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THE NATURE OF DECAY IN WOOD

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The Extent and Importance of Wood Decay

*By Burton O. Longyear

The deterioration of wood due to decay is on the whole of enormous extent. It affects either directly or indirectly practically every wood-using industry. Beginning with the forest itself decay takes a heavy toll of the timber crop and reduces the quality of the harvest. Especially is this the case in virgin stands of over-mature timber of both softwood and hardwood species and to a lesser degree in second-growth stands not under silvicultural management. Thus the amount of decay going on in the forests of the United States is a matter of great importance in the logging and lumbering industry. Altho considerable attention is now being given to tree diseases and careful studies of timber rots have been made for certain species in particular regions, the losses due to decay in this country are scarcely estimable with the present rather meagre data.

Investigations of the amount of decay in several important species of the Pacific Northwest are as follows: Douglas fir,[2] 20 to 50 percent; western white pine,[43] 7 percent; incense cedar,[3] 30 to 50 percent and sometimes much greater; western hemlock,[44] 27 to 31 percent; white fir,[27] similar to incense cedar. In the southern Rocky Mountain region the drier climatic conditions determine a somewhat lower percentage of loss due to decay. Thus for lodgepole pine[23] losses range from 7 to 10 percent with occasional areas with losses of 15 to 20 percent. Western yellow pine in the same region suffers an average loss for all merchantable sizes of 4.5 percent.[22]

From the above it is apparent that the pines are comparatively low in losses due to decay while in certain so-called "inferior species" they often run very high. In fact the inferiority of such species, from the lumbering standpoint, is often largely due to their susceptibility to dedecay.

For the Atlantic forest regions definite information on the amount of decay in the forest is even more meagre. Most of the publications, which the author has examined, that deal with the growth and management of species in this region, contain only such indefinite statements as "The losses from decay are often very high." The losses in white pine in Vermont due to one cause alone, according to the investigations of one author, equal 8 percent, for spruce 3 percent, and in mixed conifers 5 percent.[1]

Decay varies greatly not only between species, but also within the species under different soil and climatic conditions, and especially between stands and individuals of different ages. Thus Jack Pine in the Lake States is affected by rot to the extent of only 2 to 4 percent.[45] While southern shortleaf pine varies from a little over 2 percent in stands 60 to 65 years old, to a total of more than 17 percent of all

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logs in stands 170 years old.[24] Southern bald cypress is "almost normally" affected with a form of decay commonly known as "peckiness" which, while it does not usually destroy the wood for some purposes, causes deterioration estimated at 30 percent of the total supply of this species.[33]

Among the hardwoods, definite statements of the prevalence of decay are especially lacking. Studies of the heart-rots of hardwoods in the Ozark National Forest and elsewhere have shown "amounts very great," up to 65 percent in one case where fires were prevalent.[10] White heart-rot is named by one authority to be the cause of losses in certain broadleaf species amounting in many cases to 90 to 95 percent of the entire stand which would otherwise be merchantable.[38] Another author states that it is almost impossible to find healthy groves of aspen of any considerable age in the New England states, in Colorado and in New Mexico that are not badly decayed by "false tinder" heart-rot, and the same is true of mature stands of beech in Texas and Louisiana.[39] The forest products laboratory circular (1922) states that the annual deterioration in pulpwood due to fungous infection is now estimated at $5,000,000.[12].

Statements regarding the total value of the timber destroyed by decay are, for the most part, indefinite. In one case the general statement is that "millions of dollars worth of wood has rotted in the log in every state in the Union." Another writer roughly estimates the annual losses due to this cause at nearly $100,000,000 for the whole country. From the most recent estimate (1924)the total losses of wood in this country, due to decay, are about 16 percent of the total cut, or the astonishing amount of 3.5 billion cubic feet.[49] This is the equivalent of over nine billion board feet of sawn lumber and is valued at over $200,000,000.

Decay in the material cut from the forest may soon follow the harvest. In some cases this consists of the continuation of the decay processes already under way in the tree when cut. Saw logs, tie timbers, posts, poles, bolts and fuel wood are all subject to such deterioration unless attention is soon given to proper storage and to rapid seasoning, or unless they are manufactured into lumber or other finished products. The rate of deterioration varies with the species, the climatic and seasonal conditions and the size of the material. The available published information dealing with this phase of the subject is again meagre and largely indefinite in quantitative statements. Investigations of the deterioration in felled western yellow pine in southern Oregon and northern California, chiefly due to decay, have shown 13 to 18 percent injury during the first season; 63 to 76 percent for the second season, and by the end of the seventh season little or no merchantable value remained in the logs.[4]

Even in the manufactured products such as lumber, ties and fuel wood, decay is an ever-present menace unless preventive measures are taken at once. In this connection the means employed may consist of proper air seasoning, use of the dry kiln, storage under shelter, and the employment of chemical preservatives by dipping.[48] Deterioration studies of sugar and yellow pines and of Douglas fir lumber in California have shown depreciation in value amounting to from 3 to 10 percent, due largely to decay.[27]

Decay of wood and timbers during the period of service is often very great. In fact the period of usefulness of wood is in many cases largely dependent upon the resistance offered to decay. This is particularly true of cases in which the wood is subjected to the elements and especially when it is used in contact with the soil. Literature on deterioration of building timbers due to decay, in this country, offers only general statements as to total losses, but indicates that in certain cases, as in paper mills, textile mills and canning factories, it may be a very important factor of cost in carrying on these industries. Similar conditions may also determine in large measure the service period of timbers and wood used in farm buildings, residences, factories, bridges and trestles, railways, wharves, fences, telephone and other electric lines, in mines, vehicles, farm machinery and in a host of lesser ways in which wood is employed.

A grand total of all losses in the timber resources of the nation from the forest to the end of the period of service, due to decay, cannot be even approximately stated with any degree of assurance. One thing is clear, however, and that is, that it would be impressive if definitely known. It has been roughly estimated to be the equivalent of nearly eight billion board feet of lumber for the whole United States.[20]

In European countries where more thoro studies of decay losses have been carried on, over a long period of time, it is still a matter of uncertain amount except in certain cases. Due to the greater care in forest hygiene, shorter rotations, the closer utilization of forest material and the extensive use of wood preservatives, European losses are undoubtedly much lower than ours. In spite of these ways of reducing the amount of timber decay in these countries, however, the losses are stated to be heavy—that from one cause alone, according to Moller, being about $250,000 per year for the Prussian government pine forests.[25]

THE CAUSES OF DECAY IN WOOD

Ever since man began to employ wood for any purpose its tendency to decay has probably been noticed. A clear understanding of what decay is, however, has been but recently acquired. According to ancient Greek and Roman ideas all matter consisted of four elements: Dirt, air, fire and water. The readiness with which a certain kind of wood decayed depended upon the relative proportions of these elements in its composition. Thus the kinds of wood which contained a large proportion of fire decayed readily while those kinds which contained more earth were durable.[11]

The invention of the compound microscope by Janssen in 1590, followed by its improvement and use by Hooke (1635-1703), Selligues and Chevalier (1823), Amici (1827), and by Lister, opened the way for the study of plant anatomy and physiology on a scientific basis, by such men as De Saussure and Boussingault, with later refinements by the investigations of Sachs and Pfeffer. For a time, however, the findings of Liebig (1803-1873) in agricultural chemistry had a deterrent effect upon an understanding of the real nature of plant disease. Thus it was assumed that plant diseases were due to an absence of, or an excess of the necessary mineral constituents of the soil required for normal plant growth. Decay of wood was believed to be due to chemical changes of a destructive nature induced by moisture and warmth and the oxygen of the air. The term "eremacausis" used by Liebig referred to what he believed to be a kind of slow combustion in the presence of moisture and the oxygen of the air and was independent of the action of fungi which might be present.[47]

Between the years 1853 and 1884 the investigations of DeBary, Berkeley, Tulasne, Kuhn and Pasteur laid the true foundations for our present knowledge of the decay of organic substances. From 1890 to the present time the number of investigators along these lines has greatly increased and includes workers in both the systematic and the pathologic fields.

THE FACTORS OF DECAY IN WOOD AS NOW UNDERSTOOD

The factors concerned with the decay of wood may be classed as:

1. Environmental
2. Biotic.

The environmental factors concern *moisture, oxygen (air), temperature* and *food*. The biotic factors involve the presence of living organisms, in this case certain *bacteria* and *fungi*. In this the "law of the minimum" holds true with some modification. Thus, while a reduction of any environmental factor may cause a corresponding reduction in the rate and progress of decay, the presence or absence of the proper organisms positively determines whether or not any decay takes place. Accordingly, the environmental factors alone cannot cause decay, but they merely furnish the conditions under which the organisms can function. In other words decay, as in wood, is caused by the life processes of certain organisms in obtaining nourishment whereby the wood is reduced to the condition characteristic of rotten wood.

WOOD—ITS STRUCTURE AND GENERAL CHARACTERISTICS

A clear understanding of the process of wood decay involves a general knowledge of the structure, composition and other properties of wood. Due to the fact that the chief timber-producing trees of the world occur in the temperate zones the trees characteristic of those zones will be the only ones considered here.

Timber trees are roughly divided in the lumber industry into two classes:

1. Softwoods (Gymnosperms)
2. Hardwoods (Dicotyledons, under the Angiosperms)

The principal parts of a tree in the above classes consist of roots, trunk and branches. The older roots and the trunk and branches are covered with bark. Bark consists of two principal layers—outer bark and inner bark. Outer bark on the trunk of older trees is composed largely of corky cells which protect the inner bark from drying, from mechanical injuries and from attacks of parasitic insects and fungi. The inner bark consists of cells of various kinds some of which carry on photosynthesis to a moderate extent wherever the outer bark allows light to penetrate, as in the thin bark of twigs and young trunks and in crevices in the thick bark of older trunks. Another portion, the innermost, consists of the phloem elements of the vascular system thru which the elaborated food from the leaves is carried downward and distributed to the growing parts of the plant.

Between the phloem of the inner bark and the outermost ring of wood lies the cambium layer. This consists of a few rows of thin-walled cells which are capable of cell division and growth in such a way as to build new phloem cells on the outer side, next to the inner bark, and of wood or xylem elements on the inner side. In this way the cambium builds a new ring of wood each year outside of those previously formed, the first ring being formed during the first year around and in contact with the pith.

The wood of a tree shows three different sectional views:

1. Transverse.
2. Radial.
3. Tangential

In the transverse or cross section of a tree trunk the wood appears to be made up of rings concentric around the pith. These are the annual or growth rings formed by the activity of the cambium layer during each growing season. Each growth ring usually shows two more or less distinct portions, the early wood and the late wood. These two portions generally differ from each other in color, texture, and density. In some woods, as the soft woods, the difference is largely due to the difference in size of the cells and the thickness of their walls, the early wood consisting of larger, thinner-walled cells than the late wood. The change or transition from early to late wood may be gradual, as in soft pines, in spruces and most firs; or abrupt, as in hard pines, larches and Douglas firs.

In some of the hardwoods the early wood contains a band or line of relatively large pores which are replaced more or less abruptly in the late wood by much smaller pores, (e.g. Quercus, Ulmus, Fraxinus and others). These are known as ring-porous woods. In other species of hardwoods the early and the late wood are scarcely if at all distinguishable as the pores are small and quite uniformly distributed thruout the growth ring, (e.g. Fagus, Acer, Tilia, Liriodendron, etc.). Such woods are known as diffuse-porous woods.

In addition to the growth rings all species of our woods show more or less distinct lines which run in a radial direction from the pith outward to the bark. These are the medullary or pith rays. In the softwoods the medullary rays are comparatively indistinct while in some of the hardwoods, e.g. the oaks, they are very prominent. Most species of both softwoods and hardwoods show in the older trees two quite distinct portions commonly distinguished as *sapwood* (alburnum) and *heartwood* (duramen).

The sapwood forms an encircling band of varying width just inside the bark and usually differs from the heartwood in the following respects:

1. It is nearly always lighter in color than the heartwood.
2. It has a somewhat lower specific gravity when dry.
3. Its water content is greater in the living tree.
4. It is mostly less durable than the heartwood.

The relative amounts of sapwood and heartwood vary a good deal according to the species, the age of the tree and the conditions under which it grew. The percentage of sapwood to the total volume of the stem may be as high as 55 percent (*Pinus taeda*) to as low as 12 percent (*Robinia pseudoacacia*). In some species no heartwood is formed until the tree has reached the age of 50 to 100 years, (*Pinus ponderosa*), while in others the last-formed one or two annual rings alone are sapwood, (*Elaeagnus angustifolia*). The sapwood contains the only living cells of the wood; all parts of the heartwood consist of dead cells. The darker color of the heartwood is due to the accumulation within it of gums, resins, and coloring matter of various kinds.

The radial section of a log or of a piece of wood is obtained by cutting lengthwise of the grain, or longitudinal axis of the trunk, and parallel with the medullary rays. This section shows the annual rings as parallel lines across which the medullary rays extend at right angles each ray showing as a darker or sometimes lighter glistening streak or ribbon. The tangential section is taken also lengthwise of the grain, but at a tangent to the circles formed by the growth rings. It is therefore at right angles to the medullary rays, at least in part of the section which thus appears in cross section.

MINUTE ANATOMY OF WOOD

Wood, like all other parts of the plant, consists of cell elements, or their walls, of more or less diverse character. When examined under the high power of a compound microscope the cell wall appears, in cross section, to consist of three quite distinct layers. The middle layer, or middle lamella, represents the original or primary cell wall upon which the secondary layers have been laid down during growth in thickness. The middle lamella, being of somewhat different chemical composition from the secondary layers, may be dissolved by certain chemical reagents so as to cause the wood to become reduced to a pulp.

The cells* or elements of which the wood is composed may be grouped in three principal classes:

1. Parenchymatous.
2. Fibrous.
3. Vascular.

PARENCHYMATOUS ELEMENTS

The cells of this class are typically thin-walled, the three dimensions are not widely different and they are apt to be filled with living contents and stored food materials. The pith of the stem is wholly of typical parenchyma and that part of the inner bark next to the corky layer is also largely of the same character.

In the wood itself two forms of parenchymatous elements are found: (1) Ray parenchyma, (2) Wood parenchyma. The first form constitutes the bulk of the medullary rays while the latter occurs intermingled with the other wood elements, in the hardwoods. In both kinds living protoplasmic contents, starch and other reserve food materials are to be found in the sapwood. In the change from sapwood to heartwood the protoplasm dies and the other substances may be removed or disorganized wholly or in part.

FIBROUS ELEMENTS

The fibrous elements consist of thick-walled greatly elongated cells with tapering, overlapping ends and are mostly without cell contents. They comprise the chief strengthening elements of the hardwoods and the toughening, fibrous part of the bark in all species.

VASCULAR ELEMENTS

The vascular elements are of two types: (a) Tracheids, (b) Vessels or ducts. The former consist of elongated cells with closed ends and walls marked with bordered pits and sometimes with spiral thickenings. The bulk of the wood of softwoods consists of tracheids; one form, the wood tracheids, lying lengthwise of the stem and another form, ray tracheids, when present, lying parallel with the medullary rays. Vessels or ducts are normally not greatly elongated and are often of wide diameter. They have open ends where they adjoin each other in vertical series parallel to the grain of the wood. They constitute the pores in the hardwoods. They are marked in various ways according to the manner in which their walls are thickened during growth. Thus, they may be pitted, reticulate, scalariform and spiral in character. Vessels form the chief channels for water transport in hardwoods, while tracheids perform the same office in the softwoods.

