WOOD CONSTRUCTION

PRINCIPLES—PRACTICE—DETAILS

WOOD CONSTRUCTION

PRINCIPLES—PRACTICE—DETAILS

A PROJECT OF THE
NATIONAL COMMITTEE ON WOOD UTILIZATION
UNITED STATES DEPARTMENT OF COMMERCE

SPONSORED BY THE FOLLOWING CONTROL COMMITTEE

WILLIAM F. CHEW
HENRY D. DEWELL—M. AM. SOC. C. E.
F. O. DUFOUR—M. AM. SOC. C. E.
N. MAX DUNNING—F. A. I. A.
W. H. HAM
LEROY E. KERN—A. I. A.
T. F. LAIST—A. I. A.
I. W. McCONNELL—M. AM. SOC. C. E.
D. H. SAWYER—M. AM. SOC. C. E.
F. E. SCHMITT—M. AM. SOC. C. E.

PREPARED BY

DUDLEY F. HOLTMAN

Construction Engineer National Committee on Wood Utilization
Member American Society of Civil Engineers and
Western Society of Engineers

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK AND LONDON
1929

PRINTED IN THE UNITED STATES OF AMERICA

PREFACE

This handbook is an attempt to supply a rapidly growing need on the part of architects, engineers, and builders for complete and practical information on the use of wood in construction. In part, this need grew out of changes in the wood-using arts and in the lumber industry which supplies these arts. In part, it is due to the fact that construction in wood developed through long ages as a matter of craftsmanship, and many of its essential practices have not been recorded.

Fundamental facts concerning the nature and available forms of wood, and fundamental principles on the use of wood, constitute the most important part of the book. The aim has been to furnish basic information for use in designing and specifying wood construction, and to aid in the efficient selection and application of the material, and in the adoption of efficient and economical forms of design. The handbook should prove equally helpful in the office and on the job.

The first seven chapters include information on the factors affecting the use of wood in construction; lumber grading, grade provisions, and working stresses; the principal woods used in building and construction; the identification of common woods; preservative treatment; the use of paints and stains, and methods of preventing termite damage. The last four chapters contain information on approved methods of using lumber in light building construction and millwork, and in both heavy timber and temporary construction. In an appendix are given compilations showing the standard grades produced in the various species, and tables of the lumber grades used for various construction purposes.

Preparation of the handbook was undertaken to further the movement for elimination of waste, increase of efficiency, and conservation of the country's resources. Waste of our wood resources is due as much to uninformed and inefficient practices in the use of wood as to waste incurred in the forest and in the lumber mill. By showing how a simple unified grading of lumber recently adopted can be applied to give the wood user that kind of material which will serve his particular purpose most economically, and by setting forth the principles of efficient construction, the handbook will diminish waste and will produce a larger [illegible] the lumber dollar.

[illegible]ring this book the National Committee on Wood Utilization [illegible]nce from a large number of organizations and individuals. [illegible] Hoover was its primary inspiration, and the facilities of the

Department of Commerce were at the service of the Committee most liberally. The Forest Products Laboratory cooperated with equal readiness.

S. S. Cook, P. R. Hicks, T. E. Snyder, P. A. Hayward, and H. A. Gardner, have made important contributions to the book. Thanks are also due Irving K. Pond, Cram and Ferguson, John W. Weiss, George W. Niestadt, Clarence A. Jensen, H. E. Cousins, Leonard C. Wason, A. E. Wynn, H. C. Turner, Frederick L. Ackerman, Arthur L. Harmon, and to many other architects and engineers who have furnished blueprints and data, reviewed manuscript, and made many valuable suggestions. Courtesies extended by the United Engineers and Constructors, Inc., of Philadelphia, are also acknowledged.

Grateful acknowledgment is made of the aid rendered by the National Lumber Manufacturers Association. Generous use has been made of its extensive files and facilities, and of invaluable information, heretofore unpublished, resulting from years of research.

To Mary H. Bosworth who prepared the drawings and to Lotta L. Kimball who edited manuscript and read proof, I wish to express my most grateful thanks.

I acknowledge my sincere gratitude to Nelson S. Perkins, C. E. and to Leyden N. Ericksen to whom I am especially indebted for untiring and devoted assistance in all phases of the work.

DUDLEY FRANK HOLTMAN.

WASHINGTON, D. C.
May, 1929.

