INTRODUCTION

Wood, as we all know, occurs naturally. It can be used for a great many purposes, for example to produce heat, in building construction, to make furniture, paper, chemicals and clothing, and many other uses. Furthermore, it is a renewable, natural resource and as such it does not pollute the environment. Proper management of forests and plantations will ensure a sustained supply of wood for the future.

Wood is one of the earliest used raw materials. Due to its availability, versatility, ease of processing and its wide range of properties, as exhibited by the more than 30 000 tree species world wide, it is still one of the most used raw materials even in competition with modern man-made materials. Its natural variability makes it especially attractive for decorative purposes and also provides the designer with an almost unlimited choice of structural applications.

Natural wood properties such as resistance to fire and decay, dimensional stability and surface hardness, can be improved by special treatments. Other natural properties like good heat and electrical insulation, the ability to suppress sound propagation, and low thermal movement, makes wood an excellent building material.

Being such a versatile material with such a wide range of properties and applications, it is necessary to select the right wood species for each particular application, and then to use it correctly. The information presented in these timber brochures guide the reader to achieve this. These brochures cannot of course, fully cover each topic. References given at the end of each brochure can be consulted for more detailed information and in some cases, the advice of a specialist, such as a structural engineer, is required. Further advice on specific wood-related subjects can be obtained from the institutions listed on the last page of this brochure.

WOOD SPECIES

SOFTWOODS AND HARDWOODS

Wood is classified into softwood and hardwood. The term “softwood” is used for all wood from ever-green (coniferous) trees such as the pines, (radiata pine, oregon pine) and spruces. The “hardwoods” are cut from the broad-leaved or deciduous trees like Eucalyptus (gum), oak, embua, meranti and sinkwood. This classification does not indicate the physical softness or hardness of a particular species. There are many softwoods (e.g. Pinus canariensis) that are heavier and harder than some hardwoods (e.g. balsa).

PLANTATION GROWN SPECIES

The few natural forests in South Africa have been exploited by the early settlers and produce only insignificant amounts of indigenous woods. The bulk of our local wood comes from plantations of selected species, planted over the last 80 years. The main forest areas are in the Northern and Eastern Transvaal along the escarpment, northern KwaZulu/Natal, Zululand, the Natal Midlands, Transkei, and the Eastern and Southern Cape. These plantations cover one percent of the country’s total surface.

Plantations for a particular wood species are established in those areas which are best suited in terms of climate and rainfall. Half of these plantations consist of softwood like Pinus radiata, and P. pinaster (Cape Province), P. patula, P. elliottii, and P. taeda (Transvaal, KwaZulu/Natal and the Eastern Cape) and P. canariensis (Western Cape, (limited supplies)). The other half is made up of hardwoods (Eucalyptus and wattie). Eucalyptus grandis, known as saligna in the timber trade, makes up the bulk of the sawn hardwood. It was mainly planted for mining timber, but this use is decreasing. Improved eucalypt varieties are being cultivated with wood properties to satisfy the needs of the pulp, furniture laminating and construction industry. The wattie, originally planted for the bark extract used in tanning, is now also used increasingly for its wood in pulp and flooring. A list of the most common plantation grown wood species in South Africa is given in Table 1.

IMPORTED WOOD SPECIES

The traditional hardwoods like oak, beech, meranti, teak, embua and iroko are all imported to South Africa. The more important softwoods, imported from abroad, are western redeedar, Douglas-fir or Oregon pine, Parana pine and spruce. All these timbers have some specific application for which they are specially suited,
Table 1: The most common wood species grown in plantations in South Africa.

<table>
<thead>
<tr>
<th>SCIENTIFIC NAME</th>
<th>COMMON NAMES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HARDWOODS</strong></td>
<td></td>
</tr>
<tr>
<td>Acacia melanoxylon</td>
<td>Blackwood</td>
</tr>
<tr>
<td>Eucalyptus grandis</td>
<td>Saligna, Rose gum</td>
</tr>
<tr>
<td>Eucalyptus diversicolor</td>
<td>Kari</td>
</tr>
<tr>
<td>Eucalyptus marginata</td>
<td>Jarrah</td>
</tr>
<tr>
<td><strong>SOFTWOODS</strong></td>
<td></td>
</tr>
<tr>
<td>Pinus radiata</td>
<td>Radiata, Monterey pine</td>
</tr>
<tr>
<td>Pinus pinaster</td>
<td>Pinaster, Maritime, Cluster, pine</td>
</tr>
<tr>
<td>Pinus patula</td>
<td>Patula</td>
</tr>
<tr>
<td>Pinus elliottii</td>
<td>Elliotti, Slash pine</td>
</tr>
<tr>
<td>Pinus teeda</td>
<td>Taeda, Lobolly, Southern Yellow</td>
</tr>
<tr>
<td>Pinus roxburghii</td>
<td>Roxburghii, Cher pine</td>
</tr>
<tr>
<td>Pinus canariensis</td>
<td>Canary pine</td>
</tr>
<tr>
<td>Pinus pseudostrobus</td>
<td>Pseudostrobus, Pino blanco</td>
</tr>
</tbody>
</table>

Like oak for wine casks. For other applications they can be replaced by selected local timber as far as mechanical properties are concerned, but the appearance cannot be copied. Most of these imported timbers are from scarce natural resources and this is reflected in their prices. As certain species become scarce, other less known species with similar properties are marketed to fill the gap.

**Wood Structure**

A line down the length of a log represents the longitudinal direction in the log. A line drawn from the centre of the log to the bark, i.e. cutting across the annual growth rings, represents the radial direction. Any line perpendicular to both the radial and longitudinal direction, i.e. parallel to the annual rings as seen on a cross-cut stem, is called the tangential direction. In Figure 5 these directions and a radial and tangential surface are shown.