Resin ducts are tubular channels common to the wood of certain genera of conifers (eg. *Pinus, Larix, Picea, Pseudotsuga*). They arise as intercellular, longitudinal and radial channels surrounded by parenchymatous cells which secrete resin into the passageway.

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*The term cells as here used, applies chiefly to the cell walls.

The chief distinctions between the wood of Gymnosperms and that of Dicotyledons is indicated as follows.[28]

Gymnosperms	*Dicotyledons*
True vessels absent.	True vessels present.
Wood tracheids present and forming bulk of wood.	Tracheids present or absent; always subordinate.
Ray tracheids present or absent.	Ray tracheids absent.
Wood fibers absent.	Wood fibers present.
Wood parenchyma present (except in *Taxaceae*) but subordinate.	Wood parenchyma present ;often conspicuous.
Ray parenchyma present.	Ray parenchyma present.

CHEMICAL COMPOSITION OF WOOD

Chemically, woods of various kinds differ but little in their composition. Dry wood substance consists of: Carbon 50, hydrogen 6, oxygen 43.7, nitrogen 0.3 parts by weight. Cellulose $(C_6H_{10}O_5)N$ and lignin $(C_{26}H_{36}O_{72})$ are the chief constituents of wood, the former being a carbohydrate while the latter is considered by some chemists to be a mixture of at least four other substances. Hadromal, a substance of uncertain composition, was obtained by Czapek from wood and believed by him to be the lignifying substance. Others ascribe the lignification of cell-walls to the presence of coniferin, vanillin, and possibly other substances. Lignin is known as *woody substance*, the *lignifying substance* and the *incrusting substance*. Cellulose is soluble in Schweitzer's reagent (ammoniacal solution of cupric oxide) from which it may be precipitated in a gelatinous form by treatment with acids. Lignin may be removed from the cell walls of wood by boiling in a solution of caustic soda or of calcium sulphate when the cellulose is left behind. This process is extensively employed in the manufacture of paper pulp by means of the so-called soda process.

The mineral matter which remains as ash when wood is burned consists chiefly of salts of potash, soda, magnesium, manganese, ferric oxide and calcium oxide combined with silicic, phosphoric, carbonic, acetic, pommic and citric acids. These compounds penetrate the wood in all directions as a delicate mineral skeleton. The percentage of ash in wood differs considerably depending upon the species, age of the part and of the tree and the nature of the soil in which the tree grew. The ash content varies from 0.2 to 5.0 percent. In addition to the cell-wall substance and the ash content, wood may contain other materials within the cells of certain tissues or cell elements. Thus the ray and wood parenchyma cells of the sapwood may contain reserve starch during autumn and winter besides protoplasmic materials. Sugar, dextrin, and tannin are other substances also to be found in wood, especially the sapwood, of living trees or in those recently cut. Resin or pitch is a characteristic product of conifers and, in species possessing resin ducts in the wood, it may often permeate the wood more or less thoroly, as in resinous pieces of pine.

PHYSICAL AND MECHANICAL PROPERTIES OF WOOD

SPECIFIC GRAVITY (Density, specific weight).—This is determined by comparing the weight of a unit volume of oven-dried wood (100° C) with an equal volume of water at 4° C.

$$\left(\text{Sp. gr.} = \frac{\text{wt. of dry wood per. cu. ft.}}{62.43 \text{ lb.}}\right)$$

Wood substance itself has a sp. gr. of 1.56; regardless of the species from which it is taken; hence the difference in weight between different species must be due to the relative amounts of wood substance in proportion to the air space in the wood. The denser woods have thicker cell walls than the lighter ones, therefore are harder and stronger. Tropical woods show the widest variations in sp. gr., the range being for cocus and violetwood 140 to *Herminiera* 15. The former species will sink quickly in water. Any wood trom which the air is removed either by boiling or by prolonged soaking will also sink readily.

MOISTURE CONTENT OF WOOD

Freshly cut timber contains on the average from 45 to 50 percent of its weight of water. Contrary to popular opinion a tree in winter or early spring contains much more water than it does in midsummer. This is due to the rapid loss of water from the leaves by transpiration in the growing season. Different parts of the same tree also vary in their water content. Thus the heartwood of green timber is relatively drier than the sapwood, e.g. *Pinus palustris,* one inch from bark 50 percent water; two inches from bark 35 percent water; and heartwood 20 percent water. Air-dry wood contains 15 to 20 percent of moisture and even when dried at a temperature of boiling water, still retains 2.3 percent of moisture. Air-dry wood is quite safe from the attacks of wood-destroying fungi if not exposed to atmosphere of high relative humidity for prolonged periods. Wood that contains not more than 10 percent of moisture is perfectly immune to such attacks. The rapid seasoning or drying of wood generally causes the formation of checks and cracks which may later offer favorable places for the entrance of the fungi of decay in logs, and sawn material.

STRENGTH AND HARDNESS

The term strength may be generally considered as referring to the ability of a material to resist stress. The principal associated properties are stiffness, toughness, hardness, tensile, compressive, bending and shearing strength. Hardness is closely related to crushing strength and transverse shearing is the ability of the material to resist indentation. These properties vary greatly between species and considerably among the individuals of a species. All these mechanical properties in wood are also influenced by the moisture content, the temperature and the soundness of the material when tested. Thus the crushing strength of kiln-dried wood, which still contains 3.5 percent moisture, may be increased from 2.7 times in longleaf pine to 3.7 times in spruce as compared with green wood. [29]

Decay, when present in even slight degree, has a marked effect upon the mechanical properties of wood, as shown in the experiments by the writer. Thus, in transverse-bending tests upon small pieces of *Populus acuminata* a decrease in weight of 10 percent, due to decay, caused a falling off of 74 percent in strength. In an advanced stage of decay the wood elements may lose their cohesive powers to such an extent as to make it difficult to handle the wood without its falling apart from its own weight.

THE ORGANISMS OF DECAY IN WOOD

BACTERIA—It is now well established that bacteria are the direct cause of plant diseases in a number of cases. Fire or twig blight of apple, pear, and quince; crown gall of peach, plum, and apple; bacteriose of mulberry; *Pseudomonas* blight of English walnut, are some examples of bacterial diseases of trees. As to the part which bacteria play in the decay of wood, however, there appears to be more uncertainty. While investigations have shown that certain bacteria are capable of dissolving cellulose they are not considered as important factors in wood decay under natural conditions. According to studies by Schmitz the addition of cultures of cellulose-dissolving bacteria to cultures of certain wood-destroying fungi hastened the rate of decay in some cases to a considerable degree. [34]

FUNGI.—By far the most important agents of decay in wood are found among the fungi. Fungi, being destitute of chlorophyll, are unable to utilize the raw food materials of earth and air as do the green, chlorophyll-bearing plants. They are, therefore, dependent upon the organized substances of the latter class of plants for their subsistence as much as are animal organisms. Two somewhat indistinctly separable classes of fungi are recognizable depending upon their mode of life:

A. Parasitic fungi.
B. Saprophytic fungi.

Parasitic fungi gain their sustenance from, and at the expense of living organisms. They are the chief cause of the true plant diseases. Saprophytic fungi are capable of living only upon the tissues and substances of dead organisms chiefly of vegetable origin. The wood-destroying fungi belong almost entirely to this class, a few only being parasitic and these finish the work of decay as saprophytes.

LIFE HISTORY OF WOOD-DECAY FUNGI.—Two principal stages in the life cycle of a fungus are recognizable:

1. The vegetative or mycelial stage.
2. The fruiting or sporophore stage.

In its vegetative stage a wood-decay fungus consists of delicate tubular branching threads of microscopic fineness which grow into and thru the cell walls, entering and sometimes filling up the cell cavities and extracting such substances as are needed for sustenance and growth of the fungus. This part of the fungus is known as the *mycelium* or spawn and its individual branches as *hyphae.* In certain cases great numbers of hyphae interlace and grow together in the form of extensive sheets or strands of fungous tissue which may occupy cracks and openings in the wood or may even spread over or transverse the exposed surface of the wood.

Two general classes of wood-rotting fungi are recognized, based upon the appearance which they produce at the completion of the decay process, and which is due to the way in which the woody tissue is affected. These are:

1. The delignifying or white rots.
2. The carbonizing or brown rots.

In the delignifying or white rots the mycelium secretes enzymes which dissolve chiefly the lignin of the cell walls leaving the light colored or colorless cellulose behind. Wood affected by such rots usually shows numerous flecks and pits or cavities lined with whitish fibers altho in some cases the wood is uniformly decayed and consists finally of only a mass of whitish fibers.

The carbonizing or brown-rot fungi dissolve and remove chiefly the cellulose part of the cell walls and leave the lignin behind. In these rots the wood may be decayed in the form of cavities or pockets surrounded by sound wood and filled with softened wood which breaks up into small blocks or cubical masses, or the rot may extend uniformly thruout the affected area. In other cases the wood is left as a much softened mass of fibers. The characteristic colors of the decayed wood are reddish, purplish, yellowish or brownish in the initial stages; its texture is crumbly or granular in the final stages. [46]

The fruiting stage of a fungus follows the establishment and growth of the mycelium. In some cases a comparatively short time elapses between the two stages; in others a year or more may pass before fruiting occurs. Fungi, such as molds and mildews, often begin bearing spores (reproductive bodies) within a few hours of the formation of a mycelium.

In the case of most wood-rotting fungi, however, the mycelial or vegetative stage becomes extensively developed and its accumulation of reserve food material abundant before the fruiting stage is attempted. When sufficient reserve food material has been acquired by the mycelium fruiting bodies, sporophores, may appear. The fruiting bodies usually arise at some favorable external point on the decaying tree, log or piece of timber by the concentration and union of numerous hyphae into a mass of tissue. This mass of fungous tissue may at first assume the form of a small knot or knob which by continued growth becomes the mature fruiting body or *sporophore.* The fruiting body of each species of fungus is characteristic and forms the chief basis for the classification of the fungus. Thus they may take the form of shelf or bracket-like outgrowths, sometimes of considerable size, and weigh several pounds. In others the fruiting part is spread out in a thin layer upon the substratum of decaying wood and in still other cases the fruiting bodies are umbrella-shaped.

The texture of the fruiting bodies may vary from soft and fleshy in some species to hard and woody in others while their duration is from a few days, in some, to a number of years in others. The office of the fruiting body is the production of *spores* or reproductive bodies. Preceding the process of spore production a *hymenium* or spore-bearing layer is first formed upon some part of the fruiting body. Thus it may be spread over a more or less plane surface; it may cover the surface of thin plates or gills or of spines or tooth-like projections, or it may line the interior of tubes or pores in the under surface of the fruiting body.

The following classification shows the great or major groups of the true fungi:

Mycelium continuous (without cross walls).
        Class I. *Phycomycetes.*—The lower or Algal Fungi.
Mycelium discontinuous (divided by cross walls).
    Spores borne in sac-like structures (asci).
        Class II. *Ascomycetes.*—The Sac Fungi.
    Spores borne usually in fours upon specialized hyphae (basidia).
        Class III. *Basidiomycetes.*—Basidium Fungi.

The *Basidiomycetes* contain all of the fungi capable of causing decay in the heartwood of trees. About 14,000 species of fungi are known as belonging to this class. Among them are our common toadstool and mushroom fungi, many of which are edible while a few are counted among the most deadly of poisonous plants.

One order, the *Hymeniales,* contains practically all of the fungi concerned with the rotting of wood and is usually divided into the following families based upon the disposition of the hymenium or spore-bearing layer:

Hymenium superficial; flat, shell-shaped, upright or branched, leathery-textured fungi. Family—*Thelephoraceae.*

Hymenium superficial upon cylindrical, club-shaped or branched shrub-like erect forms of mostly leathery fungi. Family—*Clavariaceae.*

Hymenium superficial upon wart-like, spine-like or tooth-like projections from the leathery or woody fruit body Family—*Hydnaceae.*

Hymenium lining the interior of tubes, pores or pits within the fleshy, leathery or woody fruit body. Family—*Polyporaceae.*

Hymenium upon the sides of radiating gill-like plates upon the under surface of the commonly capitate, fleshy or leathery fruit body. Family—*Agaricaceae.*

SPORES.—In the fungi of the order *Hymeniales* the spores are uni-cellular bodies of minute size and somewhat varied shapes. Two forms of spores are known to occur in the fungi of this order:

1. *Basidiospores.*
2. Secondary spores (*Oidia, Chlamydospores*).

The majority of the *Hymeniales* have been found to be without secondary spores and in the cases where they do occur they are apparently of minor importance in the propagation of the fungus in nature. [38]

Basidiospores arise after the hymenial layer has reached the proper state of development. The hymenium itself consists of the erect cell-like tips of the underlying hyphae closely crowded together to form a definite layer. Two kinds of cells are present:

1. Sterile cells, *Paraphyses*
2. Spore-bearing cells, the *Basidia*.

Each basidium usually projects a little beyond the paraphyses and bears upon or near the apex a group of spores, characteristically four in number, each spore being attached to the basidium by a short stalk-like projection or *sterigma*.

PRODUCTION AND CASTING OF BASIDIOSPORES.—As soon as the hymenium of the sporophore of a fungus has developed sufficiently to produce spores from its basidia the casting of spores begins and may continue in some cases for a considerable period. In the softer, fleshy species only a few hours may cover the duration of the sporophore (e.g. the smaller evanescent species of coprinus). In the leathery and woody species, however, successive crops of spores have been secured from sporophores that were over a year and a half old, in some cases after they had been dried for several months and then revived. [37] Buller* found that the sporophores of some wood-destroying fungi could be kept for a period of from six to eight years before losing their vitality. The spent sporophores, under natural conditions, are often destroyed by various molds, fungus-eating insects and by rodents.

DISSEMINATION AND GERMINATION OF THE BASIDIOSPORES.—The enormous numbers in which they are produced, their microscopic size and their lightness give to the *basidiospores* great facility in the matter of dissemination. Air currents are, on the whole, of greatest importance in carrying and depositing the spores over wide areas and onto every exposed surface favorable for their germination and the establishment of the mycelium. In addition to air currents insects of various kinds, sowbugs, spiders, rodents and birds play an important part in spore dissemination in many cases.

The rapid decay of western yellow pine and other conifers killed by bark beetles is evidently hastened by the entrance of spores into the openings and channels made in the bark and wood of these trees. Buller** has estimated that one sporophore of *Polyporus squamosus* may produce 11,000,000,000 spores and that some of the puffballs may give off 1,000,000 spores a minute during several days. The necessary conditions for the germination of the *basidiospores* are the same as those for the growth of the fungus, viz. heat, moisture, and air. Snell, [37] who has investigated the conditions for spore germination with several species of fungi of importance in the decay of building timbers found that some may germinate to the extent of 40 percent in twelve days at a temperature of 3° C. (37° F.) while others show a minimum temperature of 16° C. (61° F.).

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*Buller, A. H. 1912-1913 In Brit Mycol. Soc. Trans. V. 4.
**Buller, A. H., 1909—Researches on Fungi.

The maximum temperature varies between 40 and 44° C. (104 and 111° F.) while the optimum ranged between the temperatures of 24° and 33° C. (75° and 91° F.) for the different species. In one 50 percent germination was secured in 16 hours at a temperature of 32° C. (90° F.) Spores of various ages were employed from fresh, in some, to spores seven months old, in others. Thus it appears that infection of exposed wood may take place by some wood-decay fungi at a temperature only a few degrees above freezing.

