veneered campo board, laminboard, blockboard and battenboard etc. Stoutheart, quite akin to plywood, is made of 3 or 5 veneer layers, the centre layer being much thicker than the other plies.
Composite board, also known as campo board, is manufactured by having a half-an-inch insulating board bonded with two outer 3-ply veneered panels. The core (centre) insulating board is made of wood wastes and saw dust compressed with synthetic resin. Screws do not hold well into campo board.

Blockboard is constructed with a centre core comprising solid uniformly thick wooden strips glued together side by side and sandwiched between two outer veneer layers. The width of each core lumber block is uniform and does not exceed one inch. It is most suitable for ready to use door- and window-panels. Urea-formaldehyde resin is commonly used for general purpose interior blockboards, and melamine-formaldehyde for better moisture-resistant durable blockboards. For long durable warm
or boiled water-proof blockboards or flush doors, phenol-formaldehyde, phenol-resorcinol or melamine-urea-formaldehyde adhesive is said to be most useful.

Illustration - Blockboard

Laminboard is made with a core of thin hardwood blocks, generally each not exceeding 7mm (about 1/8 inch) wide, bonded by two outer veneer layers. Laminboard is superior to blockboard.

Battenboard is similar to blockboard or laminboard, the main exception being that its uniform core blocks could be as wide as three inches or less each. This is also known as lumber-core board.

Plywood Construction:

Barring those pre-finished with metals, plywood as always is an altogether built-up wood product and its manufacturing process involves conversion of wood to the required condition, shape and size, aided by the application of glue and pressing.

In a plymill the starting point is the moistening of tree trunks (logs) by water sprinklers or by keeping those afloat in standing water, usually log ponds, lakes or backwater etc. Moistened logs are debarked and from those veneer sheets for general purpose plywood are knife-cut by rotary peeler lathes. For decorative veneers, the logs are sawn into flitches that are softened in steaming vats (mainly for hardwood species)
and then sliced to thin sheets by horizontal or vertical slicers. The peeled or sliced green (moist) veneers are clipped to the required sizes, their split edges or damaged portions patched up with glued paper tapes and then seasoned in roller dryers for elimination of moisture to the extent necessary for proper bonding effect. Small strips of dried (seasoned) veneers are laterally jointed by automatic splicer machine and this process is termed as splicing. The spliced veneers are mostly used as core, inner and back layers in plywood construction. Following the seasoning treatment, sliced decorative veneer strips are perpendicularly matched to particular designs for colour, texture and symmetrical grain patterns and the matched veneers are laterally jointed together lengthwise forming into large sheets of the required widths.

The next stage is assembling the veneers. The seasoned (dried) veneers are glued and then assembled in required number of layers with grains alternating in sandwich formation and finally pressed together culminating to built-up plywood sheets. After pressing, cold or hot, the four edges of plywood panels are trimmed to standardized sizes by rip-saws. Finally the face and reverse of each panel are cleansed and smoothed in a mechanical sander and subsequently minor blemishes are treated with putty. The plywood is now ready for dispatch to wholesale dealers and finally to the retail outlets. More details about wood, veneers, seasoning, adhesives and pressing are described in the following pages.
The sequential flow of major processing operations in a plywood manufacturing plant may be tabulated in the following order:

<table>
<thead>
<tr>
<th>Commercial plywood</th>
<th>Decorative veneer</th>
<th>Blockboard/flushdoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>- moistening logs in log yards, log ponds, lakes, backwater;</td>
<td>- logs sawn into flitches;</td>
<td></td>
</tr>
<tr>
<td>- moistening tree trunks in log yards, log ponds, lakes, backwater;</td>
<td>- flitched timber softened in steaming vats;</td>
<td></td>
</tr>
<tr>
<td>- cutting cross sections of trunks to logs of required length;</td>
<td>- veneers sliced from softened timber flitches;</td>
<td></td>
</tr>
<tr>
<td>- debarking logs;</td>
<td>- sliced veneers clipped;</td>
<td></td>
</tr>
<tr>
<td>- peeling logs to veneers;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- clipping veneers to required sizes;</td>
<td>- clipped veneers seasoned in roller dryers;</td>
<td></td>
</tr>
<tr>
<td>- taping/repairing veneer edges and splits;</td>
<td>- sliced veneers matched to designs for colour, grain pattern, and spliced; *</td>
<td></td>
</tr>
<tr>
<td>- seasoning veneers in roller dryers;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- splicing small veneer strips laterally;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- gluing seasoned veneers;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- assembling glued veneers with grains alternating in sandwich formation; *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- pressing assembled glued veneers;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- trimming the edges of built-up plywood panels;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- sanding finished plywood panels;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- minor repairing with wood putty and marking for identification of panels as per quality, gradation, sizes, trade names etc.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* At this stage spliced decorative veneers or batten strips are glued and assembled together with commercial veneers for making decorative plywood or blockboard/lumberboard respectively.
Table - II