**Sapwood and Heartwood**

The central part of the cross-section area of the stem of a tree is usually considerably darker than the ring of wood next to the bark of a tree. This is more distinct in hardwoods like tambotie and kiaat than in softwoods. This inner, darker part of the stem is called the "heartwood" while the outer, lighter coloured wood is called "sapwood" (see Figure 9).

In the growing process, new wood, called sap-
wood, is formed just under the bark of the tree. As this sapwood ages, natural substances called extractives, which are formed by the tree, are laid down in the more mature parts of the sapwood converting it to heartwood. The proportion of sapwood to heartwood in a tree depends on growing conditions and species.

In some wood species, in which it is difficult to distinguish between sapwood and heartwood, the freshly cut surface can be treated with a chemical stain to show up the heartwood.

A comparison of sapwood and heartwood shows the following:

- sapwood usually has a lighter colour than heartwood although, in some species, there is little difference
- the structure of the heartwood and the sapwood is the same
- at the same moisture content the strength and specific gravity are about the same
- heartwood has a higher natural durability than sapwood due to the extractives it contains
- sapwood can be treated more readily with preservatives than heartwood as it is more impervious
- published ratings of natural durability of wood species are based on the durability of the heartwood.

**Juvenile Wood**

Juvenile wood occurs in a cylinder around the
pith of the tree and can usually be recognised as the first six to eight especially wide annual rings. Sometimes these rings are of a slightly darker colour than the surrounding wood (see Figure 10). Juvenile wood does not mature, it is in the tree for ever. The amount of juvenile wood in a tree varies with species and growing conditions. Large volumes of juvenile wood are formed in fast-grown plantation trees like pine. Structurally and physically, juvenile wood is considered as inferior to the rest of the wood in the stem. During drying, it shrinks more along the length of the grain than mature wood and this may cause warp.

**CELL STRUCTURE OF WOOD**

The wood structure consists of long cells or tubes running parallel to the grain of the wood. The walls of these cells can be thin, for cells produced early in the growth season, or thick, in the case of cells produced later in the season. The hollow centre of a cell is called the lumen. Different types of specialised cells are present in wood. Hardwoods have a larger variety of specialised cells than softwoods. Perpendicular to the grain of the wood there are bundles of cells running from the pith to the bark of the tree, called rays. Trees grow by annually adding a layer of wood just under the bark, forming a conical cylinder over the full height of the tree.

**APPEARANCE**

**COLOUR**

Colour variations exist not only between species, but also within species. When describing colour, it is the colour of the heartwood that is usually referred to, the exception being species where there is little colour difference between heartwood and sapwood. Large differences exist between the colour of the heartwood and sapwood of some species (e.g. kiaat, see Figure 9). A freshly cut surface exposed to light usually darkens with time. A surface coating on the wood, if transparent, will also change the colour of the wood. Both the surface coating and the wood can change colour with time. The combined effect can either lighten (see Figure 12) or darken the treated surface, depending on the external influences and the properties of the coating.

Wood without any surface coating and exposed to the weather (rain and sun) can change to a variety of colours from silvery grey to black, depending on the wood, and the specific climatic and other influences.

**FIGURE IN WOOD**

"Figure" in wood is the pattern created by the wood structure on the cut surface. This pattern depends on the arrangement and relative size of the cells, the nature of the cells, the colour variations between the cell types and the direction the wood is cut. For instance, in lumber with large rays, like oak or protea, a cut parallel to the grain and through the centre (radial cut, or flat sawn) will show up the rays as prominent patches on the surface. If the same piece is cut parallel to the bark of the stem (tangential cut, or back sawn), these rays appear as numerous small lens-shaped marks on the surface. Selection of wood according to its characteristic pattern is important when making high quality furniture or panelling. Interlocked or wavy grain will cause interesting patterns by reflecting light in different directions according to the angle it strikes the wood fibres.

**GRAIN**

Grain relates to the direction and arrangement of the fibres in a piece of wood, but is non-specific. Only descriptions like "straight grain", "sloping grain", "wavy grain", "spiral grain" and "irregular grain" have a meaning when discussing grain. When grain is coarse or fine or regular, this is referred to as the "texture" of the wood. This is created by the size and the natural arrangement of the wood cells on the surface of the wood. Where hardwoods can span a wide range of textures from coarse (oak) to fine (kemassie), softwoods are all considered as having a fine texture.

**NATURAL DEFECTS**

Defects in wood refer to any irregularities or deviations from those qualities that make wood suitable for a particular purpose. Natural defects are imperfections in the wood of the living tree arising from tree-growth or irregularities in its growth. Some of these are:

- Cross-grain. In this defect the fibre alignment in the piece of wood is at an angle to the long axis of the piece. As the strength
properties of wood differ significantly along and across the grain. Cross-grain severely reduces the mechanical properties of a piece of wood. Cross-grain in a plank can be caused by spiral grain or interlocked grain in the tree.

- Knots are the bases of branches embedded in the stem of the tree. Tight knots are part of the wood structure while loose knots are not intergrown into the wood and tend to fall out after drying. Knots reduce the mechanical strength of a piece of wood because the fibres around the knots are distorted having the same effect as cross-grain on strength. Furthermore, the fibres of the knot displace clear wood with strength properties superior to the wood of the knot.

- Other natural defects such as compression failures, shakes, heart cracks and compression wood should be removed at the sawmill and should not be present in marketed lumber. Compression wood (also called reaction wood) is formed in a tree growing under mechanical stresses. It can usually be recognised by annual growth rings being much wider on one side of the tree than on the other side. The other defects are often visible as cracks or folds in the wood structure.