As to the moisture requirements for germination the spores of fungi usually need either free water or at least an atmosphere that is quite close to the point of saturation. Such conditions often prevail in nature during rainy periods out of doors, where wood is in contact with moist soil, in poorly ventilated places, as in cellars and under the floors of porches and buildings without basements. The sap which oozes from the cut ends of logs in the woods and from pruned or broken branches may furnish sufficient moisture in many cases for spore germination and infection of the wood. In all cases, probably, the presence of oxygen is essential to germination either in the moist atmosphere or dissolved in the water surrounding the spores.

The presence of nutrient media favors the germination of the spores of practically all the *Basidiomycetes*. Some, however, are able to germinate even in distilled water.[9] The influence of sunlight upon spore germination of the *Basidiomycetes* appears to be generally injurious while diffused light does little or no harm during the germination process. The viability of *basidiospores* exposed to direct sunlight has also been found to have greatly decreased, in general three days' exposure being sufficient to kill nearly all of them.[37] The retention of viability under favorable conditions of storage, as at a temperature of 12 to 15° C. (54 to 62° F.) and a relative humidity of 40 to 50 percent have shown in some cases the ability of spores to live from six months in some cases to three and even six years in others.[37]

GROWTH OF THE MYCELIUM.—The mycelium originates primarily from the continued development of the germ tube from a germinating spore. This germ tube having gained entrance to the woody tissues of the tree, log or stick of timber suited to its growth, continues to extend by terminal growth and extensive branching. The same condiions of heat, moisture and air are essential to this as were necessary for spore germination while the wood itself furnishes the nutriment for the fungus.

Another method of infection is that in which the mycelium from a decaying piece of wood may extend its operations to sound wood with which it may come in contact. This is commonly the case with piled lumber where the foundation timbers are infected and from which the mycelium may extend into sound wood piled upon them.[16] In the same way, too, the lower tier of blocks in a stack of fuel wood may be infected by mycelium growing in the surface layers of the soil, especially in wood yards where wood refuse is apt to be plentiful, and in forest litter in the woods. Log piles may become infected in the same manner if left for several seasons in the forest on the landing.

Under conditions often found in buildings having unventilated air spaces under floors close to the ground, the mycelium of certain fungi may form extensive ramifying strands or sheets of fungous tissues which may traverse considerable distances over the soil, the foundation supports and the timbers of the structure. In one such instance under the observation of the author a wooden floor in a basement room had to be replaced three times within a period of about twelve years due to the extensive growth of the dry-rot fungus, (*Merulius lachrymans*), in this manner. Posts, ties, lumber and sawn timbers cut from trees in which decay is already established may continue to decay rapidly after cutting unless measures are taken to check the growth and spread of the mycelium into the sound wood of the infected pieces and to other pieces with which they may be in contact.

THE PROCESS OF DECAY IN WOOD

Following the entrance of the mycelium into the woody tissues, either by spores or by mycelia from the soil or from decaying wood or other media, the process of decay is more or less rapidly extended to adjacent areas. Thru the agency of excretions, known as enzymes, the hyphae of the mycelium are able to bore their way thru the cell walls. This is brought about by the solvent action of the enzymes upon the various cell-wall substances and upon the contents of cells which contain reserve food materials. A number of different enzymes have been recognized in the fungi which cause wood decay. The following table gives the principal enzymes found in such fungi together with the cell-wall substances upon which they act as solvents:

Ligninase (Hadromase)------Effects the solution of lignin
Cellulase------------------Effects the solution of cellulose
Hemicellulase----------Effects the solution of himicelluloses
Pectinase--Effects the solution of the middle lamella and other pectinous substances.

The following enzymes which act chiefly upon cell contents, have also been detected in wood-destroying fungi: Esterase, maltase, lactase, sucrase, raffinase, diastase, inulase, glucosidase, urease, rennet, emulsin, catalase, lipase, tannase, amidase, and some others. These attack and remove the stored starch, protoplasm and other cell contents that may be present in the medullary rays and wood parenchyma. Not all of these enzymes are found in every wood-destroying fungus. Thus some fungi secrete enzymes which dissolve the lignified portions of the cell walls while others attack the cellulose portions. Still others are capable of removing first thte lignified portions and later the remaining cellulose.

The action of these enzymes requires the presence of water in sufficient amounts to bring the products of their action into solutions capable of being absorbed by the fungous hyphae. Thus it will be seen that the process is one of digestion, absorption and assimilation by the mycelium in which the wood furnishes the food materials. That the amount of water naturally present in the sapwood, when living trees are cut, is ample for the action of these enzymes is clearly shown in the rapid decay of such timber when left lying on the ground in the forest or when it is too closely piled for the water content to evaporate readily.

Free oxygen, from the air, is an essential factor in the process of wood decay. Buller, in discussing his investigations upon the biology of *Polyporus squamosus* states that in the utilization of carbohydrates by the fungus in respiration it seems that most of the carbon is united with oxygen from the air to form carbon dioxide. The hydrogen and oxygen of the carbohydrates, however, evidently combine to form water.[7]

Zeller (1916) in his studies in the physiology of *Lenzites saepiaria*, discusses somewhat the relation of atmospheric oxygen to the growth of fungous mycelium and refers to the findings of Müench, (1909), that the rhizomorphs of *Armillaria mellea* do not require free oxygen in the substratum but can conduct it there from the outer air. In most cases, however, a certain, undetermined amount of free oxygen is essential to the extension and activity of the mycelium. The higher density of the late wood of the annual rings seems to owe its greater resistance to decay largely, if not wholly, to its reduced oxygen content in contrast with the more porous, early wood.[50] Any condition which tends to exclude atmospheric oxygen, wholly or in part, therefore, may correspondingly retard the decay. Even the accumulation of carbon dioxide, the result of respiration of the fungus, might inhibit growth simply thru the exclusion of oxygen.

The relation of alkalinity or acidity of the substratum to fungous growth has been noted in several cases. Zeller thus found that the failure of Lenzites saepiaria to grow upon certain culture media was due to their slight alkaline reaction. When the reaction was changed to a slightly acid reaction the same media sustained a profuse growth of the fungus. After a fungus has gained some headway in a substratum, might not the process of respiration bring about a more favorable reaction due to the absorption of CO_2 and the hydrogen-ion-concentration in the free water present? This process would seem to explain in part the fact that fungi often continue growth under conditions where there is no ready outlet for the products of respiration, as in culture tubes and flasks.

PRODUCTS OF THE DECAY PROCESS

In addition to the production of CO_2 as a result of the respiration of the mycelium of wood-destroying fungi, there are often produced, as by-products of the decay process, certain dark-colored compounds which are at first in a liquid condition. These liquid substances are brownish in color and, being absorbed by the woody tissues in advance of the mycelium, often lead to the formation of blackish or dark-colored zones or lines just beyond the decaying areas.

Von Schrenk, (1900), in describing the rot of conifers due to *Trametes pini*, considered the brown substance as belonging to the "humus compounds." Rhodes, (1918), in his studies in the biology of *Polyporus pergamenus* has described a similar compound in the wood of several broadleaf species. His analyses led him to much the same conclusions and to the recognition of humic acid and humin as the component substances.

The accumulation and concentration of this humus compound in the outlying portions of the woody tissues, where decay is progressing, is regarded by the above authors as resulting in the limitation of the rate of spread of the mycelium. In this way the formation of pockets, which sometimes become entirely empty, may be accounted for, the fungus having in a sense shut itself in by its own by-products. [41]

DISCOLORATIONS AND STAINS IN WOOD DUE TO FUNGI

Abnormal colorations in wood may in most cases be due either to chemical changes in the organic cell contents, thru oxidation, or to the activity of certain fungi. In the former cases the stain does not extend below the surface layers and the wood does not lose in strength. In the latter, however, the discoloration may extend thruout the sapwood or even into the heartwood to a limited extent. These fungi cause the discolorations commonly known as sap-stain. Due to the fact that they consume chiefly the cell contents of the sapwood, they do not materially weaken the wood. The most common colors indicative of sap-stain are bluish or blackish, more rarely reddish. [5]

The conditions favorable for the production of sap-stain are the same as those for the development of decay, viz. moisture, air and warmth. These are the conditions which often prevail in stacks of recently sawn lumber in warm weather. Sap-stain may also occur in recently cut logs or in standing timber killed by insects, by fire or by girdling. Thus the bluing of the wood of yellow pine in the west usually follows the killing of the trees by the pine-bark beetle. [42]

Altho the presence of sap-stain does not materially affect the mechanical properties of the wood or its usefulness in the building industries, yet it is an indication of conditions favorable to the growth of the true wood-destroying fungi which may soon follow if the conditions remain the same. This is illustrated by the appearance of the red rot in conifers following bluing in insect-killed timber of western yellow pine. [42]

THE SAP-STAIN FUNGI

The chief cause of the blue sap-stain in timber is due to the growth of the mycelium of several fungi belonging to the genus *Ceratostomella*. A number of other genera, classed as mold fungi, which cause surface discolorations of green timber, have been listed as follows: *Alternaria, Stachobotrys, Aspergillus, Stemonitis, Gliocladium, Cladosporium, Cephalothecium, Citromyces, Clonostachys, Haplographium, Monilia, Mucor,* and *Oidium.* [14]

Recently the heart and sapwood stain of the boxelder has been referred to the fungus *Fusarium Negundi Sherb.* This fungus causes a bright coral to carmine red stain which is so frequently present in this species of tree as to give it considerable diagnostic value in identifying this wood.[15]

II. Development of a Method of Measuring the Rate and Stage of Decay in Wood

It has doubtless often been noticed that wood which is in an advanced stage of decay is much lighter when dry than a similar piece in sound condition. Thus Hartig often mentions in connection with some wood-decay fungus that "the wood becomes lighter." [13] Softness, sponginess and loss of strength are also mentioned in the same connection by various writers upon the subject of wood-destroying fungi. About fifty years ago experiments to determine the relative susceptibility were carried on in Europe by Poleck, Lehmann, and Hartig. Poleck's studies were carried on with blocks of wood inclosed in casks. Hartig employed a specially constructed cellar where the blocks were subjected to decay influences and the state of decay was determined by the loss in weight of the blocks after a certain period of time had elapsed.

In the United States the investigations dealing with the rate of decay have been largely based upon rough methods of estimating the progress of decay from superficial appearance of the timbers under observation. In most cases the studies have been concerned with the condition of posts, ties or poles that have been kept in service for a considerable period.

The first record of exact tests to show loss of strength, due to decay, appears to be the experiments of Von Schrenk (1899) in connection with his studies upon the peckiness of bald cypress and incense cedar. [40] Sound, kiln-dried timber in the form of small blocks was tested for crushing strength and the data thus secured were used as the basis for determining the loss of strength in the pecky wood. Von Schrenk and Spaulding (1903) describe other investigations dealing with the rate of decay. These experiments were concerned with the relation between the season of cutting the trees and susceptibility to decay of the wood; also a comparison between "hill" and "bottom" red oak as to durability. In these experiments the pieces of timber were merely piled out of doors and left for observation during a period of two years. Their figures indicate "the percentage of timbers upon which masses of fungi were growing and which were obviously decayed to a greater or less extent." These experiments demonstrated that sapwood decays more rapidly than heartwood, that winter-cut wood was not necessarily more durable than that cut in summer and that the slower-growing hill oak was more durable than the rapidly growing bottom oak. [39]

Buller (1904) mentions the lighter weight of wooden paving blocks which were decayed in Birmingham, England, by the fungus (*Lentinus lepideus*) but describes no tests to determine loss of weight. [29]

Rowe (1909) describes in detail the construction and operation of a culture room for testing the durability of wood by the use of different wood-rotting fungi. He quotes largely from directions supplied by Spaulding, pathologist of the Bureau of Plant Industry, Washington, D. C.[32]

Abbott (1912-1913) carried on culture tests upon sound wood of spruce, pine, hemlock, tamarack, balsam, birch and oak. Culture blocks were placed in test tubes upon a layer of wet cotton. The tubes were then plugged with cotton and sterilized. They were inoculated with a pure culture of *Trametes pini* and kept at room temperature in the dark for a period of six months. Crushing and breaking tests were then carried on to determine the loss of strength of the decayed block in comparison with sound timber.[1]

In 1913 and 1914 Humphrey, at the Forest Products Laboratory, Madison, Wisconsin, carried on tests to determine the durability of greenheart (*Nectandria Rodiaei*) by means of laboratory tests. Test specimens in the form of blocks of both sap and of heartwood were oven-dried at a temperature of 100 to 105° C. for twenty hours and then weighed. They were then placed singly in large test tubes, partly filled with moist sand, together with culture blocks of spruce or birch, and were covered with a layer of wet sphagnum. Water was added to saturate the sand, and the tubes were plugged with absorbent cotton and sterilized one hour at twelve pounds steam pressure. After cooling, each tube was inoculated with a wood-destroying fungus, a different species of fungus being used for each tube. The tubes, with one exception, were kept at room temperature for one year, after which they were opened, the blocks re-dried as before, and weighed. The loss of weight was taken to represent the extent of decay. The loss of weight varied from 0 to 37 percent, *Lenzites trabea* proving the most destructive of all the fungi employed.[17]

In 1914 the same investigator began a series of similar tests upon twenty-eight species of native American woods. The test blocks were cut 5/8x5/8x2 inches and oven-dried to a constant weight, weighed, placed in two-liter flasks on a bed of absorbent cotton together with a number of soaked culture blocks of hemlock. The flasks were prepared in triplicate and after sterilization, all were inoculated with the same fungus, *Lentinus lepideus*. The progress of decay was determined by testing, as before, one block of each species at intervals of three, six and twelve months.[18]

Zeller (1916) mentions the use of about 3000 culture blocks in studying the influence of resin upon the growth of the mycelium of *Lenzites saepiaria*. After one year the diminished weight of the blocks was determined and used as the index of decay.[50]

Schmitz (1917) used the pure-culture method upon western hemlock sawdust employing *Fomes pinicola* in association with certain cellulose-dissolving bacteria. The progress of decay was determined by loss of weight of the sawdust after a period of four months.[20] The same author in 1912 published an account of studies in wood decay in the laboratory in which western coniferous species were tested for durability in culture flasks using pure cultures of several wood-destroying fungi and rating the decay by loss of weight of the test blocks.[35]

Rhodes, in his studies of the biology of *Polyporus pergamenus* (1918), mentions the placing of blocks of wood in culture flasks and chambers, but does not record any tests upon the rate of decay nor the strength of the material.[30]

Kauffman and Derber (1922) record crushing tests upon sound and diseased locust wood in their study of the white-heart rot of that species.[19] In none of the work, so far as known by the writer, have the two tests, loss of weight and loss of strength, been accurately correlated in the same investigation.

During the year 1914 the writer, while examining a piece of timber in an advanced state of decay, became impressed with its lightness in weight. In order to make a somewhat exact comparison of this with sound wood of the same species, two pieces each of equal volume and in air-dry condition were prepared and weighed. It was found that the sound wood weighed, in this case, about twice as much as the decayed piece—a loss of approximately 50 percent in the latter.

The idea was then conceived of using the progressive loss of weight as an index of the progress of decay in wood specimens whose sound weight had been previously determined by drying to a constant moisture content after which they were to be subjected to conditions favorable for decay. It was thought that the time factor could also be determined in relation to loss of weight by using a set or series of wood specimens all of one species and each of equal volume, which would permit of examination at the end of set periods of time. The relation of decay to strength could be determined by testing each piece after drying to the constant moisture content and after re-weighing.