CONTENTS

CHAPTER IV

CHAPTER V

CHAPTER VI

CHAPTER VII

CHAPTER VIII

CHAPTER IX

CHAPTER X

WOOD CONSTRUCTION

PRINCIPLES—PRACTICE—DETAILS

CHAPTER I

FACTORS AFFECTING THE USE OF WOOD IN CONSTRUCTION

The availability of wood as compared with other structural materials, its low cost, its exceptionally high strength for its weight, and its ease of working both at the mill and in construction have maintained its prestige in the building and construction field for many generations, and late studies, which make it possible to determine by visual inspection the strength of wood within very narrow limits of range, will continue to maintain and to expand its utility and use.

In the past, the characteristic variations of wood were not so important as they are today, because lumber was cheaper and was easily obtained in large sizes and in almost clear grades. The use of clear grades practically eliminated defects and avoided many of the problems caused by variability in lumber. Plentiful supply, moreover, resulted in the use of larger sizes than economical design would indicate. But conditions have changed rapidly in the past 25 years. By experiment we have learned the structural value of the lower grades of lumber. Furthermore, the requirements of modern construction for strict economy in design have been met by the advancing knowledge of wood technology here recorded.

TIMBER RESOURCES OF THE UNITED STATES

The forested area of the world is now about 7,500,000,000 acres or one-fifth of the land area. Russia and the British Empire each contain about one-fifth of the forests of the world, followed by Brazil with around 13 per cent, and next by the United States with 9 per cent. The remaining 38 per cent of the forested area is divided among some 50 countries.

[illegible]ited States was originally provided with a bountiful supply [illegible]useful woods. Approximately one-half of the original stand [illegible]he rest has been lumbered or destroyed either by forest fires [illegible] clear the land. Compared to the rest of the world, we are, [illegible]ther well off even yet, provided that we recognize now that timber is a crop and must be treated as any other crop, *i.e.*, cared for while it is growing and provision made for a new crop after it has been cut.

Regions of Growth and Types of Forests.—The regions of forest growth in the United States are shown in Fig. 1.

In the Northeastern states the stand is made up mainly of spruce, hemlock, second-growth white pine, and the hardwoods—beech, birch, and maple.

The forests of the South and Southeast are of four types: the swamp forests of the Atlantic and Gulf coasts and the river bottoms, which furnish cypress and hardwoods, and the Mississippi Valley, which is a very important hardwood region and center of production; the forests of the coastal plains from Virginia to Texas, which furnish southern yellow pines; the plateau forests, encircling the Appalachian Range and the lower part of the mountain region, which furnish a variety of hardwoods including oak, yellow poplar, chestnut, ash, cherry, and basswood; and the coniferous forests on the higher ridges of the mountains, made up largely of spruce, white pine, and hemlock.

The Lake states in their southern portions contain large hardwood forests made up principally of maple, elm, birch, beech, and basswood, in which conifers are intermingled. Most of the hemlock and pine grow with the hardwoods. Farther north are coniferous forests of hemlock, white pine, cedar, and tamarack, in purer stands.