Some natural defects in wood can be put to advantageous use. Pine with large numbers of sound knots for instance, is used in ceilings where the poor mechanical properties are unimportant and the knots create an interesting pattern (see Figure 14). Other examples are birch or maple attacked by insects which is used for decorative veneer. A symmetric pattern is created by slicing irregularly grained stumpwood and arranging the slices as mirror images of each other.

**Physical Properties**

**Density**

The density of a piece of wood is its mass divided by its volume. Density is expressed as kilograms per cubic meter. As wood can contain large amounts of moisture which makes it heavier and also increases its volume, wood density is usually quoted for wood containing either no
moisture or for wood at a specified moisture content, e.g. 12%.

In Figure 11 it can be seen that a piece of wood consists of the material of which the cell walls are made (wood substance) and air. The density of the cell wall material of all wood species is about 1500 kg/m³. As wood is made up of different components, e.g. vessels, fibres and rays, all of which are hollow, and there are also sometimes spaces between cells, the density of the wood is determined by the size of the cells, the thickness of the cell walls and the ratio of the different components in the wood species.

The density is one of the best indicators of the physical properties of a piece of wood. In general, higher densities will make wood more difficult to dry, pressure treat and machine and will increase its abrasion and fire resistance, and hardness. For clear, straight grained wood, a higher density will indicate greater strength and stiffness. Density values for any given wood species will vary according to the position the wood was taken out of the tree, rate of growth, place where it grew and other factors. It is usually given as an average density together with the highest and lowest value measured. The density variation can be substantial, e.g. for Pinus patula the average density at 10% moisture content is 450 kg/m³ with a range from 350 to 610 kg/m³.

Density values for timbers of commercial value in South Africa are given by Wand (1990) and Van Vuuren et al (1978).

**MOISTURE CONTENT (MC)**

All living trees contain sap which consists of water with some dissolved minerals and sugars. Wood still containing all the sap or water that the tree needed to grow, is called "green" wood or "unseasoned" wood. The water in green wood fills the cell cavities (partially or completely) and saturates the cell walls. The water in the cell cavities is called "free" water and is relatively easily evaporated from the wood. The water in the cell wall is called "bound" water, as it is chemically bound to the cell wall and is more difficult to remove during the drying process than the free water.

The amount of water in a piece of wood is called its "moisture content" (MC). MC is expressed as a percentage of the mass of the completely dry wood.
MC = (mass of water in a piece of wood / mass of the completely dry wood) × 100%.

[The SABS specifies MC as gram of water per kilogram of completely dry wood (g/kg), e.g. a MC of 120 represents 120 g of water per kilogram of completely dry wood and is equal to a MC of 12%.] The lower the MC, the dryer the wood. The MC of wood can range from over 200% in the sapwood of some living trees down to 0% in artificially dried wood kept in a sealed container with all the moisture removed. A MC of over 100% means that the mass of water in a piece of wood is more than the mass of the same piece if completely dry.

If wood contains no moisture at all, it is called "oven-dry" or "bone-dry". Kiln-dried wood or oven-dried wood is wood that was dried artificially in a kiln or oven in contrast to air-dried wood which was dried by leaving it exposed to the atmosphere. The terms "kiln-dried" or "oven-dried" do not indicate the moisture content of the wood. Kiln-dried wood can still contain any amount of water depending on the MC at which drying was stopped.

All wood exposed to the atmosphere contains some water. As green wood dries, the free water in the cell cavities evaporates before the bound water in the cell walls. At the stage when all the free water in a piece of wood has evaporated, but all the bound water is still in the cell walls, the wood is said to be at fibre saturation point (fsp). This corresponds to a MC of about 30%. The fibre saturation point can vary between 25% and 35% for different wood species and also depends on the wood density, but is, for all practical purposes, taken as 30%. As drying continues from the fsp downwards, the wood starts to shrink as it loses its bound water. The loss of free water does not cause shrinkage of the wood.

**HYGROSCOPIC BEHAVIOUR**

Wood is a hygroscopic material. This means that it will release or adsorb moisture from the air until its MC has stabilised in relation to the moisture content and temperature of the surrounding air. This moisture content of the wood, which is in equilibrium with its surroundings, is called the "equilibrium moisture content" (EMC). This EMC is not a stable condition, but varies as the relative humidity and the temperature of the surrounding air changes (see Figure 5).

Sawn timber, stacked under a roof in an open shed in South Africa, will eventually dry to an EMC of between 8% and 15%. The rate of drying will depend on the weather conditions, the wood species and the thickness of the wood. Figure 7 shows a map of the country and the annual average EMC a piece of wood will eventually reach in each part of the country protected against direct sun, dew and rain. These EMC values will be reached irrespective of whether the initial MC of the wood was higher or lower than the EMC of this area.

**SWELLING AND SHRINKAGE**

As wood dries below its fibre saturation point (fsp) it shrinks, and if it adsorbs water below fsp, it swells. No swelling or shrinkage occurs above fsp. The amount of swelling or shrinkage (moisture movement) is in proportion to the change in the amount of bound water and differs in the longitudinal, radial and tangential direction. Longitudinally the movement is so small that it is usually not considered. In the radial direction, depending on the wood species, the lumber dimension will change by between 4% and 8% of the green dimension when dried from fsp to oven-dry. In the tangential direction this change is about twice as much. The effect this shrinkage has on the shape of lumber cut from different parts of a log...
important for wood installed in large areas (like floors) as the total moisture movement will be large. If installed at a higher MC than the EMC of the site, it will shrink and leave gaps between the boards, while if at a lower MC it will swell and lift the floor (refer to SALMA Timber Brochure 3.2 Floors and flooring).