World Production - Wood-based Panels

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>Million</td>
<td>4.75</td>
<td>15.39</td>
<td>32.82</td>
<td>39.36</td>
<td>49.16</td>
</tr>
<tr>
<td>Europe</td>
<td>Cubic</td>
<td>1.09</td>
<td>2.68</td>
<td>3.93</td>
<td>3.58</td>
<td>3.23</td>
</tr>
<tr>
<td>North &amp; Central America</td>
<td>- do -</td>
<td>3.32</td>
<td>8.88</td>
<td>16.09</td>
<td>17.52</td>
<td>22.95</td>
</tr>
<tr>
<td>South America</td>
<td>- do -</td>
<td>0.08</td>
<td>0.20</td>
<td>0.73</td>
<td>1.15</td>
<td>1.54</td>
</tr>
<tr>
<td>Asia</td>
<td>- do -</td>
<td>0.17</td>
<td>1.90</td>
<td>9.70</td>
<td>11.33</td>
<td>18.34</td>
</tr>
<tr>
<td>Africa</td>
<td>- do -</td>
<td>0.01</td>
<td>0.20</td>
<td>0.30</td>
<td>0.51</td>
<td>0.61</td>
</tr>
<tr>
<td>USSR</td>
<td>- do -</td>
<td>0.81</td>
<td>1.35</td>
<td>2.04</td>
<td>2.02</td>
<td>2.30</td>
</tr>
</tbody>
</table>

Particleboard

| World      | - do - | *   | 2.55 | 19.16| 41.20| 47.70|

Fibreboard

| World      | - do - | 2.83 | 6.07 | 11.21| 16.08| 17.39|

* figure in cubic metres not available

Data: Yearbooks of Forest Products,
Food & Agricultural Organization (UN), Rome

Wood in Plywood:

As it is timber being the principal raw material for this industry, both hardwood and softwood are put to use in making plywood. Hardwood and softwood are simple commercial terms. Ordinarily hardwood
trees have broad leaves and they grow seeds in seed-cases; some of these are also known as deciduous trees because they shed their leaves annually. Softwood trees represent those bearing narrow middle-shaped leaves and naked seeds. But these are not the exclusive characteristics on which botanical classifications are made. Hardwood, as the name implies, is expected to be harder and denser than softwood. But there are exceptions, for some softwood species may be denser and harder than hardwood. Many hardwood species shrink, expand, swell or distort, though not as much as most softwood varieties do. Again some softwood species may be harder than hardwood. Few hardwood species, namely poplar, balsa and willows are softer than some softwood timber. Noteworthy among other broad-leaved hardwood species are teak, mahogany, sal, oak, beech, ash, elm, walnut, maple, alder, chestnut, ebony, ironwood and rosewood etc. These trees take a pretty long time (about 30 to 100 years) to grow to full maturity and so the availability of hardwood is limited as compared with softwood. Besides, most of the tropical hardwood species have attractive colours and ornamental grain and that make them most suitable for exotic furniture articles and decorative plywood. These are the reasons why hardwood timbers are scarce and quite expensive. Hardwood species are extensively used in shipbuilding, speedboats, durable furniture, tools and decorative plywood.

Most of the evergreen trees, that grow thin, with narrow needle-shaped leaves bearing naked seeds produce softwood. Softwood producing trees, also occurring aplenty in the tropical plains, grow and mature in about a quarter of the time normally taken by hardwood trees.
Some of the important coniferous (conifer) softwood trees having their seeds enclosed in cones are pine (all types), spruce, fir, redwood, larch, hemlock, cedar, deodar, chir etc. Easily available and generally cheaper than hardwood, softwood timbers are widely used for packaging, paper making, roofs, staircases, floors, doors, windows, furniture and plywood manufacture, and other general purposes. Softwood being resinous, soft and structurally simple, it is mostly used for joinery work and light furniture. Softwood timbers provide 80 per cent of the wood required for commercial purposes.