In order to try out the idea, a set of fify-six specimens of *Populus acuminata* was prepared from clear portions split from a recently cut tree. The split pieces were first air-dried in the laboratory over a heating radiator and were then carefully planed to the exact size of ¼x ½x6 inches. Twenty-four of the pieces were of sapwood and thirty-two were of heartwood, and each piece was cut with the ½-inch face tangential to the growth rings. The finished pieces were then numbered consecutively at each end by means of india ink. After drying to a constant weight at a temperature of 72° C. (162° F.) the pieces were planted to their full length in sandy loam soil in a covered galvanized ash can of suitable size. The soil was maintained in a moist condition and the can was kept in the laboratory at temperatures ranging between about 65° to 75° F. (or at times higher) or at that of living-room temperatures.

At thirty-day intervals two or three pieces, each of sap and of heartwood, were removed from the can, cleaned by brushing carefully, dried to the same constant moisture content as before, and re-weighed. While still dry the specimens were subjected to the transverse breaking test and the load sustained at the breaking point ascertained. The weights were taken at the nearest centigram and the breaking loads at the nearest tenth of a pound. In computing the loss in breaking strength several pieces of average weight were broken when sound and the results averaged as a basis of comparison for those in the process of decay.

The breaking tests were performed by resting the test pieces upon narrow-edged supports placed 5½ inches apart. Pressure was applied to the center of the pieces by means of a small horizontal rod from which was suspended at the ends a loop of strap iron carrying a tin pail. Iron weights were then placed in the pail until near the breaking point of the test piece after which dry sand was carefully poured in to complete the test. The total weight sustained by the piece at the breaking point was then determined by weighing the pail and its contents.

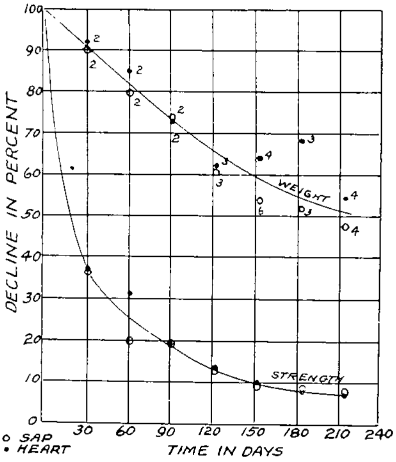


Diagram 1—WEIGHT-STRENGTH CURVES FOR EXPERIMENT I.

Graph Diagram No. I shows the results of this preliminary test, Experiment I, the percentage losses in both weight and strength for sap and heartwood separately. Perhaps the most striking feature shown in this chart is the pronounced loss of strength which a comparatively small loss of weight produces. The greatest loss in weight of any one piece was 55.7 percent; the greatest loss in breaking weight was 97 percent, at the end of 217 days. In some cases the pieces of wood were removed from the soil with considerable difficulty due to the greatly softened and fragile condition when wet. The average weight in grams of each piece was as follows:

Sapwood	6.47 gms.
Heartwood	6.30 gms.

The average load-carrying capacity to the breaking point was for:

Sapwood	67.7 lbs. (av. of 2 pieces)
Heartwood	70.3 lbs. (av. of 4 pieces)

The suggestion arises that the slightly greater weight of the sapwood may possibly be due to its higher content of reserve food materials which might be lacking in the heartwood, but which do not add to the strength of the wood.

Examination of the sapwood from the trunk of a tree cut in December, however, showed but very meagre starch content when treated with potassium iodide-iodine, altho twigs and small branches were found to contain an abundance of both starch and oil globules.

It was noted that the pieces which were left in the soil until the close of the test were usually decayed more at the top end than at the bottom end. This was evidently due to the better aeration at the surface of the soil and possibly to the accumulation of carbon dioxide in the lower levels of the soil, which had no air drainage. (Fig. 1 D.)

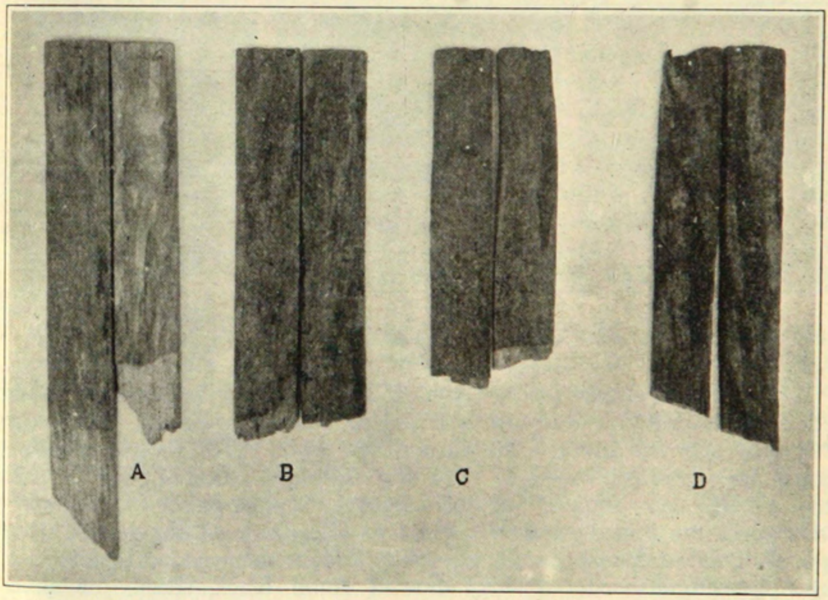


Fig. 1—TEST PIECES, NATURAL SIZE, EXPERIMENT I.
A—30 days in soil. B—152 days in soil. C—217 days in soil. D—217 days in soil showing upper and lower ends of the same piece.

NOTES ON THE TEST PIECES

MICROSCOPIC FEATURES EXPERIMENT I

The appearance of the test pieces varied to a considerable extent depending upon the length of time they were in the soil. This is shown by the photographs of three sets of specimens of heart and sapwood which had been under conditions of decay during periods of 30, 152 and 217 days respectively. (Fig. 1.)

At the end of 30 days the pieces of both sap and of heartwood were strongly discolored, the former slightly more than the latter. The prevailing color of the dried pieces was a very light slate-gray or almost a mouse color with here and there faint purplish-red tints or streaks. A few umber-brown streaks and flecks also occurred here and there in the surface of the pieces. The colors were quite unevenly distributed giving the surface of the wood of both pieces a blotched and streaked appearance. The colors within the wood were also very unevenly distributed being most pronounced at or just below the surface. Transverse sections of the pieces showed this very clearly, the colors extending below the surface in a radial direction as streaks and bands which faded out as they reached the interior of the wood. The colors in the sapwood extended much deeper and were more intense than those in the heartwood. (Fig. 2.)

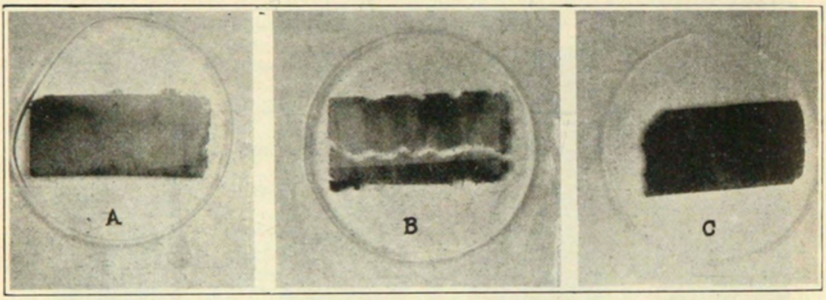


Fig. 2—CROSS SECTIONS OF TEST PIECES MAGNIFIED 2½ TIMES
A—Heartwood 30 days in soil. B—Sapwood 30 days in soil. C—Sapwood 217 days in soil.

The colors of the pieces tested 152 days were considerably darker than those of the 30-day test and had become more evenly distributed not only over the surface, but thruout the wood. The mottled appearance, however, continued to show quite plainly. Pieces remaining in the soil 217 days showed but little change in color, either in the intensity or in the distribution of the colors. In some of the pieces, deep purplish-red stains appeared, especially within the wood. In all cases the pieces under a hand lens, showed small black specks or short streaks as of some dark-colored material imbedded within the surface of the wood. Microscopic examination of these black specks showed that they were composed of thick-walled, dark-colored fungous cells in the form of small sclerotial masses.

The manner in which the test pieces fractured in breaking varied with the stage of decay. Sound wood broke with a considerable splintering on the lower side. In the 30-day-test pieces there was no splintering, but the manner of breaking, as shown in the photographs, gives evidence of some longitudinal shear. Pieces exposed to periods of more than thirty days always broke squarely off with only a somewhat jagged fracture in some cases.

MICROSCOPIC FEATURES—The wood of *Populus acuminata*, the wood used in the experiment, is an excellent example of a diffuse-porous wood. The description of the common cottonwood, *Populus deltoides*, as given in the guidebook for the identification of woods for ties and timbers (Koehler, 1917), applies quite closely to this species.[21]

Micro-chemical tests of sound wood, by use of chlor-zinc-iodine, show that the wood of *P. acuminata* closely resembles that of yellow birch as described by Rhoads.[30] Thus the cell walls of the medullary rays and of the vessels show the strongest lignification, while the tertiary and secondary thickenings of the wood-fiber walls respond strongly with the cellulose reaction, as exhibited in the blue-to-violet coloration.

Examination of the partly decayed wood showed that the tertiary and secondary layers of these elements are the first to be dissolved while the middle lamella and the vessel and ray cell-walls yield but slowly. Even in the badly decayed wood the latter elements were still intact to a considerable extent.

The rapid decline in strength of the wood, in comparison with the loss in weight, evidently is due to the early weakening of the prosenchyma or fiber elements. It appears that the decay-producing fungi which first attacked the wood in this experiment were largely cellulose-dissolving fungi. On the other hand it may be that the early stage of decay in this case was considerably influenced by the activity of cellulose-dissolving bacteria in conjunction with fungi, as exemplified in the findings of Schmitz.[34] Sections of the wood in the earlier stage of decay reveal the presence of numerous hyphae which are especially plentiful in the lumina of the wood fibers.

No attempt was made in this investigation to identify the various fungi which were concerned in causing decay. The number of such fungi which would be involved in this process might naturally be expected to be large. Their identification would have made this an impracticable part of the experiment as planned, which was to devise and try out a comparatively simple method for determining the progress and stage of decay in wood and its relation to strength of the material.

The results of this preliminary experiment seemed, on the whole, to be satisfactory and to indicate quite clearly the feasibility of this method in making studies of the exact relation between the stage of decay and the mechanical properties of wood. A study of the diagram showing in graphic form the decline in weight and strength, due to the corresponding progress of decay, reveals a rather striking correlation. The pronounced falling off in the strength curve in relation to a slight decrease in weight is impressive and indicates that even a small amount of decay is of large importance in weakening the material.

The irregular way in which the decay attacks wood together with the variability of even carefully selected pieces, accounts probably for the lack of regularity of the results. The comparatively small number of pieces, two to three each of sap and of heartwood, upon which the curves were based, would also tend to cause irregularities in the graph. It is probable that curves should be based upon at least ten pieces of each kind of wood at each interval of the test period in order to reduce these irregularities.

FURTHER TESTS EXPERIMENT II

Following the preliminary experiment, further tests upon a larger scale and employing a variety of wood species were projected. In this experiment the pieces of wood were mostly made ½x1x8 inches in size and were planted in a specially constructed galvanized iron box 1½x2x6 feet in size. Several holes were punched in the bottom to facilitate air and water drainage, and a cover in two pieces was made for the top. This box was then filled, first with a two-inch layer of coarse gravel and upon this a ten-inch depth of fine sand with an admixture of about 10 percent of garden soil. The pieces of wood were planted to their full length in an upright position and in regular rows one inch apart, with the pieces one-half inch apart in the row. Altho each piece of wood was numbered at each end, a diagram of the planting was made to avoid possible future mistakes in the numbers. (Fig. 3.)

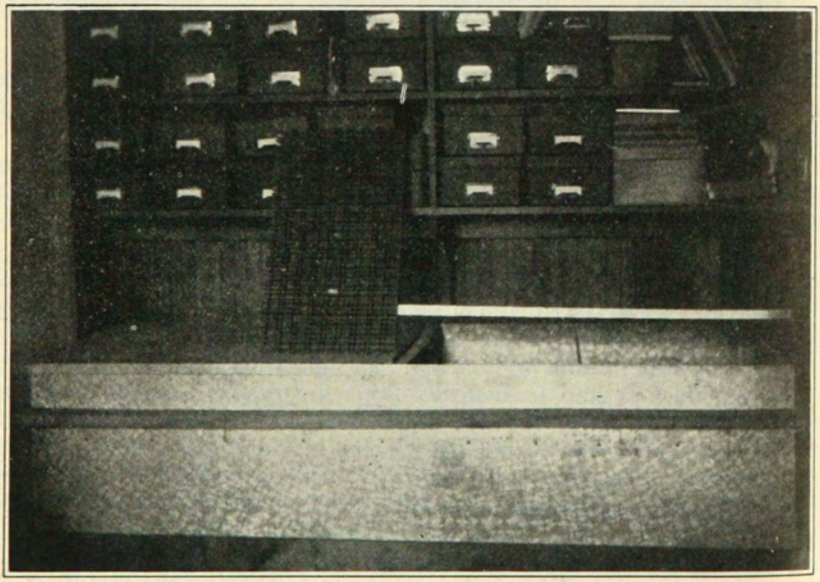


Fig. 3—GALVANIZED IRON BOX USED IN EXPERIMENT II. Rack used in planting the test pieces so as to give regular spacing. Filing boxes on shelves used to store the test pieces

The list of softwoods and hardwoods planted comprised the following species:

Softwoods

Juniperus scopulorum
Picea Engelmanni
Pinus contorta, two lots
Pinus edulis
Pinus ponderosa
Pseudotsuga taxifolia
Sequoia sempervirens
Thuya plicata, two lots

Hardwoods

Acer negundo
Catalpa speciosa
Elaeagnus angustifolia
Fraxinus lanceolata
Gleditsia triacanthos
Juglans nigra
Malus malus
Populus acuminata, four lots
Robinia pseudoacacia
Ulmus americana

All of the above species were of local growth except those of *Sequoia* and *Thuya.* With a few exceptions sapwood and heartwood of each species were tested in separate pieces. The softwoods were all assembled in one end of the box and the hardwoods occupied the remaining space. The moisture was maintained at a suitable degree by occasional sprinkling of the surface of the soil. The box was supported upon a base about one foot high and was kept in a basement room warmed by steam heat in winter. On account of the lack of artificial heat in the basement during the summer the average temperature was lower than the winter temperature. A range of variation was noted during the first year of from 60° F. during April, to 73° F. in October, with a probable average of about 65° F. The temperature fluctuations were perceptible in their influence upon the rate of decay in summer and in winter, being just the reverse of those outdoors.