The natural variations in the climate will normally not cause substantial changes in the EMC of the wood and therefore the moisture movement will be limited. For wood exposed to direct sunshine, rain and dew, the changes in MC and the consequent swelling or shrinkage will be much larger and must be allowed for by proper design.

Other methods to limit the swelling or shrinkage of wood in use are:

- selection of wood species with small radial and tangential swelling or shrinkage
- retarding the moisture adsorption and loss rate by applying a coating containing a water repellent
- designing the structure in such a way that the wood is protected against excessive wetting and drying.

If, under special circumstances, green wood
(i.e., wood not dried) has to be used, allowance should be made for the shrinkage that will occur. When pieces of green lumber are jointed together, the difference in radial and tangential shrinkage must be taken into account (see also SALMA Timber Brochure 1.7 Timber Joint Design and Fasteners).

Wood is normally kiln-dried to a MC between 10% and 15%. Suitable MC values for wood for different applications are given in Table 2.

**Table 2: Typical moisture content values of wood for specific uses.**

<table>
<thead>
<tr>
<th>APPLICATION OF THE WOOD</th>
<th>RECOMMENDED MC(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural timber</td>
<td>15 - 20</td>
</tr>
<tr>
<td>Transport containers,</td>
<td>13 - 16</td>
</tr>
<tr>
<td>garden furniture</td>
<td></td>
</tr>
<tr>
<td>Exterior windows and doors</td>
<td>12 - 15</td>
</tr>
<tr>
<td>Furniture in unheated rooms</td>
<td>8 - 12</td>
</tr>
<tr>
<td>Furniture in heated rooms</td>
<td>6 - 9</td>
</tr>
<tr>
<td>Musical instruments</td>
<td>5 - 7</td>
</tr>
</tbody>
</table>

Wood that is to be treated with a preservative has to be dried to a MC of below 25% (see SABS Code of Practice 05).

Wood at a MC below 20% will not support fungal growth.

Kiln-dried wood has several advantages over green wood, some of which are:

- improved strength and rigidity
- stable cross sectional dimensions
- better gluing and nail and screw holding
- low electrical conductivity
- reduced weight
- improved resistance to biological decay.

**ELECTRICAL PROPERTIES**

Wood at 0% moisture content has a very high electrical resistivity (of the order of $10^{10}$ ohm.m), but drops to $10^7$ ohm.m at 30% MC. At the same moisture content, softwoods are slightly better insulators than hardwoods. This dramatic change in electrical resistance between oven-dry (0% MC) and fibre saturation point (30% MC) is the basis of resistance moisture meters for measuring the MC of wood in this MC range. Above

Whenever SABS specifications are mentioned, the latest published version applies.
tsp resistance moisture meters will still give a reading, but the MC value cannot be trusted. Below 15% MC, wood is for all practical purposes considered as a non-conductor. Wood treated with salts, e.g. copper chrome arsenate (CCA) and at a MC above tsp, should be considered as a conductor.

Wood placed in an alternating electromagnetic field, e.g. in a microwave oven, can be heated and dried. It is mainly the moisture in the wood that interacts with the electric field and is heated. In the same way some adhesives used in finger joints and veneers can be quickly cured by placing the glue joint in an alternating electromagnetic field.

**THERMAL PROPERTIES**

Wood is a poor conductor of heat. For the same thickness it is a heat insulator five times better than solid brick. Heat conduction along the grain is about 2.5 times greater than across the grain. Dry wood of low density is a much better insulator than wet, high density wood as the air in the cells of the wood is the main reason for its insulating properties. This low heat conduction also slows down the rate at which heavy wooden beams weaken under extreme heat as during a fire. A wooden construction in a fire will therefore remain structurally sound much longer than a metal construction.

This insulating property of wood is used in timber-frame construction. Even the air space created by the framework is an effective thermal barrier which can be enhanced by filling with other insulating materials. Good insulation can be achieved without increasing the wall thickness (see SALMA Timber Brochure 3.1 Timber frame construction).

The thermal expansion of wood is so small that it is usually not considered in comparison to the expansion of wood with a change in MC. Only in very long spans, and when changes in MC are so small as not to be considered, should the thermal expansion be taken into account. This is of the order of $3 \times 10^{-6}$ m/m along the grain and about 8 times more across the grain. In large wooden floor areas expansion joints should therefore be provided (see SALMA Timber Brochure 3.2 Floors and flooring).

**ACOUSTIC PROPERTIES**

Acoustics is concerned with audible sound, its
propagation and its adsorption. In concert halls the sound must be propagated from the instruments to the audience without unwanted echoes, but at the same time without damping the sound. Wood was found to have just the right properties as a wall cladding for this purpose, reflecting sufficient sound but also reducing resonant vibration.

In other cases, the sound propagation through a building must be prevented (noise control). Sound energy carried by the air molecules can be converted into heat energy by friction of the air molecules against any material with an open cellular structure like wood. The sound waves set the wood panels in motion, but the internal friction in the wood structure damps the vibration. By mechanically separating the two skins of a wooden wall and filling the intermediate space with sound adsorbing material (which will also serve as heat insulation), sound propagation can be effectively controlled in wooden structures (see SALMA Timber Brochure 1.3 Noise control in timber buildings).

DURABILITY AND WEATHERABILITY

Degrading factors that destroy wood can be classified as

- biological factors, e.g. fungal growth, wood beetles, termites and marine borers, and
- physical and chemical factors.