Heartwood and Sapwood:

Structurally a tree consists of four main parts - the roots, the stem, the trunk with branches and branchlets, and the leaves. The roots provide firm anchorage to the tree and draw from the soil water and along with it mineral salts that pass upward to the leaves. The leaves store the nutrition derived from mineral solutions drawn from the soil and absorb energy from the Sun and atmospheric gases in the process of photosynthesis. The trunk is the best and only portion useful for conversion to veneer sheets that are utilized in making plywood.

Heartwood is the deep coloured central portion of a log and it is the inactive wood as it does not take any active part in the life of tree except to give rigidity to the trunk. Heartwood contains little food for wood pests and is therefore less liable to infestation by woodborer and other insects. Thus, this part of the tree is most useful and valuable for woodworking industry. Heartwood is often much darker, stronger and denser than sapwood. From a fresh tree, moisture of heartwood
may vary from 30 to 90 per cent. Sapwood, the light coloured outer portion beneath the bark of a tree, which consists of living wood grown over a period of last ten years or so contains enough starch and sugar that invite infestation by various insects. As the name implies, sapwood is for conduction of sap (liquid) essential for a living tree. In a live tree, therefore, sapwood's moisture content may be as high as 200 per cent. Ordinarily, sapwood is not suitable for cabinet construction or structural work, for it tends to twist, warp and shrink. Both heartwood and sapwood are adequately seasoned - thereby the excess moisture content eliminated - and utilized in the manufacture of plywood. In woodworking industry the timber intended to be used must be properly seasoned so that its moisture content is restricted to between 8 and 12 per cent.

Veneer:

A veneer is a thin wood sheet, which may be produced by sawing, slicing or peeling. Sawn veneers are quite thick; besides, the sawing process being much wasteful is not practised in plywood industry for making veneers. Veneers from decorative wood species are sliced by mechanically operated horizontal or vertical slicing machines. For slicing, the logs are sawn into flitches and then softened in a steaming vat. From water-soaked flitches, veneers are sliced flat in straight sheets. Wood species having ornamental grain patterns are sliced to very thin veneer sheets that are laminated onto plywood, blockboards or flushdoors for attractive appearance. Standard plywood panels pre-finished with decorative veneers are distinguished as decorative plywood, decorative flushdoors etc.
Veneer sheets used in making general purpose plywood are mostly knief-cut in rotary peeler lathes. The logs are moistened by water sprinklers or by keeping those afloat in confined water (mostly log ponds), then debarked and finally fitted on a peeler lathe. The mounted log is rotated against a horizontal knief blade affixed in the lathe and thus the log is peeled off into almost continuing veneer sheets. Unlike in sawing method, the wood is not wasted in wood dust while veneers are sliced or peeled. Veneers, if peeled, are quite thin, and more so when sliced, than those produced by sawing. The peeled veneers are essentially utilized for construction of general purpose standard commercial plywood and are thus termed as commercial veneers. The commercial veneers that are exclusively used as centre (core) plies, mostly for cross-banding, in plywood manufacture are technically called the core veneers and those used on either side of a plywood panel are the face and back veneers. The face and back veneers must necessarily be free from worms, knots, knot-holes, borer-holes, open splits, cracks, other visible defects and stains. Of course, veneers having minor stains and firmly grown-in small knots are utilized as inner layers in plywood construction. The peeled commercial veneers vary in thicknesses ranging from 0.09 to 0.32 cm or more.