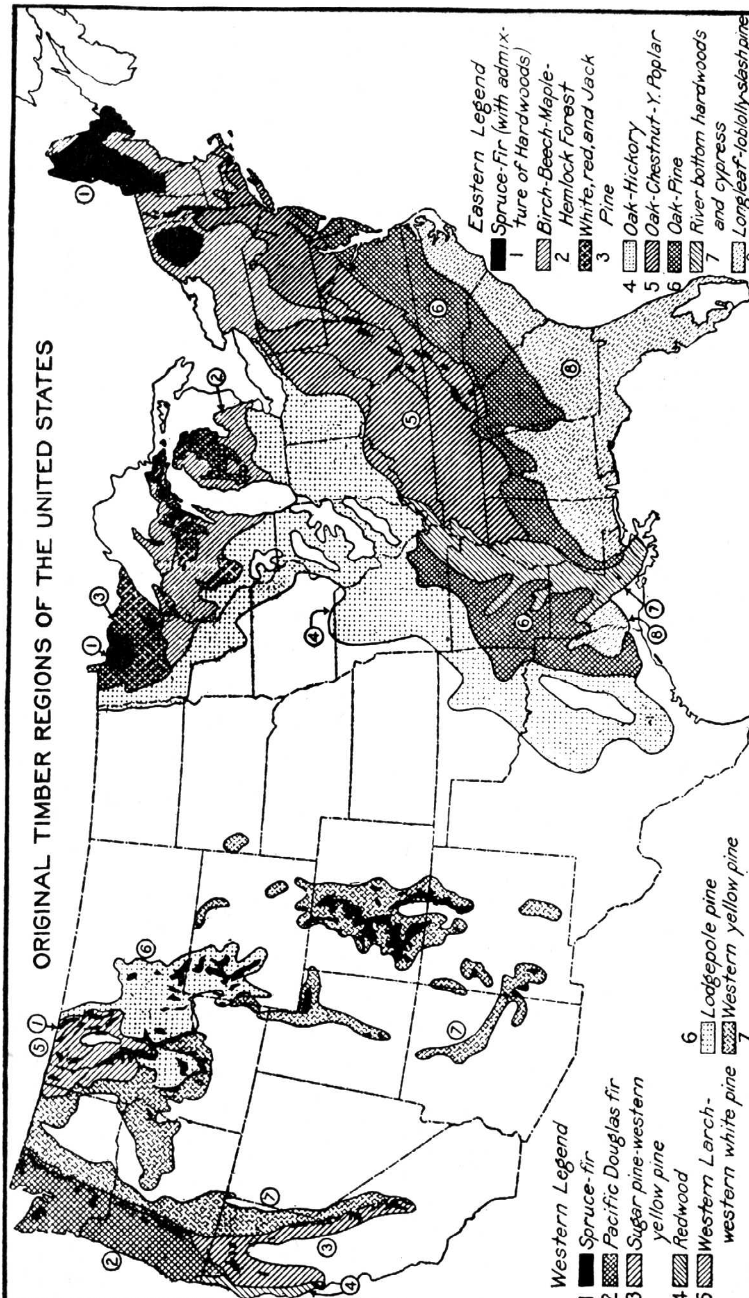
In the forests of the Rocky Mountains and Inland Empire region the principal timber trees are western larch, western yellow pine, western white pine, lodgepole pine, and Douglas fir.

The Pacific Coast forests of Washington and Oregon are made up principally of Douglas fir, West Coast hemlock, Sitka spruce, and western red cedar. Farther south in California, redwood, western yellow pine, sugar pine, and Douglas fir are the principal woods. Hardwoods are comparatively scarce on the Pacific Coast. Certain species of cottonwood, oak, birch, alder, and maple occur in limited quantities.

Estimates of Stand of Timber.—The total stand of timber in the United States on the 470,000,000 acres of forested land is estimated at some 2,200,000,000,000 board feet. Slightly more than one-half is on the Pacific Coast, about one-fourth of the total amount is in the Southeast, and the remainder is distributed throughout the Lake states and the Northeastern states, with a small proportion in the Rocky Mountains.

Figure 2 shows the relative stands of saw timber by states.

Shifting Centers of Production.—The lumber-producing centers in the United States have shifted from region to region as the stand of virgin timber was cut out. Until 1860 the bulk of the lumber produced was cut in the Northeastern states and the Allegheny Mountains. For the next 30 years the stands of white and Norway pine of the Lake states furnished the bulk of the country's lumber. The industry then moved into the

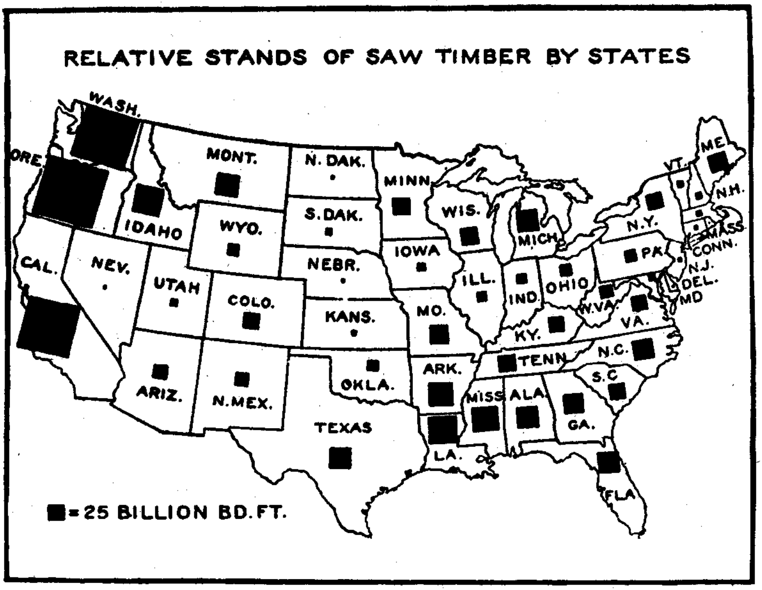


(Courtesy United States Forest Service.)