Often these factors are present simultaneously to cause severe destruction. Severe decay takes place in timber in contact with the ground under temperature and moisture conditions that favour fungal decay.

The durability of timber is determined mainly by its natural resistance to insects and wood destroying fungi. Weatherability describes its resistance to the climatic factors. The type and concentration of the extractives in the wood make it naturally durable. As extractives only occur in the heartwood, only the heartwood is considered when discussing natural durability. Sapwood, which usually contains no toxic extractives, is not naturally durable. Fortunately sapwood is much easier to treat with preservatives than heartwood to make it just as durable.

Timber can be classified in five durability classes based on the service life of 50 x 50 mm untreated heartwood stakes half buried in the ground. The five classes are given in Table 3, indicating some of the wood species in each class. Under more favourable circumstances these expected life-times might be longer, but the relative ratings will remain the same (data from Building Research Establishment, UK). For more information, refer to the following SALMA Timber Brochures:

<table>
<thead>
<tr>
<th>Durability class</th>
<th>Durability</th>
<th>Average service life</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Parishable</td>
<td>Less than 5 years</td>
<td>All sapwood, irrespective of species, ash, balsa, beech, birch, lime, P. patula, P. canariensis, P. elliottii, poplar, willow.</td>
</tr>
<tr>
<td>II</td>
<td>Non-durable</td>
<td>5 - 10 years</td>
<td>E. grandis, E. microcorys, E. saligna, meranti (yellow), fir, elm, maple, red oak, P. radiata, spruce</td>
</tr>
<tr>
<td>IV</td>
<td>Durable</td>
<td>15 - 20 years</td>
<td>Blackwood, cedar species, cypress species, kari, kempas, white oak, sequoia.</td>
</tr>
<tr>
<td>V</td>
<td>Very durable</td>
<td>More than 20 years</td>
<td>Afrotomosia, abizia, African ebony, iroko, jarrah, lignum vitae, makore, podouk, teak, Rhodesian teak, tallowwood.</td>
</tr>
</tbody>
</table>
1.2 Timber - design for durability
1.5 Treating timber
2.5 Decking timbers
2.6 Outdoor timbers.

CHEMICAL REACTION OF WOOD

Wood is very resistant to most chemicals like salts, dilute acids and alkalis and organic solvents. Even strong acids and alkalis will only slowly destroy wood. Caustic soda should, however, be kept away from wood.

Although penetration of chemicals into softwoods is faster than in most hardwoods, softwoods are more resistant to chemical attack. Resins in softwood prevent the penetration of the chemicals into the wood structure making resinous softwoods even more resistant. For this reason resinous softwoods like the heartwood of Douglas fir and slash pine (P.elliottii) are used in the construction of chemical factories and laboratory benches.

Wood is naturally acid with a pH value between 3 and 6. At high temperatures and high moisture content, wood releases acids which will corrode metals in contact with it. Precautions should be taken when selecting metal fasteners for timber used under hot and wet conditions. Timber treated with preservative salts, e.g. CCA (copper chrome arsenate) and used under wet conditions, will corrode even galvanised fasteners.

STRENGTH, HARDNESS AND TOUGHNESS

The many strength properties of wood include not only its resistance to loads causing bending, direct tension and compression, shear and torsion, but also its resistance to abrasion, indentation and impact. These strength properties vary according to the direction in which the load is applied relative to the direction of the grain, i.e. whether the loads are parallel to the grain or at right angles to it, either in the radial or tangential direction. Timber is much stronger under bending, tension and compression stresses parallel to the grain than to stresses perpendicular to the grain.

Other factors affecting the strength of wood are natural defects like knots (number, size and position in the piece of wood), spiral grain, distorted grain, compression wood, pitch pockets and decay. To these have to be added manufacturing defects like cross-grain (slope of grain) and drying defects. All this means that the strength properties of a piece of wood can vary widely.

In order for timber structures to be properly designed to meet safety requirements, while at the same time being designed economically and not wastefully over-designed, the strength properties of each piece of timber should be known to the designer. For this purpose each piece of timber is graded for strength (stress-graded) and marked according to a grading system.

FACTORS AFFECTING TIMBER STRENGTH

The strength of timber under load is also affected by the duration of the load and the type of load, i.e. static (continuous) or cyclic (dynamic). Under a static load, i.e. a beam supporting a constant mass for more than three months, the beam could sag due to deformations in the wood fibres, called "creep", if the load exceeds 0.6 times the permissible load for short duration loading.

Cyclic loading, which occurs in bridges or buildings exposed to high winds, can be tolerated far better by timber structures than by most other structural materials. It has been shown that timber subjected to 30 million stress cycles of tension parallel to the grain, still retains 40% of its static strength. The effect of cyclic loading should be considered in designing timber structures and especially their effect on the metal fasteners used. Reference should be made to SABS Code of Practice 0163: Structural use of timber. Part I: Limited state design and Part II: Allowable stress design.

Temperature has an effect on the strength of timber. If used continuously at temperatures above 40°C, design stresses should be reduced. Very high temperatures will weaken the timber with time. Below 0°C timber has slightly higher strength values under bending, compression and shock loading.

The moisture content (MC) of timber has a significant influence on its strength. Except for shock resistance, all strength properties are reduced by an increase in MC up to fibre saturation point. For this reason, structural timber should have an initial MC below 20% and
should be protected against large variations in MC during use. Published strength properties of clear defect free timber are normally determined at a MC of 12%. Correction factors for higher MC values can be found in SABS 0163.

Combinations of elevated temperatures and high MC, as found in indoor swimming pools, saunas and cooling towers, need special consideration. Some strength properties of SA pine treated with CCA are affected (see SALMA Timber Brochure 1.5 Treating Timber) but other preservative treatments have little effect on strength properties.