Moisture Content and Seasoning:

Moisture being the most prominent substance which regulates the life and growth of a tree, wood's properties are therefore influenced by its environment. In a solid trunk, freshly cut from a tree, the water begins to evaporate till the moisture in it reaches the equilibrium point
as that of the surrounding environment. If the trunk is sawn into boards or planks the moisture evaporates still faster. Moist wood when placed in a dry warm place releases its moisture and shrinks, conversely dry wood stored in a humid condition absorbs moisture and expands. However, in woodworking technology, "moisture content" is the weight of the moisture in wood expressed as per centage of the weight of the same wood in completely dry state and it is denoted as follows:

\[
\frac{\text{Weight of the moist wood} - \text{weight of the dry wood}}{\text{Weight of the dry wood}} \times 100 \quad \text{per cent moisture content}
\]

For instance, when a piece of wood contains moisture to the extent of 10 per cent of the weight of the same piece of wood in dry condition, the moisture content is said to be 10 per cent. An electronically operated portable "moisture meter" instantly indicates the moisture content on any wooden surface.

Thus wood, unlike an inert substance, being sensitive to weather its properties are affected by temperature and humidity and to overcome the problem of expansion and shrinkage, the seasoning treatment of wood is essential. The desirable limit of the moisture content should be the same as that of the environment where the finished product is to be placed or used. In plywood construction, the veneers and wooden core blocks (for blockboards etc.) are seasoned in steam- or oil-heated roller driers and drykilns respectively. Without adequate seasoning, proper flatness of the veneers, to be glued for plywood making, cannot be ensured.
This is essential for adequate bonding effect between the two opposing veneer layers as also to avoid internal stress which otherwise may be caused by shrinkage differences between the unevenly seasoned veneers in successive layers. Shrinkage, warping, delamination and splits occur in finished plywood due to any change or major variation in the permissible moisture content limit in the veneers used. Ordinarily veneers are required to be so dried as to retain around 10 per cent moisture content. As per ISI (now Bureau of Indian Standards) classification IS:303:1975, plywood "shall have a moisture content not less than 6 per cent and not more than 15 per cent."

Adhesive:

The other major input utilized in the conversion process of plywood production is adhesive. The words adhesive and glue are synonymous. The efficacy of a glue is judged by the strength and durability of the adhesion which the finished panel maintains under exposure to various weather conditions. In plywood making or laminating decorative material onto a fabricated panel the adhesives that are used may be classified in the following categories - animal glues, vegetable glues and synthetic glues. Originally animal blood albumen, casein and vegetable glues were used in the manufacture of plywood. Synthetic resin was introduced in the USA and few Western countries in 1930; in India this was put to use in 1957.

Animal glues, made from gelatines derived from animal hoofs, hides, bones and other wastes from slaughter houses, lose their adhe-
sive properties if exposed to moisture and are subject to quick attack by micro-organisms. Blood albumen glue if used under heat-curing process will have quick bonding effect, but the plywood becomes moderately water-resistant and is thus suitable for only indoor but not outdoor use. In Western countries blood glue, once extensively used in making sheathing plywood (for covering framed structure), has now been replaced by various synthetic resins.

Casein glue - derived from skimmed milk and mixed with other additives - is a protein product; it loses bonding strength and is also subject to infestation by micro-organisms should it remain exposed to humid weather for a long time. Casein glue is mostly used for making tea chest plywood in India. Hot-pressed casein glue makes somewhat better water-resistant lumber-cored interior plywood. Various types of casein glue mixed with formaldehyde, urea and other additives are also used in making interior plywood of durable quality.

The commonly used vegetable adhesives viz. soybean and starch glues are most economical but not water-resistant. Plywood panels made with vegetable glues are neither weather-resistant nor durable, as those will delaminate if exposed to humid weather or water. Thus soybean glue, another protein product and starch glue, chiefly made from cassava flour, have same deficiencies as that of a pure casein glue. Starch glue used with cold- or hot-pressing treatment is only suitable for low grade products. Ordinarily starch glue is used under cold-curing process for making low priced disposable plywood for packaging boxes etc.
Hot-pressed soybean glue makes low water-resistant commercial plywood and decorative plywood that may be suitable for only interior application where humidity is very low. For better bonding effect, soybean mixed with synthetic resin is utilized in making moisture-resistant plywood for exterior application. Among other additives used in improving the bonding strength of these adhesives are tamarind seed powder, de-oiled groundnut cake powder and coconut-shell powder.

The moisture from purely vegetable or animal glues is reduced or eliminated under cold- or hot-pressing process. But following long exposure to weather, finished panels bonded with vegetable or animal glues will reabsorb moisture and are thus liable to delamination and consequently not durable enough in extremely humid condition.