Oven-drying was performed in an electric oven at a temperature of about 70° to 72° C. after a preliminary seasoning over a heating radiator, or above a steam pipe. The temperature employed, while comparatively low, was thought to be less apt to sterilize the wood or to bring about other possible changes in its structure and composition than the higher temperatures regularly employed in securing oven dryness. At first the pieces were loosely piled crib-wise upon the upper and lower shelves of the oven. It was soon found, however, that the pieces on the lower shelf were not reduced to the same moisture content as those on the upper shelf, even after a prolonged drying period. In order to secure uniformity in the drying of all the pieces placed in the oven at one time, it was found necessary to remove the shelves supplied with the oven and to dry the pieces in an upright position all at the same level. This was accomplished by constructing a drying basket of wire netting with wires across it in such a way as to keep the pieces of wood apart by about one-half inch. This plan was found to work satisfactorily not only in securing uniform dryness of the test pieces, but also in facilitating the work of handling the pieces while weighing and in testing them for breaking strength. (Fig. 4)

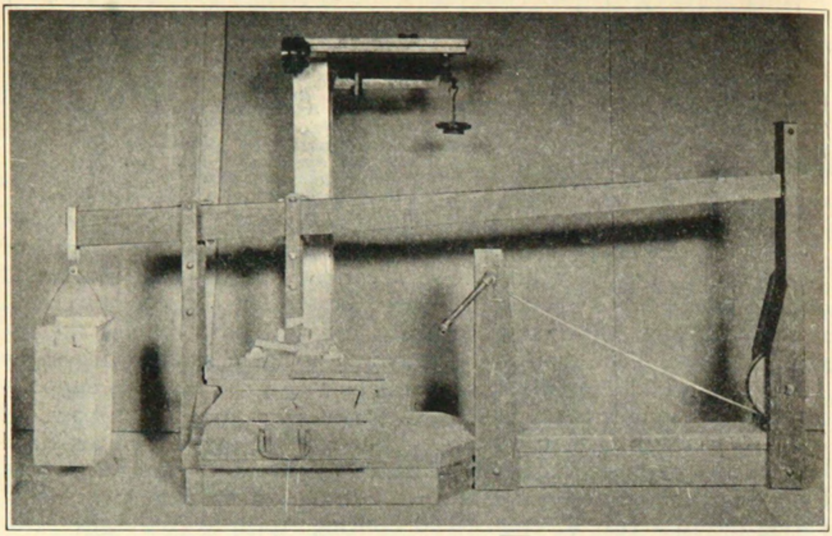


Fig. 4—MACHINE USED IN TESTING THE PIECES FOR BREAKING STRENGTH

In this experiment the pieces were weighed to the nearest decigram (0.1 gm.), which was about one-third of one percent (0.3 percent) of the average weight of the pieces. On account of there being no testing machine available, which was capable of denoting the comparatively small and accurate pressures desired in this experiment, a special machine for the purpose was contrived which proved satisfactory. This machine consists essentially of two parts: (1) A lever of the first class in which the power is applied by means of a hand-operated windlass and pulley for increasing the power by reducing the speed; (2) A platform scales of the ordinary type capable of recording pressures up to 800 lbs. Loads at the breaking point were all recorded at the nearest pounds. (Fig. 5.)

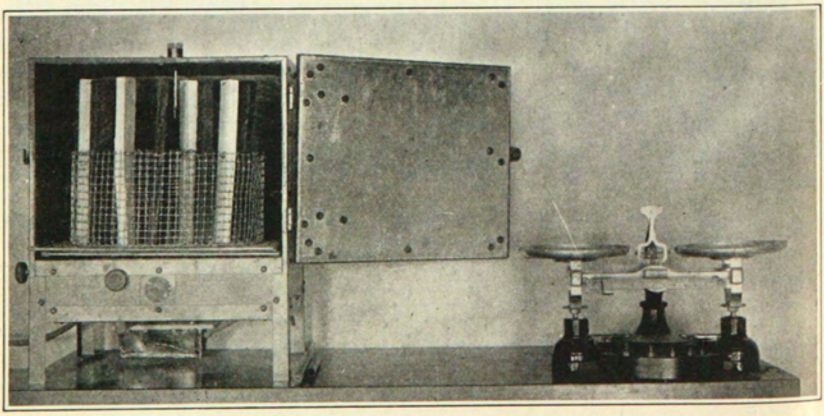


Fig. 5—DRYING OVEN AND SCALES USED IN EXPERIMENT II.

COTTONWOOD—(*Populus acuminata*)—Material obtained from large trees grown on College Campus. This was made the leading species in Experiment II. due to a plentiful supply of clear material and because it gave comparatively quick results in decay.

The following lots of specimens of this wood were prepared and tested:

Lot 1.—One hundred and one (101) pieces ½x1x8 inches consisting of sapwood 52, heartwood 49. The number of annual rings per inch was counted in each piece in order to determine if possible, the relation between growth-rate and resistance to decay.

Lot 2.—Ten (10) pieces, mixed heart and sapwood, 1x1x8 inches, planted in the decay box indoors. The purpose was to study the relation between size and shape of the piece and the rate of decay.

Lot 3.—Fifteen (15) pieces ½x1x8 inches planted in a wooden box, without top or bottom, filled with the same sand-soil mixture as used in the test indoors. The box was located in the edge of a shrubbery bed and was sunk into the ground with the top a little below the level of the ground surface. This lot was intended to offer a comparison, as to rate of decay, with that planted in the decay box indoors.

Lot 4.—One hundred (100) pieces of combined sap and heartwood planted in decay box, fifty (50) seasoned and fifty (50) unseasoned pieces, all split from branches 2 to 3 inches in diameter. The purpose of this lot was to use the method in determining the influence of seasoning upon the rate of decay.

Lot 5.—This lot comprised ten (10) pieces of sap wood and eleven (11) pieces of heartwood. Five of the sapwood and six of the heartwood pieces, were planted top end down, in relation to position in the tree trunk. The pieces were split from trunk-wood and were planted in the decay box indoors. The purpose was to apply the method in de-

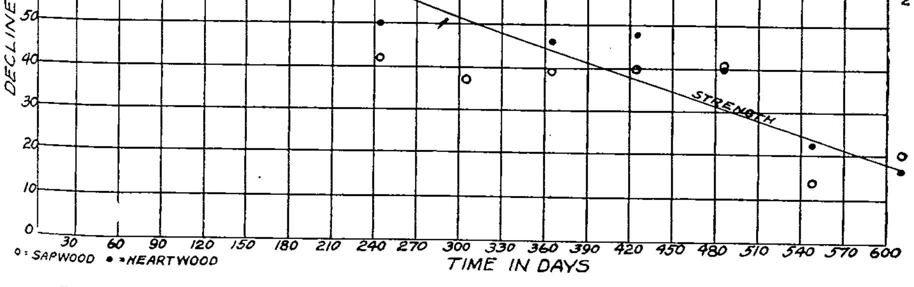


Diagram II—WEIGHT-STRENGTH CURVES FOR EXPERIMENT II, LOT 1 termining the possible effects upon the rate of decay due to position of the piece in the soil.

NOTES UPON THE RESULTS OF THE TESTS OF COTTONWOOD IN EXPERIMENT II.—

Lot 1.—The results of this test, as shown by graph diagram II. are practically the same as in the preliminary experiment. The rate of decay in the preliminary experiment, however, was much higher than that in the second test (Lot 1.). Thus in the former experiment the loss of weight at the end of 217 days averaged about 50 percent, while in the second case the average loss of weight was 8.5 percent at the end of the same period of time. This difference is apparently due to: (a) The higher average temperature which prevailed in the first case, and (b) the larger size of the test pieces used in the second case.

The average weights of the pieces of Lot 1, were:

Sapwood (average of 52 pieces)	29.8 gms.
Heartwood (average of 49 pieces)	30.3 gms.

This is 4.7 times greater than the average weight of the pieces used in Experiment I.

The average breaking load for sound wood was, for:

Sapwood (average of 3 pieces)	334 lbs.
Heartwood (average of 4 pieces)	344 lbs.

A comparison of the graphs shows that the ratio of decay to strength remains about the same in both cases.

The average rate of decay in Experiment I during the 217-day period, was about 5.6 times as rapid as that in Experiment II, Lot 1. Unfortunately it is impossible to estimate, quantitatively, the effects of the heat factor in the first experiment. It is believed, however, that the temperature averaged at least 5° F. higher thruout the period of the test than that in the second experiment. This in itself would probably cause a decided increase in the rate of decay in Experiment I, especially as the temperature was considerably below the optimum for most fungi in both cases.

The appearance of the test pieces of Lot 1, in Experiment II, showed the same features of uneven discolorations as those of Experiment I. The effects of the decay were more uniform in the advanced stages in the former case, however, probably due to more equal aeration thruout the soil matrix in the large decay box.

The relation between rate of growth and rate of decay was studied in a number of pieces of Lot 1. The following table, based upon the same period of time for each, gives the results of this comparison:

Kind of wood	No. of pieces	Growth rings per inch, av.	Loss in weight in percent	Difference in excess, percent
Heartwood	9	5.6	19.7	5.5
Heartwood	9	8.8	14.2	0.0
Sapwood	7	6.0	7.7	0.0
Sapwood	7	9.0	9.2	1.5

The above table indicates that while the narrower rings of heartwood are the more resistant to decay, just the reverse condition is found in the sapwood. The explanation possibly may be that as the wider growth rings of the sapwood occur nearest to the heartwood they partake somewhat of the nature of the latter while still having the appearance of sapwood. Comparison of a much larger number of pieces showing a wider range of growth rates should be made in order to determine more positively these relations. In this study the specimens used in the comparison were all taken from the same tree and therefore would seem to indicate the true relation between rate of growth and resistance to decay.

Lot 2. The ten pieces composing this lot were each made to contain twice the volume of the pieces in the preceding lots. A comparison of the rate of decay in this lot with that in Lot 1, illustrated in graph-diagram III, shows that the pieces of larger volume decay more slowly proportionately than the smaller ones. This was to be expected from the comparison of the results of the preliminary experiment. In the present case, however, the pieces were tested under the same conditions as those of Lot I so that differences in the various factors of decay were eliminated.

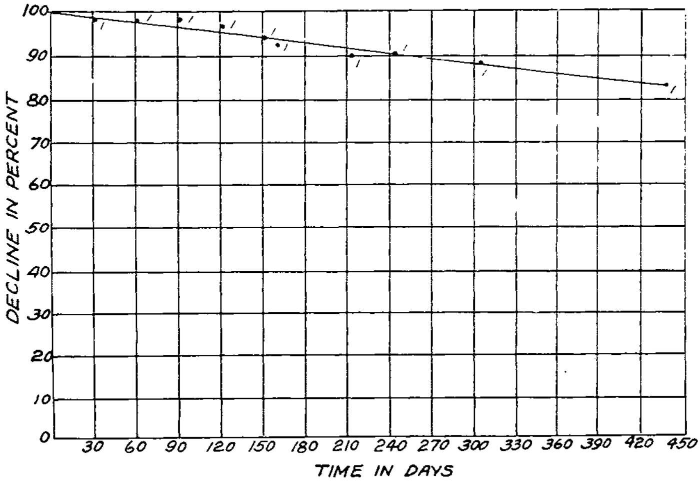


Diagram III—WEIGHT CURVE FOR EXPERIMENT II, LOT 2

The following table shows the relations found to exist by comparing the results of the tests with Lots 1 and 2 Experiment II:

Decline in weight at end of test periods

	120 days	300 days	420 days	Average
Lot No. 1.............	4.0%	15.0%	25.0%	
Lot No. 2.............	3.0%	12.0%	17.0%	
Decay ratio (inverse) (1) to (2)........	1.33	1.25	1.47	1.32
Weight ratio of sound wood (2) to (1)..	2.00	2.00	2.00	2.00
Surface ratio (2) to (1)	15.	1.5	1.5	1.5

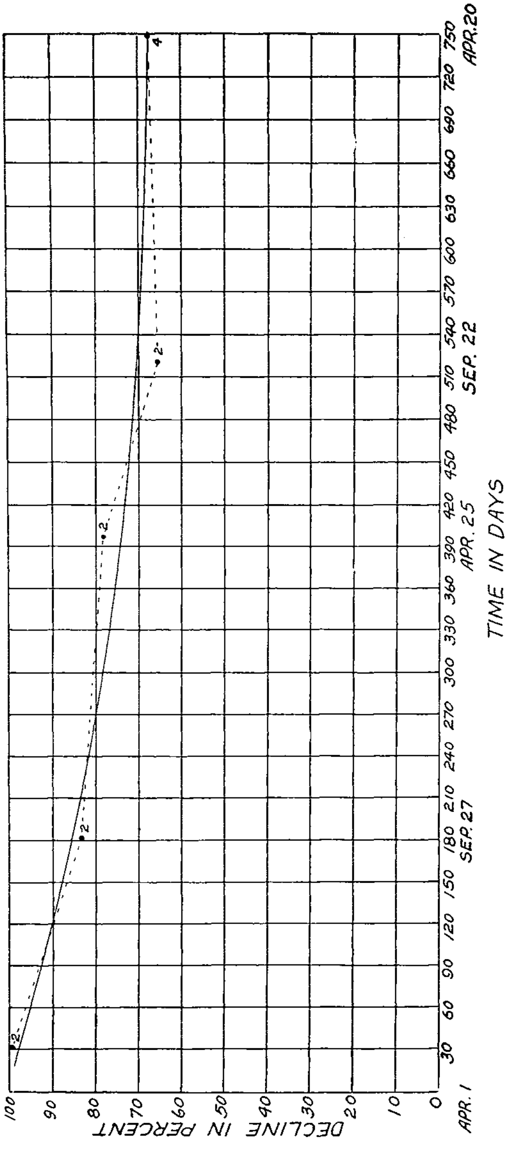


Diagram IV—WEIGHT CURVE FOR EXPERIMENT II, Lot 3

A study of the foregoing table reveals the following relations between size and shape of piece and the rate of decay: The decay ratios, obtained by dividing the percentage of loss in Lot 1 by that in Lot 2, show that in this case the rate is on the average 1.32 times faster in the smaller pieces than in the larger ones. Thus the rate of decay is inversely as the size of the piece, or small pieces decay more rapidly than larger ones. The weight-ratio (equivalent to volume in this case), of sound wood, obtained by dividing the average weight of the pieces of Lot 2 by that of the pieces of Lot 1 shows that the pieces of Lot 2 are twice as large as those of Lot 1.

The surface ratio, obtained by dividing the surface of a piece of Lot 2 by that of a piece of Lot 1, shows that the pieces of Lot 2 expose only 1.5 times as much surface as those of Lot 1 while they contain twice as much wood by volume and weight. This is much closer to the decay ratio than is the weight-volume ratio. If equal weights (volumes), of wood from Lots 1 and 2 are compared it is evident that the surface factor is the important one in determining the rate of decay rather than the weight (volume) factor alone. This result also accords with the evidence showing that decay of sound wood begins at the surface and extends inward in a more or less regular manner. Thus it appears that pieces of timber subjected to decay should have such shape as to expose the least possible amount of surface in proportion to volume. Cylindrical posts, on account of their exposing the least relative surface to the action of the factors of decay, are to be preferred to those of square or rectangular form while those reduced to semi-cylindrical, or triangular form, either by sawing or splitting, are the least desirable in shape. Season checks, cracks and holes may serve to increase the surface area exposed to decay and permit it to extend rapidly to interior portions of the timber.

Lot 3.—The most pronounced result in this test is the influence of season upon the rate of decay. Thus from June first to October first of the first year, the rate of decay was most rapid and exceeded that in the decay box indoors about twice. This is to be accounted for in the much higher temperatures out-of-doors, under the heat of direct sunshine, as compared with the cool basement room where the decay box was situated. Breaking tests of these specimens were not carried on. Graph diagram IV.