Fig. 1.—The original eastern forests formed 83 per cent and the western 17 per cent of the total. Of our present forest land the East has 75 per cent and the West 25 per cent. But the West now has 61 per cent of the remaining saw timber supply.

southern yellow pine belt on the Atlantic and Gulf seaboard. Meantime, the output of the Pacific Coast region has been steadily climbing, and in time will exceed that of the lumber regions of the East.

Timber Cut Annually in the United States.—Approximately 22,000,000,000 cu. ft. of timber is cut annually from the forests of the United States. There are undoubtedly several billion more cubic feet destroyed by fire and insects, so that 25,000,000,000 cu. ft. is a conservative estimate of the yearly drain. To balance this drain, there is the annual



(*Courtesy United States Forest Service.*)

FIG. 2.

growth which on the Pacific Coast alone, according to the United States Forest Service, may be expected to approximate 14,000,000,000 feet annually as a result of the application of intensive forest-management methods. Sources of supply will continually renew themselves under the careful supervision of cutting, and the scientifically gauged rate of replacement now practiced in both federal and state owned forests. The amount of timber cut annually for various kinds of material is shown in Table 1. The largest single item is fuel wood, followed closely in quantity by lumber. Fuel wood and lumber together make up nearly three-quarters of the material cut annually from our forests.

The average annual lumber production is given in Table 1 as 37,700,000,000 board feet. Lumber production has not been quite as high as this in recent years. The figure for 1926 is 36,935,930 and for 1927, 34,529,450 board feet.

TABLE 1.—TIMBER: WOOD REMOVED ANNUALLY FROM FORESTS OF THE UNITED STATES, WITH APPROXIMATE VALUATION

Material used or destroyed				Equivalent in lumber sawed from same trees			Equivalent in standing timber			
Kind	Unit	Quantity	Approximate value or cost,[1] dollars	Hard-woods, M board feet	Soft-woods, M board feet	Total, M board feet	Hard-woods, M cubic feet	Soft-woods, M cubic feet	Total: M cubic feet	Total: Per cent
Fuel wood	Cords	100,000,000	475,000,000	3,500,000	1,500,000	5,000,000	6,650,000	2,850,000	9,500,000	38.33
Lumber, dimension material, and sawed ties	M board feet	37,700,000	1,138,917,000	9,425,000	28,275,000	37,700,000	2,064,075	6,192,225	8,256,300	33.31
Fencing	Number of posts	900,000,000	225,000,000	165,000	660,000	825,000	360,000	1,440,000	1,800,000	7.26
Ties, hewed	Number	70,000,000	73,500,000	1,680,000	420,000	2,100,000	672,000	168,000	840,000	3.39
Pulp wood	Cords	5,000,000	79,750,000	195,000	2,145,000	2,340,000	48,700	536,300	585,000	2.36
Mine timbers	Cubic feet	293,000,000	56,913,000	439,500	439,500	879,000	197,775	197,775	395,550	1.60
Cooperage:										
Tight staves	M staves	350,000	19,250,000	399,000	133,000	532,000	87,450	29,100	116,550	
Tight heading	M sets	24,000	12,000,000	141,800	36,200	178,000	31,000	8,000	39,000	
Slack staves	M staves	1,200,000	18,000,000	240,400	121,600	362,000	52,800	26,400	79,200	1.27
Slack heading	M sets	90,000	10,800,000	166,500	166,500	333,000	36,490	36,500	72,990	
Hoops	Thousands	120,000	1,800,000	21,500		21,500	7,080		7,080	
Shingles	Thousands	9,000,000	37,710,000		900,000	900,000		198,000	198,000	0.80
Distillation wood	Cords	1,400,000	9,268,000	185,000		185,000	120,000	13,000	133,000	0.54
Veneer logs	M feet, log scale	576,000	25,079,000	587,520	103,680	691,200	90,000	15,980	105,980	0.43
Tanning extract wood	Cords	1,000,000	10,250,000	87,000		87,000	95,000		95,000	0.38
Poles	Number	4,250,000	10,625,000	55,000	200,000	255,000	11,700	43,550	55,250	0.22
Vehicle stock, woodenware, handles, furniture, etc.	M board feet	200,000	7,288,000	197,700	2,300	200,000	45,070	730	45,800	0.18
Piling	Number of pieces	1,500,000	6,000,000	40,000	140,000	180,000	7,800	31,200	39,000	0.16
Excelsior wood	Cords	200,000	1,800,000	60,000	15,000	75,000	18,720	4,680	23,400	0.09
Export logs and hewn timbers	M board feet	100,000	3,445,000	50,000	50,000	100,000	9,200	9,200	18,400	0.07
Lath	Thousands	2,000,000	9,620,000							
Total			2,232,015,000	17,635,920	35,307,780	52,943,700	10,604,860	11,800,640	22,405,500	90.39
Destroyed by fire[2]	M cubic feet	1,080,000	10,000,000	500,000	1,750,000	2,250,000	330,000	750,000	1,080,000	4.36
Destroyed by insects, disease, and windfall	M cubic feet	1,300,000	12,000,000	1,000,000	4,000,000	5,000,000	325,000	975,000	1,300,000	5.25
Grand total			2,254,015,000	19,135,920	41,057,780	60,193,700	11,259,860	13,525,640	24,785,500	100.00