Hardness of wood is an indication of its resistance to indentation and is measured as the force required to press a steel ball of given diameter into the wood. Hardness depends on which surface of the wood is tested and the density of the wood. The higher the density, the harder the wood. Hard wood is more difficult to saw and plane and is more resistant to wear.

Toughness describes the ability of a piece of wood to absorb shock loads without breaking. This property is required for handles of hammers and picks. Species suitable for this purpose are Eucalyptus globulus, E. maculata and E. paniculata, while most softwoods have a low toughness.

Data on strength properties of locally grown woods and the most important exotic woods together with some typical uses is given by Banks (1954) and Wand (1990).

**Graded wood**

Only if the strength properties of a piece of lumber are known can it be used optimally in a structure. By using stress graded lumber, the minimum lumber can be used to obtain the required strength and stiffness in a structure. This minimises the dead load of the structure and the costs. For this purpose timber is stress graded using one of the methods described below.

It was found that the strength of a piece of timber can be related to the density of the wood and the magnitude and position of natural and manufactured defects in the piece of timber. These properties can be evaluated by visual
inspection of each piece by a person trained as a grader. Timber graded visually is marked as Vx, where "V" stands for visual and "x" is a number representing the bending stress in megapascals (MPa) that the piece can safely sustain under long-term loading. Visual grades are available as V4 and V6.

As visual grading relies on the training, experience and judgement of a person, an alternative method based on the stiffness of the board as determined by a machine is also used. By this method each board is flexed, bent or twisted by a fixed amount and the force to do this is measured. Colour codes can be sprayed onto the timber indicating the grade along its length. The lowest grade measured on the piece of timber is its overall grade and is indicated on its end as Mx, where "M" indicates mechanical grading and "x" is a number representing the bending stress in megapascals (MPa) that the piece can safely sustain under long-term loading. Mechanically graded timber is available as M4, M6, M8, M10 and M12.

Another form of grading is proof grading in which case the piece of timber is put under a stress in the same direction as it will be loaded in service. This stress is higher than the design stress and if the piece of timber survives the test without damage it is marked Px on one end. "P" indicates proof grading and "x" is the number corresponding to the static test load that was applied. See SALMA Timber Brochure 2.2 Rough sawn and regularised timber for a description of proof grades.

The relationship between bending stress and other stresses like tensile stress parallel to the grain and modulus of elasticity have been determined and tabulated for commercially available pine timber products in SABS 0163: Part II. Using graded timber, modern roof trusses are designed to provide the exact support required, utilizing the full strength-range of structural timber. This optimizes the use of timber and keeps it competitive.

This whole system of grading has been under review for a number of years and in a recent "In-grade" testing programme, it was found that V4 grade material, when mechanically tested, actually yielded strengths comparable to M5. This led to the development of a new system of visual grades, i.e. V5, V7 and possibly a V10 at a later stage, with corresponding M-grades. See SALMA Timber Brochure 2.2 Rough-sawn and
Table 4: Sizes of rough-sawn South African pine

<table>
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<tr>
<th>Board thickness (mm)</th>
<th>25</th>
<th>38</th>
<th>50</th>
<th>63</th>
<th>76</th>
<th>89</th>
<th>102</th>
<th>114</th>
<th>127</th>
<th>152</th>
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</table>

Notes: For structural timber sizes (used for roof trusses, etc.) see SABS 563, SABS 1146 and SABS 1245. For industrial timber sizes (e.g. flooring, furniture, pallets, etc.) see SABS 1359 and SABS 563.

regularised timber for further information on grades.

**WOOD CONVERSION**

**POLES**

Timber is used in the round form as poles in fencing, vineyards, orchards, as transmission poles, as framework for constructions and in landscaping. All poles should be treated with preservatives for durability as poles contain large proportions of non-durable sapwood. Wire wrapping and gangnail plates are often used to prevent end-splitting of the poles in use (see SALMA Timber Brochure 2.7 Poles and pole structures).

**SAWN TIMBER**

Depending on the position the piece of timber occupied in the log it can be called tangentially sawn (flat sawn) or radially sawn (quarter sawn) timber. In Figure 8 the piece marked (1) is radially sawn as the width of the piece is in the radial direction while (2) is tangentially sawn. It can also be seen that after drying the radially sawn piece retains its shape, but this is not the case for the tangentially sawn piece. Radially sawn timber is considered as being more stable in shape with changes in MC and is for this reason selected for specific applications where the shape of the individual pieces is important. Radially sawn floor boards also have a higher resistance to abrasion as the high density late-wood is uniformly exposed on the surface.

Most sawn wood in South Africa is used as structural timber, mainly in roof constructions, or as industrial timber for furniture, crates, cable drums and pallets.

Structural timber, suitable for all normal building work, is covered by SABS 563, which defines one visual stress grade (V4) and one mechanical stress grade (M4). Structural timber suitable for use in engineering structures is covered by SABS 1245, which defines three stress grades of visually and mechanically stress graded timber (V or M6, M8 and M10). Sub-grade structural sized timber is clearly marked with black crosses on both ends, distinguishing it from graded timber. In the coastal areas of South Africa, all structural timber must be treated with preservatives (see SALMA Timber Brochure 1.5 Treating timber).

Industrial timber is covered under SABS 1359. This makes provision for four grades: Clear, Semi-Clear, Select and Industrial grade intended for use in specific products. Sub-grade material is called crating.

Sawn wood is available in standard widths and thicknesses as given in the Table 4. Standard lengths are available from 1.8 m upwards in units of 0.30 m. Grades and sizes for SA grown hardwoods are similar to those for industrial timber. The grades are described in SABS 1099. For more information refer to SALMA Timber Brochure 2.2 Rough sawn and regularised timber.