Lot 4.—The pieces used in this test were split from green, peeled branches 2 to 3 inches in diameter. Those from the 2-inch branches were practically all sapwood, while those from the 3-inch branches contained about one-fourth heartwood. Fifty of the pieces were planted in the green or unseasoned condition while the other fifty pieces were dried in the oven to the stationary moisture content at 71° C. and then planted with the others in the decay box. Ten pieces each of the unseasoned and of the seasoned pieces were removed and tested for loss of weight at somewhat regular intervals. The dry weights of the unseasoned pieces were based upon the results of drying the fifty seasoned pieces from their green condition.

The results of this test show that, in this case at least, seasoning hastened the rate of decay especially during the early period of the test. Later on, however, about the same rates were continued to the end of the test altho the same levels were not reached. (Diagram V.)

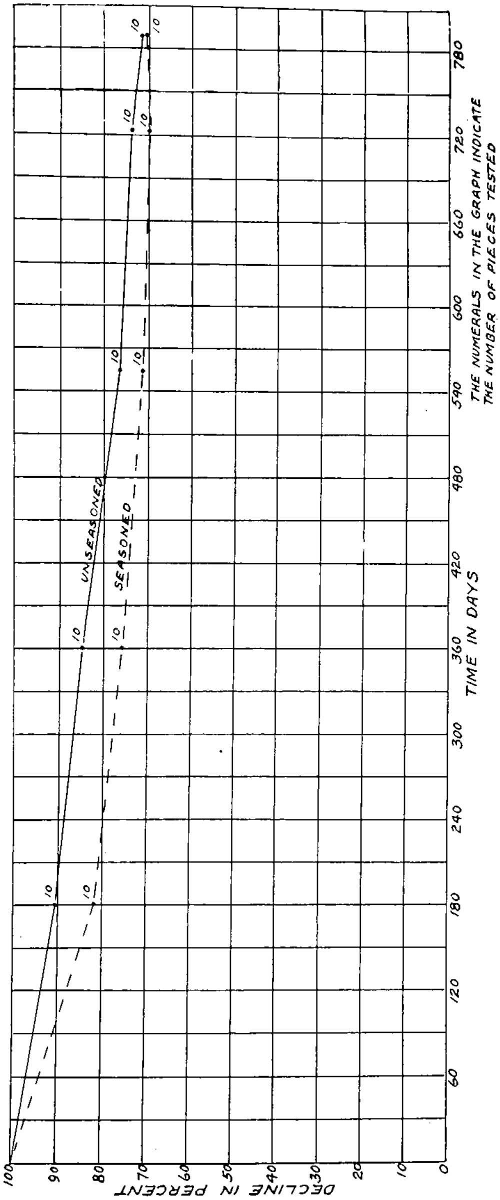


Diagram V—WEIGHT CURVE FOR EXPERIMENT II, LOT 4

This result is the reverse of that nearly always ascribed to seasoning of timbers that are to be set in the soil. It appears to sustain the contention of some persons that aspen posts set green will outlast those set after preliminary seasoning. A possible reason may be that the living sapwood resists infection better than the same wood after being dried and after the cells are all dead.

Crumley (1910) discusses a similar result in the case of tests upon the relative durability of post timbers examined after a period of service in fences. He found that the heartwood from the center of the log, in split, halved or quartered posts, was the first to decay, while that part just underneath the sapwood was the last to yield. He ascribes the more rapid decay of the center heartwood to be due to the presence of knots which may have already been infected with decay before they were covered by the outer growth rings.[8] It appears that further and more extensive tests are needed along this line in order to establish sounder principles in the practice of seasoning post timbers that are to be set untreated.

In Technical Notes No. F-33, 1924, of the Forest Products Laboratory, the records of two investigations of timbers under service conditions are given, which show that seasoning has little or no influence upon the durability of timbers used in contact with the soil. In the case of railway ties used in the roadbed of the Northern Pacific Railway a difference in favor of seasoning amounting to a little over one month was noted. In the case of poles used by the American Telephone and Telegraph Company, the green poles showed a trifle less rate of decay than the seasoned ones. It is also noted that all timbers to be used in buildings, however, should be seasoned before use to prevent the entrance of decay fungi before the moisture content drops below that required for fungi to grow.

Lot 5.—The purpose of this test was two-fold: First, to apply the method in measuring the rate of decay; Second, to determine the influence, if any, upon planting the pieces in reverse positions with reference to top and bottom ends. The results, as shown in graph-diagram VI. are evidently too conflicting to establish any positive principle. This is particularly apparent when the behavior of the individual pieces is studied from the following table. This may be due in part to the comparatively small number of test pieces used and in part to the fact that they were not very uniform in size and shape.

It may mean, however, that it makes little or no difference as to which end of a post is set in the ground except that most consideration should be given to placing the larger end, which is almost always the butt end, in the soil. This conclusion agrees with that of Crumley,[8] who studied the matter in connection with his investigations upon the relative durability of fence posts in actual service.

The following table shows the results observed from the behavior of the individual pieces, which in lot 5 were planted in reverse positions with reference to top and bottom ends:

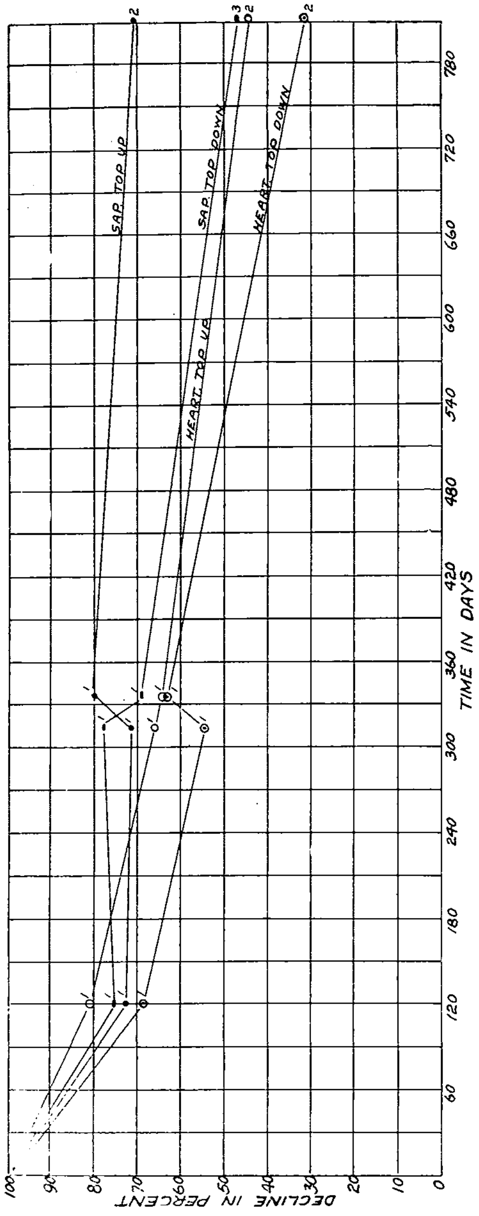


Diagram VI—WEIGHT CURVE FOR EXPERIMENT II, LOT 5

Kind of wood	Position of Top	Piece No.	Length of Test, Days	Loss in weight percent	Average
Heartwood	....Up	1	120	19.0	19.0
Heartwood	.....Up	2	324	34.0	35.0
Heartwood	.....Up	3	324	36.0	
Heartwood	....Up	4	830	76.5	55.7
Heartwood	....Up	5	830	35.0	
Heartwood	....Down	6	120	31.7	31.7
Heartwood	....Down	7	324	45.5	41.2
Heartwood	....Down	8	324	37.0	
Heartwood	....Down	9	830	36.5	48.7
Heartwood	....Down	10	830	61.0	
Sapwood	......Up	11	120	27.7	27.7
Sapwood	......Up	12	324	28.7	24.3
Sapwood	......Up	13	324	20.0	
Sapwood	......Up	14	830	28.0	29.0
Sapwood	......Up	15	830	30.0	
Sapwood	......Down	16	120	24.5	24.5
Sapwood	......Down	17	324	22.0	26.5
Sapwood	......Down	18	324	31.0	
Sapwood	......Down	19	830	63.0	53.0
Sapwood	......Down	20	830	56.0	
Sapwood	......Down	21	830	40.0	

SUMMARY

1. The progressive loss of weight during decay in wood may be used as a measure of the rate and extent of decay.

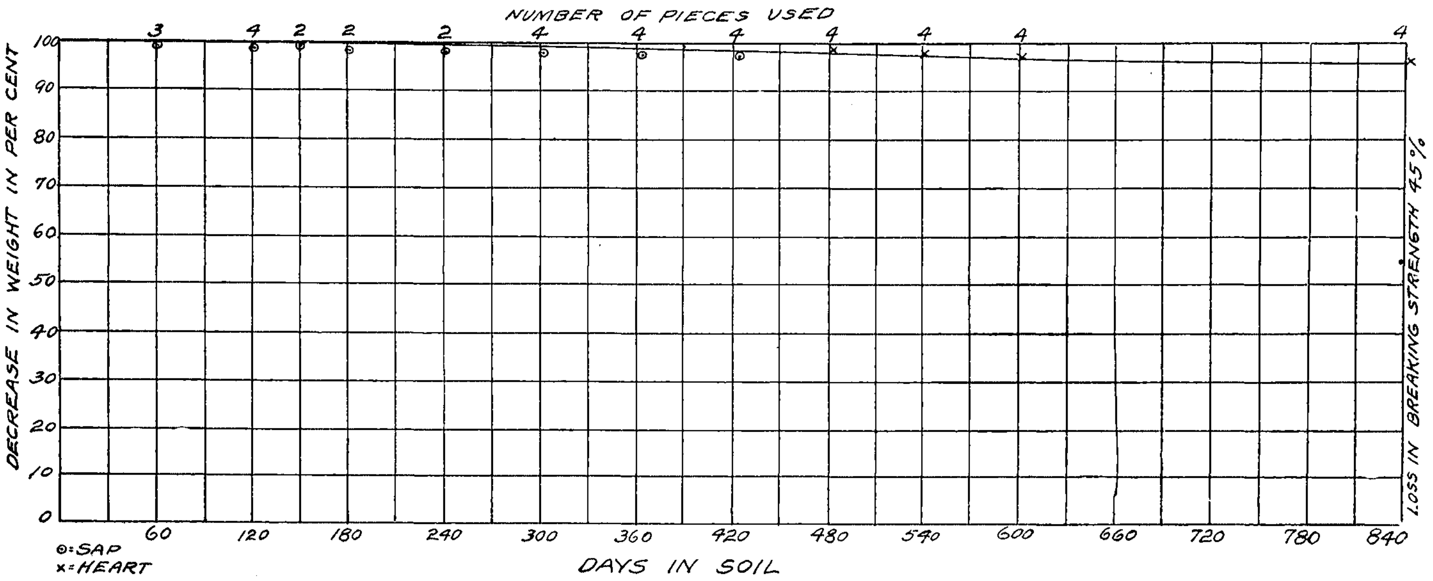
2. The influence of decay upon the mechanical properties of wood may be readily determined by experiments similar to those described.

3. A comparatively simple method has been employed as described, whereby other relations affecting the rate of decay may be investigated, such as:

   a. The rate of growth of a species.
   b. The climatic and soil conditions under which it grew.
   c. The influence of seasoning.
   d. The influence of relative position in the soil.
   e. The influence of size and shape of the piece.
   f. The influence of soil texture and composition and water content.
   g. The influence of temperature.
   h. The influence of preservative treatments.

4. The accuracy of the determinations depends largely upon the number of test pieces employed and their uniformity in size and shape. At least ten pieces of a kind should be tested at each interval in order to secure better averages.

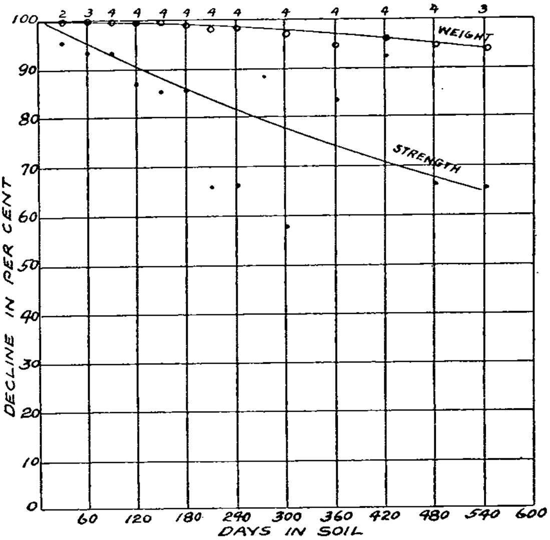
5. Out-door tests may be carried on with very little expense for equipment other than for a suitable drying oven, pair of fairly delicate balances, and for some a form of testing device for strength determinations.



ROCKY MOUNTAIN RED CEDAR (*Juniperus scopulorum*).

From foothills of Colorado. 41 test pieces ½x1x8 inches. Growth rings per inch, 22 to 80.

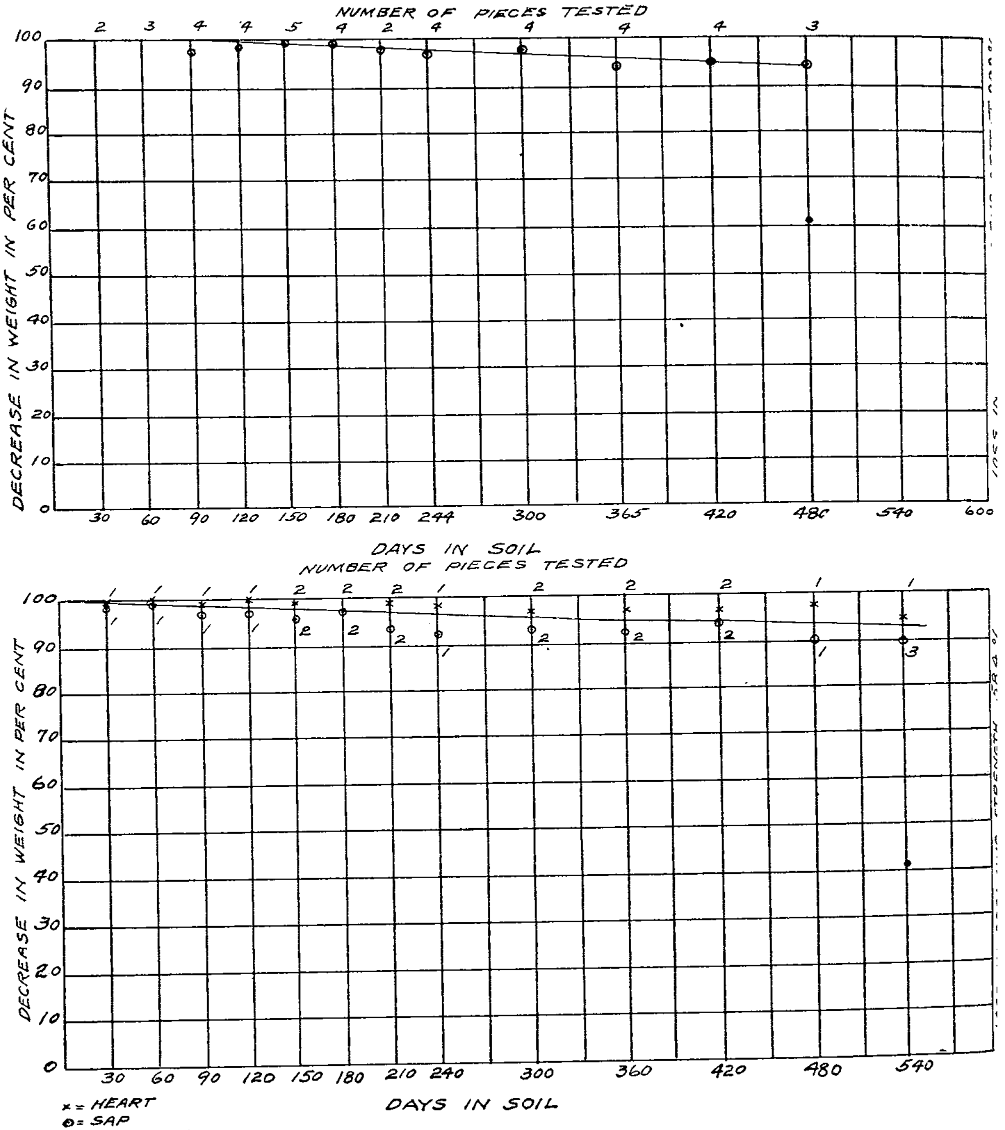
The wood of this species is hardly distinguishable from that of the eastern red cedar (*Juniperus virginiana*). The trees are not so large as the eastern species and grow more crooked and knotty. The extensive use of the Rocky Mountain red cedar for fence posts in the early days has nearly exhausted the more accessible supply. The reputation for great durability is borne out in this test. In contrast with the western red cedar (*Thuya plicata*) the strength of the Rocky Mountain red cedar shows a decided falling off due to decay at the close of the test period.