A broad range of formaldehyde based synthetic adhesives namely, urea-formaldehyde, phenol-formaldehyde, melamine-formaldehyde, melamine-urea-formaldehyde, phenol-resorcinol-formaldehyde are used in making plywood and various other reconstituted wood-based panels. Urea-formaldehyde glue cured with cold- or hot-pressing can resist plain water but not hot water and thus it is suitable for only general purpose interior plywood, moisture resistant blockboard, standard particle-board and medium density fibreboard. The most reliable water-proof glues are the derivatives of phenol. Hot-pressed panels with phenol-formaldehyde resin are highly resistant to water (cold, hot or steam), dry heat as also micro-organisms; formaldehyde itself being a disinfectant substance.
This glue is primarily used to produce warm and boiled water-proof exterior type plywood, particularly of hardwood species, moisture-resistant particleboard and waferboard. Phenol-resorcinol-formaldehyde resin mostly cured under hot-pressing and quite resistant to cold or hot water, is also used in making exterior type plywood. Melamine-formaldehyde or melamine-urea-formaldehyde resin makes better moisture-resistant particleboard as also blockboard, and warm or boiled water-proof plywood for exterior application. Melamine-formaldehyde resin is also utilized in many forms of decorative laminating work.

Thus plywood made with hot-pressed synthetic resin is generally resistant to water. Synthetic resins undergo chemical changes, more so in hot-pressing process, when bonded with wooden elements and well permeate into wood fibres all over the veneer sheets. This phenomenon gives strength to each veneer layer on either side and makes the built-up panel weather-proof, resistant to shear and splitting as also wood-boring insects. In short, hot-pressed synthetic resins make superior quality durable plywood compared with those bonded with vegetable or animal glues under cold- or hot-pressing treatment. Nonetheless, in order to ensure the quality and durability of a finished panel the adhesive is required to be spread over the entire veneer sheet evenly and uniformly. Glueing and bonding must be sufficiently sound to remain stable in normal atmospheric
humidity and temperature variations.

Pressing:

The next stage is pressing to fasten together the glued veneer sheets that have been assembled cross-wise. The pressing time and intensity of heat, in case of hot-pressed curing, are as much important as the efficacy of the adhesive in order to ensure the quality and durability of the built-up or laminated construction. Uniform and just adequate pressure is needed for most effective adhesion, because excessive pressure and/or heat may not only squeeze out the glue and a poor bonding will result but also destroy the properties of the glue and the built-up panel itself. The duration of pressing time depends on the type of glue and the curing process, hot or cold.

Low value non-durable plywood panels for tea chests, packing boxes and chair seats etc. are ordinarily cold-pressed at room temperature in manually operated screw-jack presses or in hydraulic presses. In case of certain glues, heat cannot be applied as it will merely cause the adhesive to melt and ooz out of the glued veneer sheets. The glues applied in cold-pressing are mostly obtained from natural sources like starch, soybean, casein and animal derivatives.
For higher value superior quality durable plywood, the glued veneers are hot pressed in hydraulic presses. The press is heated with hot water, steam or thermal oil. In hydraulic presses, the hollow steel patterns filled with hot water, steam or thermal oil are closed and the glued veneer sheets thus pressed are built-up plywood panels. In hot-pressing, usually at $80^\circ$ to $175^\circ$ C, the adhesives applied are mostly based on synthetic or soybean solutions.

Reconstituted Wood-based Panels:

A variety of improved reconstituted wood-based panels, as distinct from plywood, that have been developed in recent times are manufactured almost similarly, but they look and perform differently depending primarily on the shape and size of the wood particles used. The range of reconstituted panel products includes particleboard, fibreboard, medium density fibre-board (MDF), waferboard, oriented strand board (OSB), cement-bonded particleboard, flakeboard and, the newest innovation, laminated veneer lumber (LVL). For industrial and interior application of these panels urea-formaldehyde resin is used and phenol-formaldehyde adhesive is utilized in making those suitable for exterior purpose.