**FINGER-JOINTED TIMBER**

By removing mechanically weak sections from a
piece of timber its mechanical properties can be increased. To obtain adequate lengths of this stronger wood, the pieces are end-jointed using finger joints and an appropriate glue. Beams of a given cross-section and any required length can be manufactured in this way. The strength properties of these finger joints are rated as V8 or M8 if the timber used has the same or a higher rating. The type of glue used determines if the timber can be used outside (exterior grade glue) or only inside buildings. An advantage of this method of producing structural timber is that exact lengths can be delivered with a minimum of waste from off-cuts and no end-jointing on the building site is required.

**LAMINATED TIMBER**

Glue-laminated timber is timber created by finger-jointing short lengths of defect free (clear) wood and then laminating these to form beams of any desired width and thickness. Glue is used to keep the pieces together. For exterior applications, water resistant glue is used and for interior applications, non water resistant glues can be used, but seldom are. Both hardwoods and softwoods are used for gluelam structures. As the laminations can be bent while gluing them together, almost any desired shape can be produced. Beams of any length and cross section can be produced and the strength properties are superior to those of solid wood as any defects can be removed from the parts that make up the beam. By resawing these beams lengthwise, boards of any thickness can be produced which are used as tops for laboratory benches and tables.

For more information refer to SALMA Timber Brochure 2.9 Laminated timbers. Specifications for the grading of laminations and the manufacture of gluelam beams are contained in SABS 1460.

**BOARD PRODUCTS**

Wood-based panel products or board products are commercially available as plywood, blockboard, fibreboard, medium density fibreboard (MDF) and particleboard. They differ mainly in the process used in manufacturing. Their main application is in products with large flat surface areas like built-in cupboards. These boards are required to be dimensionally stable under normal variations in moisture content.

**Plywood** is formed by gluing layers of veneer on top of each other with the grain of alternative layers at right angles to each other. An uneven number of layers are used to have the grain on both sides of the board in the same direction and to balance the construction. It is available in various thicknesses. It is used where strength and dimensional stability is required as in containers, timber-frame houses, concrete shuttering, vehicle floors and boats.

**Blockboard** or battenboard has a core of pine timber strips glued together to form a slab which is faced on both sides by a layer of veneer (at right angles to the strips), plywood or hardboard. It is dimensionally very stable and is therefore used for shelving, furniture, cabinet making, shuttering and underground in mining.

**Particleboard** is manufactured from wood particles ranging from sawdust to specially shaped wood flakes and is bonded with synthetic resin under pressure and heat. The particles used in the board and their distribution over the thickness of the board determines the mechanical properties of the board. Particleboard usually has high density surfaces composed of finer material and a lower density core of coarser material. Its main uses are for built-in cupboards, carcass work for furniture and partitioning.

All the above board products are classified as interior or exterior depending on the type of adhesive used.

**Fibreboards** are produced from wood fibres which are bonded together by means of their felting properties and intrinsic adhesive properties. No adhesive is used in the bonding process. In principle it is closely related to paper but, is manufactured in thicknesses over 1.5 mm. If not compacted in the hot press, it is sold as softboard for ceilings. In the compacted form it is called hardboard, and is used for furniture backs, drawer bottoms, door skins, and linings in the automotive industry. Tempered hardboard is treated during manufacturing to make it more water resistant.

Medium density fibreboard, known as MDF, is similar to hardboard. It uses only *Eucalyptus* fibres, a synthetic resin as binder and is pressed to a lower density than hardboard. It has excellent machining properties for profiling and is used in furniture replacing some solid wood, particleboard and blockboard.
All these board products can be purchased with overlays of melamine paper, other man-made materials or veneers which make them useful for a variety of applications. Wood panelling for instance is an indoor decor device offering warmth and elegance and can be used in any room. For more information refer to SALMA Timber Brochure 2.10 Board products.

**Timber Protection**

The useful life of timber can be extended by protecting it against biological hazards, e.g. fungal growth, wood beetles, termites and marine borers, as well as weathering and fire (see also the sections on durability and weathering and chemical resistance of wood).

Timber can be protected by the correct design of the structure, by covering the timber with a coating or finish, by painting it with a retardant paint and by treating it with chemicals (preservatives). In many cases all three measures are taken simultaneously to give adequate protection against all potential hazards.

Unprotected timber will weather when exposed to rain, dew, direct sunshine, wind and frost. This exposure is usually on one side of the timber only and leads to excessive swelling and shrinkage which causes the gradual disintegration of the timber. With good design, protection against direct rain, dew and sunshine can be achieved. It can also prevent the accumulation and retention of moisture that would lead to biological attack in parts of the structure.

Although weathering itself is a slow process at a rate of about 6 mm per 100 years, the cracks accompanying the weathering allow dirt and moisture to enter the wood and can form an ideal environment for fungal decay. This process is much faster than weathering.

Treatment improves either durability or appearance or both. Preservatives and decorative coatings will improve resistance to weathering. The appearance of weathered timber can be quite attractive. Weathering need only be slowed down to extend the life of the wood. Varnishes and water repellents can retain the natural appearance of the wood and also give protection, in which case they should contain ultra violet absorbers. Opaque finishes (e.g. paints) are even better, but obscure the natural appearance of the wood (refer to SALMA).