ENGLEMANN SPRUCE (*Picea Engelmanni*)

Source of material—Colorado National Forest, 9,000 ft. elevation.
Size and number of test pieces,—50, ½x1x8 inches. Growth rings per inch, 14 to 37.

Englemann spruce, when compared with cottonwood, shows a durability more than five times greater than the latter species during the same period of time. The strength curve in this case, however, is largely problematical due to the very uneven character of the test pieces in relation to knots and cross grain. This is exhibited in the wide range of results in breaking strength as shown on the graph-diagram above. In nearly all cases a low breaking strength was associated with some defect in the piece such as cross grain or small knots.



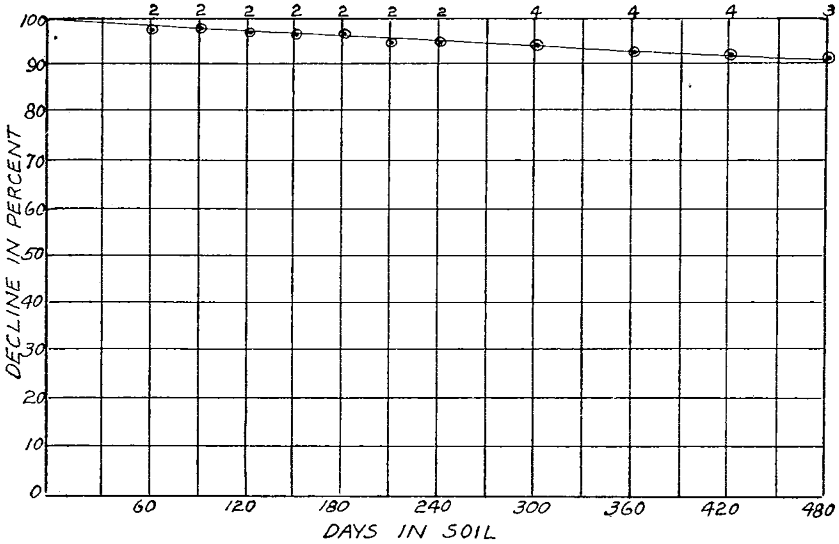
LODGEPOLE PINE (*Pinus contorta*)

Mountains of Northern Colorado.

83 pieces, ½x1x8 inches. Growth rings per inch, 6 to 68.

Two lots of pieces, from different trees, were tested separately. In one case no distinction was made between sap and heartwood. The graphs showing loss of weight agree very closely, it will be noted.

From the results of these tests it would appear that the wood of lodgepole pine is not inferior in durability to western yellow pine. The data of breaking strength was very irregular due to lack of clearness in the material employed and has therefore been omitted except at the end of the test period.

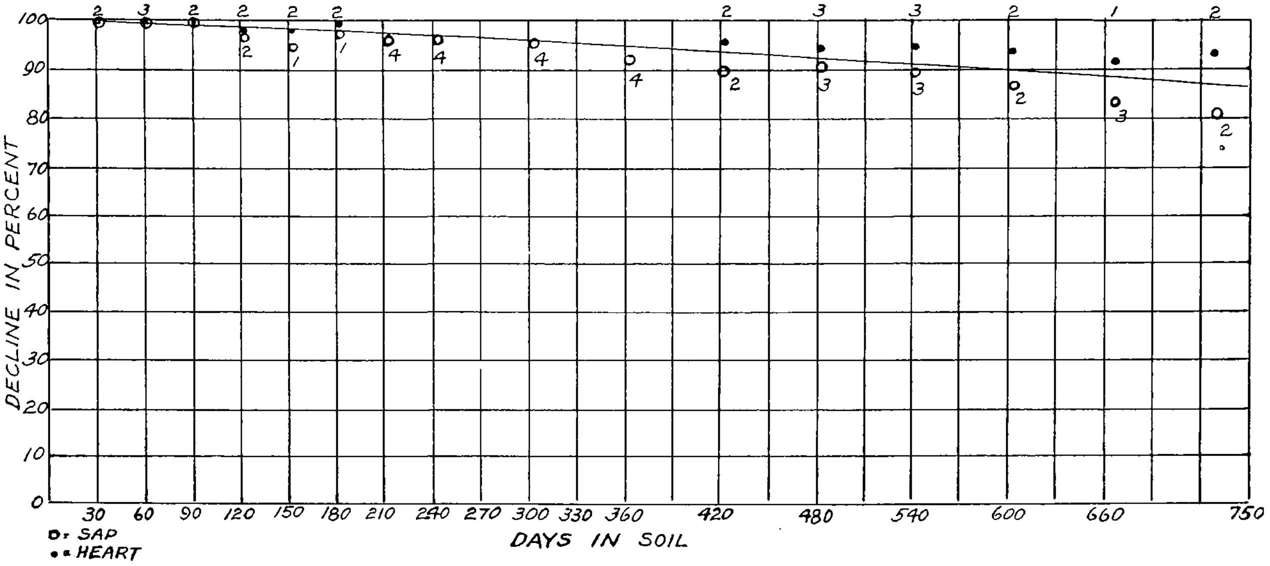


PINYON PINE (*Pinus edulis*).

Material from tree grown near Manitou, Colorado.
29 pieces ½x1x8 inches. Growth rings per inch 30 to 56.

No distinction was made between heart and sapwood. A few of the pieces were somewhat pitchy, but this did not appear to increase their durability appreciably.

From the results of this test the wood of the pinyon pine is shown to be somewhat less durable than that of the other two species tested. The strength data, like that from the other pines, was very irregular, due to the cross-grained, knotty character of the available material and was therefore omitted as being unrepresentative of the species.



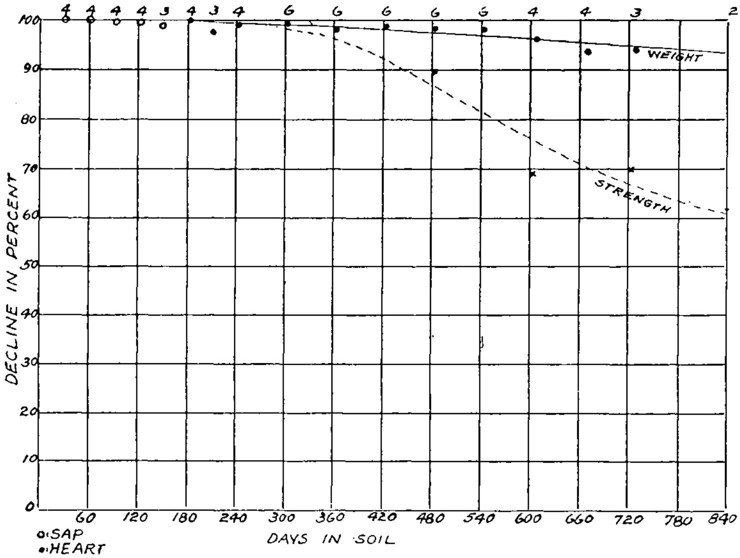
WESTERN YELLOW PINE (*Pinus ponderosa*)

Material from two trees grown in foothills of northern Colorado.

61 pieces ½x1x8 inches. Growth rings per inch, 10 to 43.

Most of the sapwood pieces were discolored by the blue stain so common to the wood of this species that has been seasoned slowly with the bark on. No increased susceptibility to decay could be discovered in those pieces thus discolored. Some of the heartwood pieces contained considerable pitch and in such cases a lowered rate of decay was perceptible.

On account of the cross-grained, knotty character of the trunks available, the strength data proved to be unsatisfactory and was not graphed.

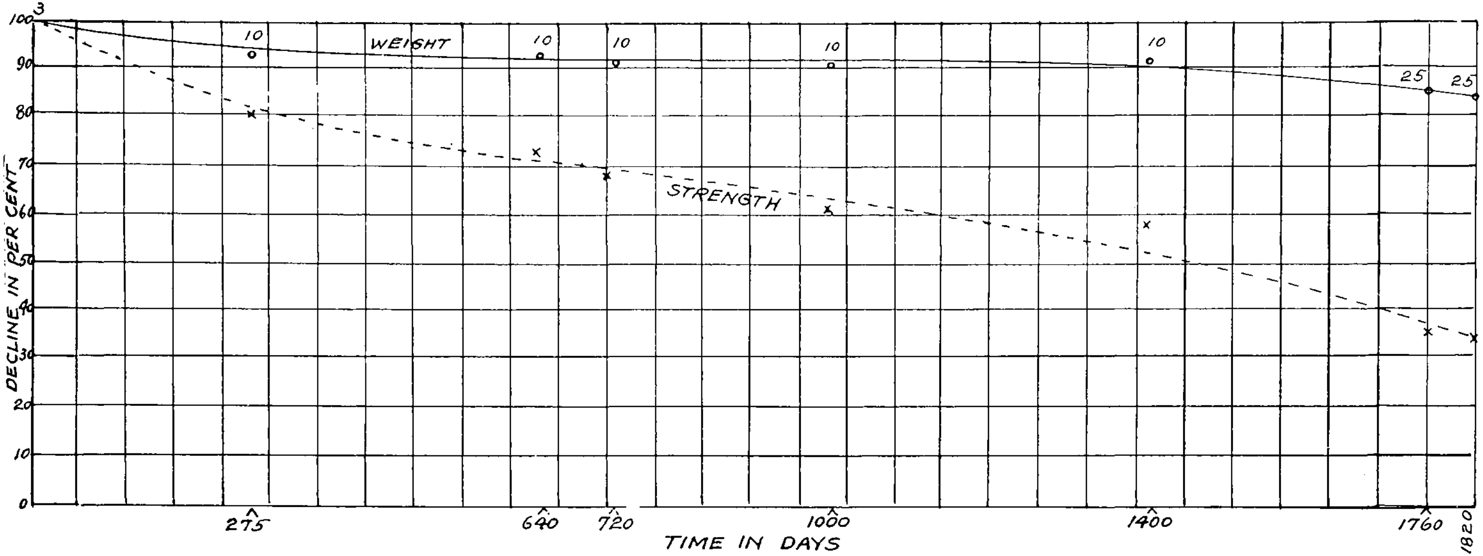


DOUGLAS FIR (*Pseudotsuga taxifolia*)

From Pingree Park, Colorado, Elevation 9,050 ft.
63 pieces ½x1x8 inches. Growth rings per inch, 12 to 100.

Douglas Fir in this test bears out its reputation for durability. The very slow rate of growth of this species at high elevations is also indicated by the narrow growth rings, most of the test pieces showing at least 25 per inch. On account of the very thin sapwood, in the log from which the material came, very few pieces of such wood were obtained and these all showed the narrowest growth rings.

The greatest strength exhibited by any one piece was 436 pounds after being in the soil 150 days.

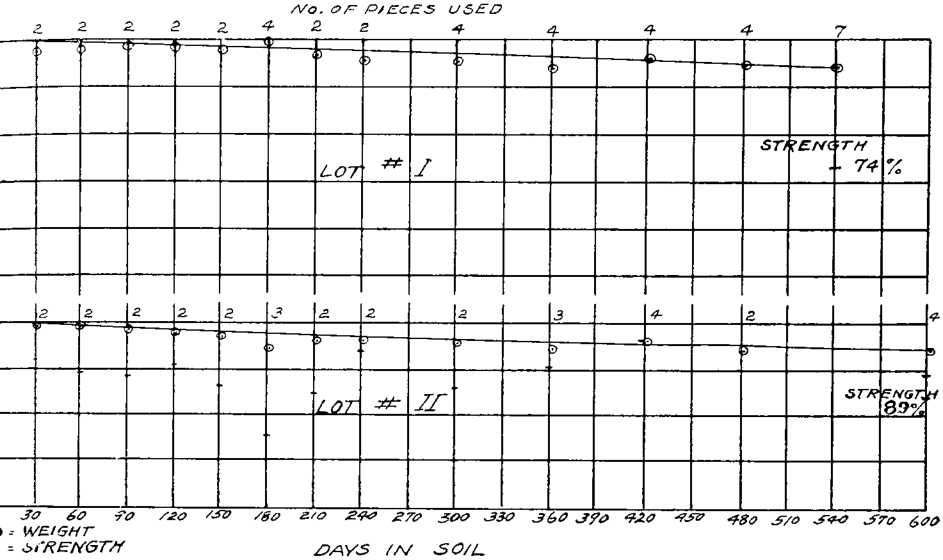


REDWOOD (*Sequoia sempervirens*).

Material supplied by the California Redwood Association, San Francisco, California.

100 pieces ½x1x8 inches, rough sawn.

The results of this test indicate that redwood belongs in the class with our most durable species. It outranks any of the hardwoods employed in these tests and equals the western red cedar. One prominent feature exhibited by the wood of this species was the formation of a closely adhering layer of the sandy soil around the test pieces. This layer was almost black in color and had the appearance of a mixture of tar and sand. It appeared to be caused by an exudation from the wood itself and was similar in some respects to the coating which formed about the test pieces of black walnut and the locusts, except that it was comparatively free from fungous hyphae. It is believed that the loss in weight during the first stage of the test was due as much to the loss of this exudation from the wood as to incipient decay.



WESTERN RED CEDAR (*Thuya plicata*)

Material taken from fence posts produced near Boville, Idaho. Number and size of test pieces: Lot 1. 41½x1x8 inches; Lot 2. 32, ½x1x8 inches. Growth rings per inch: Lot 1, 12 to 28; lot 2, 20 to 48.

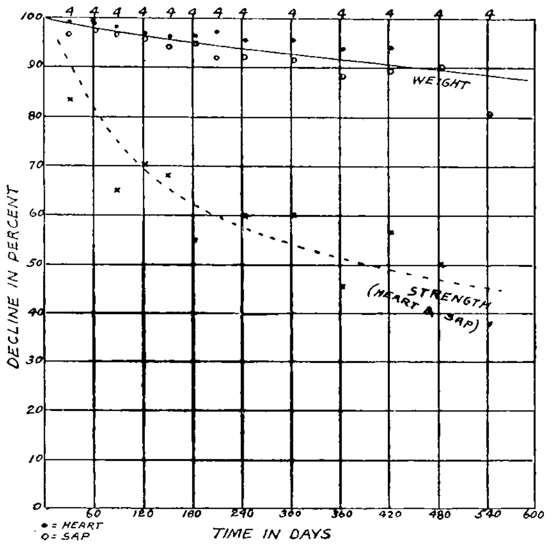
Lot 1 was taken from a post split from apparently dead standing timber. Some portions were considerably darker than is common to green timber. Breaking tests of the darker, in contrast with the lighter colored wood showed practically no difference in strength between the two. The durability tests showed no appreciable difference between the light and dark colored portions.