Averages from selected records, 1914–1922, except mine timbers, 1905.

[1] Based on values of approximately 1919, milled products at the mill, fuel at point of production, all others at point of consumption except exports (declared valuation).

[2] These figures express mainly that part of the damage done by fire which can be readily stated in dollars, namely, the loss of merchantable timber. Other damages suffered are the loss of young growth and forage, the injury of trees, opening the way to inroads of insects and disease, the deterioration of forest types resulting from the decrease of valuable species which are sensitive to fire, accelerated run-off followed by soil erosion and irregular stream flow, destruction of animals, fish, and birds, and the prevention of recreational use. One of the most menacing features of the present forest situation is the lowered productivity of forest soils, sometimes amounting to absolute sterility, which results from the action of fires.

COMPOSITION AND STRUCTURE OF WOOD

The uses to which wood is put depend upon its properties, and its properties are determined by its chemical composition and its physical structure. The chemical and physical nature of wood is fundamentally different from that of other common structural materials. The chemical composition of all woods is approximately the same. The physical structure, however, varies greatly. It is this variation in structure that is principally responsible for differences in the properties of different woods.

Chemical Composition of Wood.—Wood is made up chiefly of carbon, oxygen, and hydrogen. When perfectly dry about half its weight is carbon, and half oxygen and hydrogen, in almost the same proportion as in water. It contains, also, about 1 part in 100, by weight, of earthy constituents and a similar amount of nitrogen. When wood is burned, all these materials disappear into the air except the earthy constituents. The nitrogen and water taken up by the roots of trees were originally in the air before they reached the ground. It is true, therefore, that when wood is burned those parts of it which came from the air go back into it in the form of gas, while those which came from the soil remain behind in the form of ashes.

Physical Structure of Wood.—Wood, like all other plant material, has a cellular structure. It is made up chiefly of very small tubes or cells of various kinds which have special uses in the life of the tree. Some conduct water from the roots to the crown, some store away digested food, and others merely strengthen the structure of the wood and hold it together.

Most of the cells in wood are very much longer than they are wide and for this reason are called *fibers*. A typical living cell consists of a wall surrounding a cavity which contains a soft jelly-like substance called *protoplasm*, in which the life processes are carried on.

In the wood of living trees, comparatively few cells contain living protoplasm. In most of the cells, the protoplasm disappears as the cells mature and fill up with air or water or with varying proportions of each. Occasionally, other materials such as resins, gums, and mineral matter are deposited in the cell cavities. The cells of wood are all grown together tightly forming a more or less coherent but porous material.

The cellular structure of wood is responsible to a large extent for some of its advantages as a construction material. The cell cavities allow the cell wall to "give" so that nails and screws can readily be driven into lumber, thus affording a comparatively easy means of fastening two pieces together. In most commercial woods, over one-half of the volume is occupied by cell cavities. This makes them relatively soft and easily worked. They, therefore, can be shaped into various forms with simple tools and comparatively little labor.