**Table 6: Hazard classes for wood products**

<table>
<thead>
<tr>
<th>Hazard class</th>
<th>General area of timber use</th>
<th>Typical uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>H6</td>
<td>Marine:</td>
<td>Piing, retaining walls, slipways, groynes, jetties, walkways</td>
</tr>
<tr>
<td></td>
<td>Timber constantly or periodically in contact with estuarine or sea water and subject to marine borer attack</td>
<td></td>
</tr>
<tr>
<td>H5</td>
<td>Fresh water:</td>
<td>Piing, retaining walls, slipways, culverts, groynes, flood gates, jetties, drains, walkways, industrial cooling towers</td>
</tr>
<tr>
<td></td>
<td>Timber constantly or periodically in contact with fresh water or heavy wet soil</td>
<td></td>
</tr>
<tr>
<td>H4</td>
<td>Exterior with ground contact:</td>
<td>Agricultural posts, landscaping structures, playground structures, building, fencing, pergolas, car ports, flower boxes, decking, bridges, stakes, piling</td>
</tr>
<tr>
<td></td>
<td>Timber in direct contact with the ground</td>
<td></td>
</tr>
<tr>
<td>H3</td>
<td>Exterior above ground:</td>
<td>Balustrades, fencing bearers and slats, outdoor decking and beams, garden furniture, laminated beams, weather board, steps, cladding, stairs, log homes, gates, fascia boards</td>
</tr>
<tr>
<td></td>
<td>Timber not in contact with the ground but exposed to leaching and weathering</td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>Interior:</td>
<td>Laminated beams, roof trusses, structural timbers, ceiling boards, flooring, doors, cupboards, skirting, window frames</td>
</tr>
<tr>
<td></td>
<td>Timber used under a roof, not in contact with the ground and not exposed to leaching and weathering</td>
<td></td>
</tr>
</tbody>
</table>
Timber Brochure 1.6 Surface coatings for timber).

Only the sapwood of both hard and softwood can normally be pressure treated successfully. This implies that the heartwood of non-durable species, such as pine, can never be considered as durable even after pressure treatment.

Many of the more abundant wood species, like pine, have little natural durability, and have to be treated to protect them from insect and fungal attack. All hard-wood poles used in the Republic of South Africa and all construction soft-wood used along the coastal belt of South Africa is by law required to be treated against insect attack (see SALMA Timber Brochure 1.5 Treating timber).

Timber used indoors should be protected against insects and fungi. This is done by pressure treatment with preservatives like CCA and TBTOL, or with boron preservatives. The latter will leach out if exposed to wet conditions so it is not fixed in the wood. For exterior use, timber is treated with preservatives like CCA or creosote. Although soluble in water during the pressure treatment process, CCA is chemically fixed in the wood after a given curing period and does not leach out. These preservatives are therefore used outdoors and in marine applications where maximum protection is required.

Treatment with CCA does not prevent water from penetrating the wood and as mechanical strength decreases with moisture content, this has to be taken into account when designing exposed structures with CCA treated timber. An example is the end-posts in vineyard and fruit trellises which are currently creosote treated poles to overcome the problem of timber failure during successive irrigation cycles on the highly stressed end-posts. The problem can be reduced by treating the CCA poles with a water repellent.

Creosote treated timber is to a large extent water repelling, but its appearance might be considered as unattractive and it is difficult to paint or varnish. CCA treated timber retains its wood surface texture and can be painted or varnished if required. For more information refer to the following SALMA Timber Brochures:

- 1.2 Timber - design for durability
- 1.5 Treating timber
- 1.6 Surface coatings for timber

Depending in which environment timber is to be used, it is exposed to different hazards and is therefore treated with preservatives to give maximum protection against the specific hazards. Five different hazard classes have been defined for which the types of preservatives, the depth of their penetration and the minimum amount of preservative per cubic metre of timber are specified. When ordering preservative treated timber, the end-use should be considered and the appropriate hazard class must be specified. In Table 5 the five hazard classes as identified by the South African Wood Preservers Association (SAWPA) and specified in SABS Code of Practice 05 are described, together with typical timber products used under these conditions. Timber used under hazard class H6 would need the highest protection available while timber used under hazard class H2 would be protected against insects and fungal attack only.

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READING LIST

CENTRES

Department of Wood Science, Stellenbosch University, Private Bag X5018, Stellenbosch 7599. Tel (021) 808-3290, Fax (021) 808-3603.

Division of Forest Science and Technology, Forestek, CSIR, PO Box 395, Pretoria 0001. Tel (012) 841-2620, Fax (012) 841-2689.

Forest Owners’ Association, PO Box 1553, Rivonia, 2126. Tel (011) 803-3403, Fax (011) 803-6706.

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Lignum Lab, PO Box 33049, Glenstantia, Pretoria 0010. Tel (012) 420-2430, Fax (012) 48-3589.

Saasveld School of Forestry, Private Bag X631, George, 6530. Tel (044) 71-1011, Fax (044) 71-2437.

South African Bureau of Standards (SABS), Private Bag X191, Pretoria 0001. Tel (012) 428-7911, Fax (012) 344-1566.

South African Lumber Millers’ Association (SALMA), 5 Hulley Road, Isando, Private Bag X686, Isando 1600. Tel (011) 974-1061, Fax (011) 974-9779.

South African Timber Growers’ Association (SATGA), PO Box 800, Pietermaritzburg, 3200. Tel (033) 45-1366, Fax (033) 94-8484.

South African Wood Preservers Association (SAWPA), Private Bag X686, Isando 1600. Tel (011) 974-1061, Fax (011) 974-9779.

Wooddressed Panel Producers’ Association, PO Box 34, Auckland Park, 2006. Tel (011) 726-5300, Fax (011) 726-8421.

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PHOTOGRAPHS

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Figure 4: Courtesy of Die Bergkelder.

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