Particleboard:

Chipboard, commercially known as particleboard, is made of small wood chips (particles) which are bonded with synthetic resin under heat and pressure. Wood wastes shredded into small chips are screened, dried, mixed with resin and finally compre-
seed into a board. In flat pressed particleboard the wooden chips are mainly parallel to the plane of the board. The wooden chips are mostly vertical to the plane of the board in extruded particleboard. The final product is finished by light sanding or laminated with paper, plastic, ceramic or other materials. Commercial production of particleboard started in the USA in the early 1940s and thereafter in other countries. Made from wood residues of sawmills and other wood wastes, even without debarking, particleboard contributes toward maximum wood utilisation. This is manufactured in various thicknesses, ranging from 6 to 25 mm, and in different categories like i) low density, ii) medium density and iii) high density. A high density urea-formaldehyde bonded particleboard is a good flooring material. Urea-formaldehyde resin is considered suitable for standard particleboard and phenol-formaldehyde or melamine-urea-formaldehyde adhesive for better quality moisture-resistant particleboard. Compared with plywood and blockboard, particleboard's utility is rather limited, for it does not contain continuous fibres, nor does it hold screws firmly and it is far less resistant to bending as also splitting. For aesthetic purpose edges of a particleboard are covered with lumber or veneer banding, plastic edging or paint filler. Originally developed to replace scarce lumber, particleboard is suitable for interior uses and as a core material for making other wood-based boards with veneers.

Fibreboard:

Two major kinds of fibreboard - insulating board and hardboard - are generally produced. In fibreboard manufacture,
wood is chipped and reduced to fibres, then mixed with water and bonding adhesive to form a slurry, which is pressed into a mat and the excess water is squeezed out with rollers. Finally the mat dried in ovens in a continuous process makes insulating board. It is usually flat-pressed but may also be moulded. In making hardboard, the mat is hot pressed either before or after the drying process. Thus hardboard has a greater density than insulating board. Insulating board is mainly used for false ceilings and hardboard for TV cabinets. As in the case of particleboard, wood wastes and low quality unbarked wood are utilized through pulp preparation in making fibreboard. Rosin, paraffin, wax and other chemicals are added to the pulp to increase resistance to micro-organisms and insects. Paraffin-wax emulsion is used to obtain high degree of water resistance to the finished compressed board and also other additives to improve water resistance and strength. The boards are also finished with patterns of perforations, tiles and other designs or with overlays of vinyl, ceramic or metal. According to the pressure applied and the resultant density achieved, fibreboards are broadly classified into the following categories - rigid insulation fibreboard, semi-rigid insulation fibreboard, hardboard, special densified hardboard and medium density fibreboard. A low density fibreboard, or commonly called softboard, makes an ideal ceiling material.

Medium Density Fibreboard:

Popularly called MDF, medium density fibreboard is an inno-
vation of the 1970s. It is reconstituted from refined wood fibres mixed with synthetic adhesive under heat and pressure. Normally urea-formaldehyde resin is used for this material. The thermal-mechanical processing of chipping, refining and pulping of wood fibres for MDF is similar to that followed in making hardboard. But MDF is formed and pressed dry in the same manner as is done in case of particleboard. Unlike particleboard, it has a very fine and compact wood-fibre structure and a smooth surface completely free from knots and cracks; it does not delaminate nor does it require any edge-banding and it holds screws well. MDF, technologically termed as "engineered wood", can be moulded, shaped, carved, grooved or turned on lathe just like solid wood. Far more stiff, tough, and resistant to impact, moisture, splitting, warping and wood-boring insects, MDF has uniform density and strength in all directions. MDF, available in thicknesses of 6, 8, 10, 12, 15, 18, 25 and 35 mm, is ideally suitable for interior applications like pelmets, false ceilings, partitions, panelling, shelves, panel doors, shutters, cabinets, table tops, beds and a variety of assorted fixture and furniture pieces for household and industrial uses. It is available in natural form or pre-finished with decorative veneers, paints, varnishes or laminated with vinyl, decorative paper or melamine. In developed countries, particularly in the USA, Finland, the Netherlands, West Germany, Japan, UK, Sweden, France, Italy, Spain and Japan, MDF is fast replacing plywood and particleboard. This impressive
success of MDF is due primarily to its substitution for scarce and costly natural solid wood in those countries. In Western countries MDF is being increasingly used for making expensive and durable furniture articles. As of 1987 there were nearly 50 MDF plants all over the world with an estimated annual capacity of 4.4 million cubic metres and until March 1988 a further 19 plants with an additional capacity of 1.6 million cubic metres have reportedly been set up.(1)

Waferboard:

Waferboard is produced from wood wafers sliced from hardwood or softwood that have little or no commercial use. The wood wafers, varying in width, thickness and length are coated with waterproof synthetic resin, then arranged randomly in several layers and finally bonded together using high heat and pressure. Ordinarily phenol-formaldehyde resin is considered suitable for this material. This product, lighter than particleboard, owing to much less application of resin, is considered as an ideal plywood substitute suitable for outdoor application. In the developed countries it is being increasingly used for outdoor furniture, showroom fittings, bookcases, storage carts, bedboards and toys. In the USA, the explosive growth in demand for waferboard and oriented strand board in recent years continues to affect plywood, which for many decades has enjoyed a major share in wood-based panel products market.
Oriented Strand Board:

Oriented Strand Board, popularly known as OSB, is a non-veneered panel produced from long (usually more than six inches) but narrow strands of wood fibres which are oriented lengthwise and cross-wise in several layers and bonded with water-proof synthetic resin. It is among the most expensive wood-based panels.

Cement-bonded Particleboard:

Cement-bonded particleboard, a composite panel made of wood chips and a special cement derived from blast furnace slag from steel industry, is considered as a fire-proof wood-based material. A dependable substitute for asbestos and mostly used in building construction, cement-bonded particleboard offers some unique advantages. For instance, it is strong; it inhibits spread of fire, and resists impact, rot, insect and moisture; it has sound insulating properties and can as well be used in cold and damp environment.

Laminated Veneer Lumber:

The latest innovation wood-based panel is the fabricated laminated veneer lumber or LVL, which has been developed and introduced in the USA very recently. Its manufacturing process is almost similar to that of plywood. The significant differences in the methods of manufacturing LVL and plywood are the assembling, pressing and final processing. For LVL manufacture,
the veneer thickness is generally 3.2 mm (1/8th inch) and most of the wood species used are the same as those suitable for plywood. The equipment for veneer peeling, drying as also glueing, and even the type of glue used are the same as in normal plywood production. A US $35 million LVL plant, first of its kind in the world, was commissioned in North Carolina, USA in April 1987. This plant is now producing LVL with moisture content as low as 5 to 7 per cent and sizes ranging from 2' x 8' to 2' x 16' and in length up to 36 feet. This material is claimed as fairly suitable for use as joists, rafters, trusses and girders etc.

Pre-finished Panels:

The surface of any of the aforesaid wood-based panels may be natural or treated with vinyl or ceramic finish. A plywood or blockboard surface may be treated with a layer of veneer made from decorative wood species like rosewood, teak etc. or laminated with metal or decorative paper (DAP) and this adds to the visual beauty of the finished products. Nowadays, speciality boards prepared with aluminium, lead or finish foils, and other composite panels are being increasingly used in industrially developed countries. Very recently a new overlaying material made of phenolic-resin-impregnated kraftpaper has been introduced in the USA. This, known by its trade name METRON, is designed for hot-pressed lamination to plywood, waferboard, particleboard and other wood-based
panels and it provides a smooth uniform surface for application of high quality interior and exterior paints.

SUBSTITUTES FOR PLYWOOD

Over the past several years much thought, time and fortune have been devoted to thrust in some altogether new packaging materials in place of the long familiar plywood. Pioneered by a firm in the Netherlands, aluminium laminated multi-wall kraftpaper sacks are now put to use, partly replacing plywood chests, for tea exports from Kenya and Malawi. Tea despatched bulk in these bags, duly palletized and then containerized, is claimed to be protected from fume, moisture, damage and pilferage. Apart from additional expenses involved for palletization and containerization, these paper bags cannot be used for despatch of tea from remote areas unless there exist adequate transport facilities for movement of containerized loads. Very recently introduced in India on an experimental basis for just a few small consignments of tea exports, the paper sacks made mostly from imported components, including the special quality kraftpaper, have so far failed to evoke any satisfactory response from the tea industry. The alarming rise in cost of paper, acute shortage of raw material (timber) for the paper industry and absence of complete infrastructural facilities for ade-
quate local production are some of the major constraints that seemingly hold-up the prospect of these specially devised paper bags making any significant headway in India in the immediate future.