Because of the cavities in the cells, most woods, when dry, are fairly light for a given volume. This is of advantage in the manufacture of woodwork requiring a certain size but not great weight or strength. The cell cavities act as dead air spaces which retard the transmission of heat and sound, thus making lumber especially adaptable for building purposes, since it tends to keep the heat in during the winter and out during the summer and makes the building comparatively soundproof.

The figure in wood, which for some purposes is an important asset, is due largely to difference in the size and arrangement of its various cells.

On account of its porous nature, wood holds paint so that it will not scale off so readily as when applied to non-porous surfaces such as metal and stone. Preservatives may be forced through the cells and thus increase the durability of lumber. Glue penetrates the fibers and obtains a hold, making it possible to secure a stronger glue joint in wood than in non-porous materials.

Collectively, the different kinds of cells are spoken of as *elements.* A certain size and arrangement of the elements, varying within certain limits, are characteristic of each species or groups of species and help in identifying the different kinds of woods and in judging their qualities.

The wood of cone-bearing or coniferous trees (like the pines and spruces) has but few kinds of cells, while that of the broadleaf trees (such as oaks and maples) is much less simple. But in each case some of the cells have thick walls and small openings, and others have wide openings and very thin walls. In climates, like our own, which have regularly one season of growth and one of rest, the cells of the layers of new wood formed each year are arranged in a definite way. When growth begins in the spring, and the fresh twigs and leaves come out, there is a great demand for water in the crown to supply these moist green new parts of the tree. Water rises in most trees through the newer layers of the wood and especially through the last ring. Consequently, at first the tree makes thin-walled cells with wide openings, through which water can rise rapidly to the ends of the branches. Later on, when the demand for water is not so great, and there is plenty of digested food to supply material, the cells formed are narrow and thick walled. Thus, the summerwood in each year's growth is heavier, stronger, and darker in color than the springwood. In such species as maples and gum, which have no well-defined springwood, this does not hold.

It is correct to speak of each year's growth in trees in the temperate zone as an "annual ring," for as long as the tree is growing healthily it usually forms a ring each year. Occasionally, a tree does not produce a layer of wood over its entire trunk for a year or several years, and so no annual rings are formed in certain sections of the trunk. On the other hand, two rings may appear in one year, but they are generally so much thinner and less sharply differentiated from each other than the rings on each side that it is not hard to detect them. Very often, both do not extend entirely around the tree, as a true ring always does in a normally growing tree. Whenever the growth of the tree is interrupted and begins again during the same season, such a false ring is formed. This happens when the foliage is destroyed by caterpillars and grows again in the same season or when a very severe drought in early summer stops growth for a time, or it may also happen after late spring frosts.

HARDWOODS AND SOFTWOODS

No definite degree of hardness divides the "hardwoods" from the "softwoods." In fact, the only absolute distinction which can be made between the two classes of wood has nothing to do with their hardness or softness.

The principal botanical distinction between these groups is that the seeds of the hardwoods are enclosed (angiosperms) and that the undeveloped seeds of the softwoods are exposed (gymnosperms). This distinction is in itself of no commercial importance. But there are numerous general differences which make it necessary for wood users constantly to refer to these two groups by some name or other. Differences in structure, appearance, properties, size, quality, manufacturing methods, and regions of growth keep the woods of the two groups separated, from the logging operation down through the manufacturing process to ultimate use.

The terms *hardwoods* and *softwoods* are the most generally accepted popular names for the two classes of trees, although they are perhaps the most misleading in meaning. It is true that many so-called hardwoods, such as oak, hickory, sugar maple, and black locust, are notably hard and that many so-called softwoods, such as most pines and spruces, are rather soft. But there are a number of outstanding exceptions. Basswood, poplar, aspen, and cottonwood, which are all classified as hardwoods, are, in reality, among the softest of native woods. Longleaf pine, on the other hand, is about as hard as the average hardwood, although it is classified as a softwood. Yew, another so-called softwood, is about three times as hard as basswood and considerably harder than most oaks.

Another common name for the softwoods is "conifers." This is more accurate than softwoods, as all native softwoods except those of the yew family are cone bearing.

Softwoods are sometimes spoken of as "the evergreens," and hardwoods as "the deciduous trees," from the fact that most trees in the former group keep their foliage the year round and most of those in the latter group lose their leaves during the fall or winter months. The exceptions among the softwoods are bald cypress and tamarack, which have no leaves in winter. With hardwoods it is more or less a matter of climate. Many tropical hardwoods are green the year round.