Among the commonly known metallic and non-metallic substitutes put forth as alternatives to standard plywood are asbestos, aluminium, steel, sheet glass (safety glass, figured glass, wired glass), plastic and fibre-glass etc. In terms of durability, strength and aesthetic value, plywood is far superior to asbestos. Aluminium is free from rusting and corrosion, but so is not steel, and none of these is free from quick decaying particularly if exposed to extreme weather conditions. Due to easy conductivity of heat both are not quite well suited for application in dwelling houses. Fibre-glass has been developed for use as hulls in small rafts and speed boats. Another new product fibre-glass reinforced plastic (PFRP), which requires highest level of manufacturing skill, has been introduced for application in automobiles, railway compartments, aircraft, spacecraft and marine vessels. But the usage area for this material is extremely limited, owing to various factors, including the prohibitive cost.

Another product patented as "woodplast" - basically a mixture of plastic and wood - has been recently developed by the IIT, Kharagpur. Woodplast, which resembles wood in appearance, is claimed to be resistant to water, flame, stain and termites. But its production cost is said to be even more than the average market
price of teak - one of the expensive hardwood species. Therefore, its credibility for commercial success is quite doubtful, at least in the immediate future. Nonetheless, commercial production of "wood-plast" has not commenced in India as yet.

Moulded doors and windows made of rigid PVC, of late marketed in India, are stated to be heat and sound insulating, resistant to warping, splitting and moisture. Being water resistant, PVC sheets may be suitable for partitioning, false ceiling, wall cladding and for making bathroom door, kitchen cabinet etc. PVC products available in various prefinished shades are liable to quick discolouration, but fresh coating of paints on a PVC material cannot have lasting effect. It is also subject to shrinkage, expansion and quick break-up in extreme weather, particularly if installed externally. Worse still, it being an inflammable material, any PVC product is a potential fire hazard. Above all, plywood products are more economical than moulded PVC goods.

Another newly developed building concept for interior application is gypsum plaster board, which has been recently launched in India. Popularly known as "gypboard", it is made with the basic raw material gypsum - an important commercial mineral extensively used in making cement, paper and paint etc. Gypboard is claimed to be fire-resistant as also well suited for wall-lining, partitioning and false ceiling with a satin-smooth surface. But this too is very expensive - more than six times the price of standard quality plywood ordinarily used for similar applications.
Unique Qualities of Wood:

Wood can be easily converted into log or plank, and can be shaped, turned, jointed, gilded, glued, polished or painted. Some wood species have inimitable textural beauty, exquisite grain pattern, soothing natural shades and exclusive aromatic scents. While wood is insulating to heat, it also imparts a feeling of warmth. These properties make wood the best suited material for house building construction and domestic as well as office furniture articles. Due to its unique natural acoustical characteristic, wood can produce and absorb sound or it may amplify sound originating from other bodies. And this matchless quality makes wood the only appropriate substance for musical instruments. In relation to its weight and density, wood possesses high tensile strength. Due to certain very peculiar intrinsic qualities and characteristics, some wood species are exclusively suited to specific utilities. For instance, tennis rackets, hockey sticks, diving boats and gymnasium equipment etc. are best serviceable if those are made from ash wood, due primarily to its flexibility and toughness. Similarly willow wood is used for making best cricket bats. Teak wood, resistant to fire and acid, is efficacious as table tops in chemical laboratories.

The unique chemical composition, structure and properties contribute to the versatility of wood. As compared to durability,
applicability, plentiful availability, aesthetic value and price of timber, none of the substitute materials can perfectly match with wood and hence its indispensibility. In short, there is no substitute for wood - Nature's irreplaceable and abounding gift.

Thus the built-up plywood not only embodies all the qualities of wood but is also more durable and versatile than sawnwood. In such usage areas where wood is essentially befitting, plywood is all the more conveniently suitable and less wasteful than sawn timber.

Nonetheless, the new-generation "engineered" wood panels, namely medium density fibreboard (MDF), oriented strand board (OSB), waferboard and, the newest, laminated veneer lumber (LVL) are now considered as by far the best dependable substitutes for sawn timber and even more utilitarian than the commonly used veneered plywood. Best suited for joinery and carpentry, MDF is fast replacing plywood and particleboard in advanced industrial countries. Waferboard, OSB and LVL are on the brink of a genuine breakthrough as the most appropriate wood-based materials for building construction.