Lot 2 was taken from a perfectly sound post which had evidently been cut green. A comparison of the graphs of the two lots shows that the difference in durability in favor of the second lot is too small to be of practical importance.

The average weight and breaking strength of 10 pieces of each lot were as follows:

Lot No.	Weight gms.	Strength lbs.
1	20.6	249
2	23.4	305

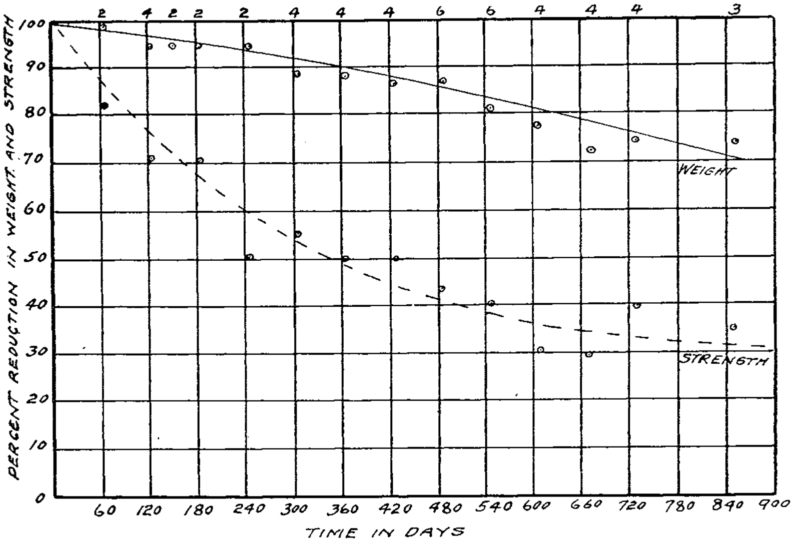
The loss of strength at the end of the test periods shows a difference of 15 percent in favor of the green cut wood. Perhaps the most remarkable feature of this wood brought out in the test is the comparatively little loss in strength value, due to decay, in contrast with most other species. This fact probably accounts for the high position which this wood occupies in its uses as poles and posts.



Box Elder (*Acer negundo*)

From tree grown on college campus.
52 pieces ½x1x8 inches. Growth rings per inch, 3 to 7.

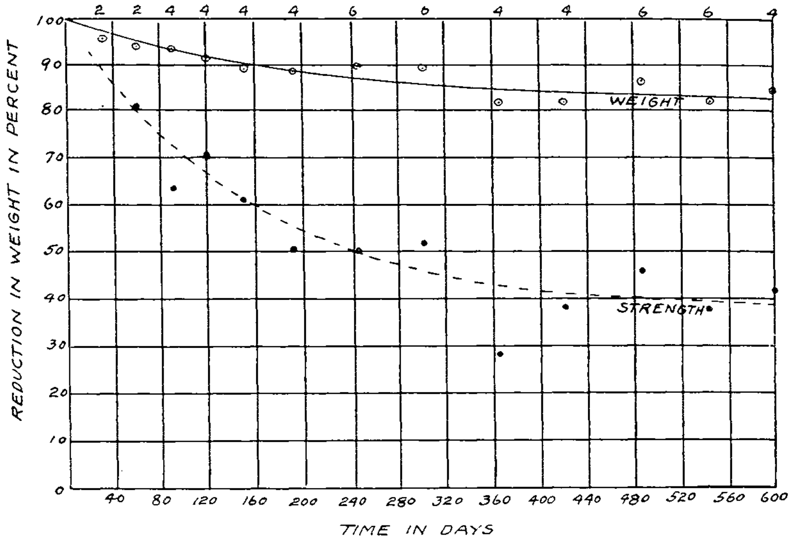
The wood of the box elder, like that of the other maples, is generally considered as of low durability. In this test it was found to rank with such species as ash, apple and even with the sample of catalpa which was used. A striking feature of the wood, as shown by the graph, is the profound influence of a slight loss of weight, due to decay, upon the strength of the wood. The strength of the sound material is indicated by the fact that one of the pieces of heartwood carried a maximum breaking load of 562 pounds.



CATALPA (*Catalpa speciosa*)

From tree grown on college campus.
52 pieces ½x1x8 inches. Growth rings per inch, 2 to 4.

No distinction was made between heartwood and sapwood, there being very little of the latter in the trunk. Catalpa wood has been considered as one of the very durable species and is usually classed with the locusts in that respect. The test here recorded, however, indicates that its wood is no more durable than that of the green ash. The lack of durability in the test specimens used may be accounted for, perhaps, in the very rapid rate of growth made by the tree, which stood in the open thruout its life. This is in accord with investigations made at the Ohio Experiment Station with the durability of fence posts in which it was found that the wood of very rapidly grown black locust was low in durability in comparison with that of slow growth.

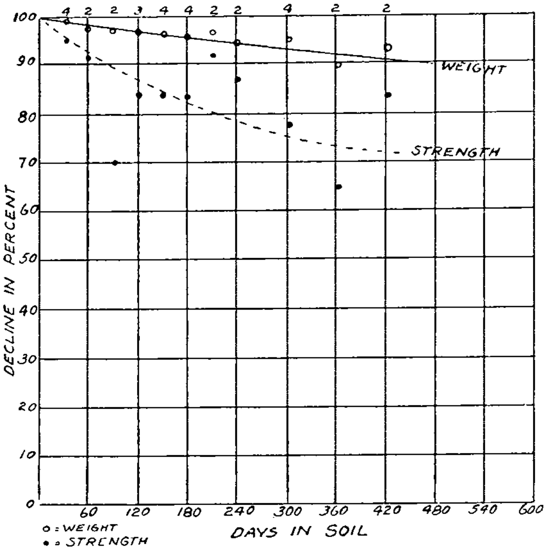


RUSSIAN OLIVE (*Elaeagnus augustifolia*)

From tree grown on college farm.
60 pieces, all heartwood, ½x1x8 inches. Growth rings per inch, 2 to 5.

Russian olive is one of the comparatively few species of broadleaf trees which can be grown successfully on the Great Plains without irrigation. Altho a tree of small to medium size it is capable of making a remarkably rapid growth under irrigation and can be grown to fence-post size in a comparatively short time. A study of the graphic chart, however, indicates that the wood of such rapid growth, at least, is low in durability and appears to be but little better than cottonwood.

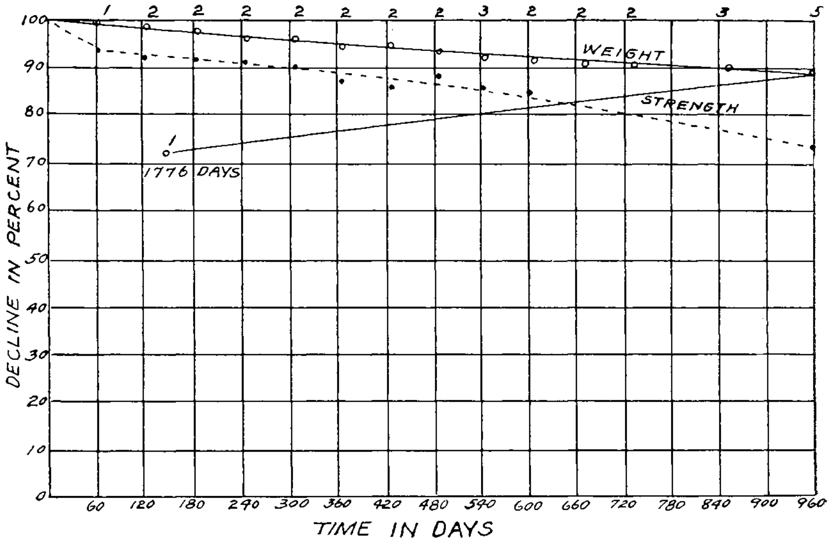
In all probability the wood of slow-growing trees would show a higher degree of durability than that used in this test. One peculiarity of the tree is that the change from sapwood to heartwood begins at a very early age and continues so rapidly that only the last-formed annual ring remains sapwood, at least in trees of such rapid growth as that employed.



GREEN ASH (*Fraxinus lanceolata*)

From tree grown on college campus.
35 pieces ½x1x8 inches. Growth rings per inch, 5 to 16.

Ash is known to be comparatively short-lived in contact with the soil. This is shown by the comparison of the graph of this species and those of durable species such as black and honey locusts, which are about twice as long-lived. The chart gives the combined tests of heartwood and sapwood. The very irregular results from the strength tests were probably due largely to the somewhat cross-grained and knotty character of the wood of some of the test pieces.



HONEY LOCUST (*Gleditsia triacanthos*)

Material from tree grown on college campus.
62 test pieces ½x1x8 inches. Growth rings per inch, 3 to 10.

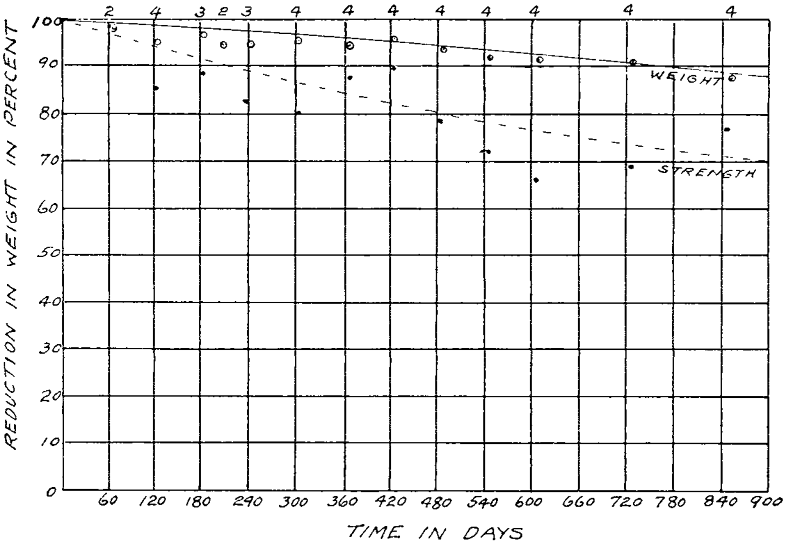
Average breaking strength based upon 3 pieces of sound wood—534 lbs.

Average weight of sapwood based upon 10 pieces------53.7 gms.

Average weight of heartwood based upon 10 pieces ----50.5 gms.

According to this test honey locust wood is not in any way inferior to black locust either in strength or durability. The test pieces when removed from the soil, were covered with a closely adhering layer of soil ¼ to ½ inch thick held together apparently by some exudation from the wood. A similar case is noted in connection with the tests of California redwood.

The greater average weight of the sapwood is believed to be due to the presence of stored food material which is lacking in the heartwood.



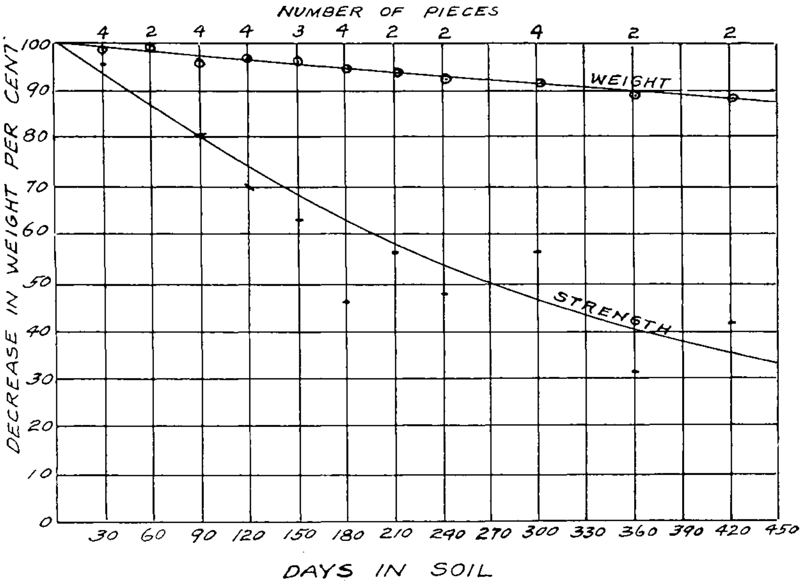
BLACK WALNUT (*Juglans nigra*)

From college walnut grove, 8½-inch trunk.
47 pieces ½x1x8 inches. Growth rings per inch, 4 to 12.

According to this test black walnut is a wood of high durability, a fact which has long been established in practice. Due to the very narrow layer of sapwood in the trunk from which the material came no attempt was made to test it separately.

The greatest load carried to the breaking point by any one piece was 450 lbs.

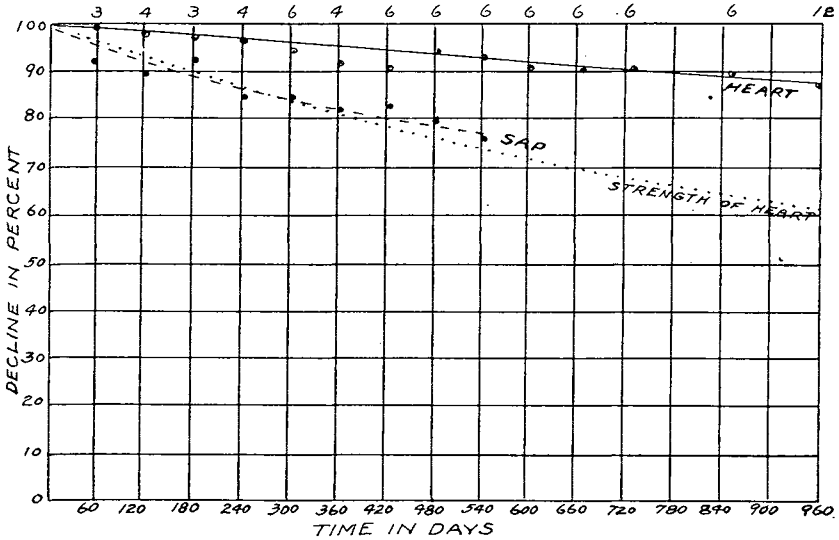
The test pieces when removed from the soil were covered with a closely adhering layer of the sandy soil which was felted together by a mass of dark colored fungous filaments. When this was scraped off the surface of the pieces soiled the hands with a sooty substance, probably an exudation of coloring matter from the wood. A similar condition was noted in connection with honey locust, black locust and, in a lesser degree, in catalpa. No careful study was made of this phenomenon which appears to be common to the most durable species of hardwoods tested.



CULTIVATED APPLE (*Malus malus*)

Material from local orchard.
Size and number of test pieces: 34, ½x1x8 inches, heartwood.

The durability of apple wood is not great when contrasted with that of red cedar and other species of great durability. In comparison with the least durable species tested, cottonwood, it shows a loss in weight of only 12½ percent in the same time that caused a loss of 25 percent in the cottonwood. Strangely enough, however, the strength loss, proportionately, was much greater in the apple than in the cottonwood.



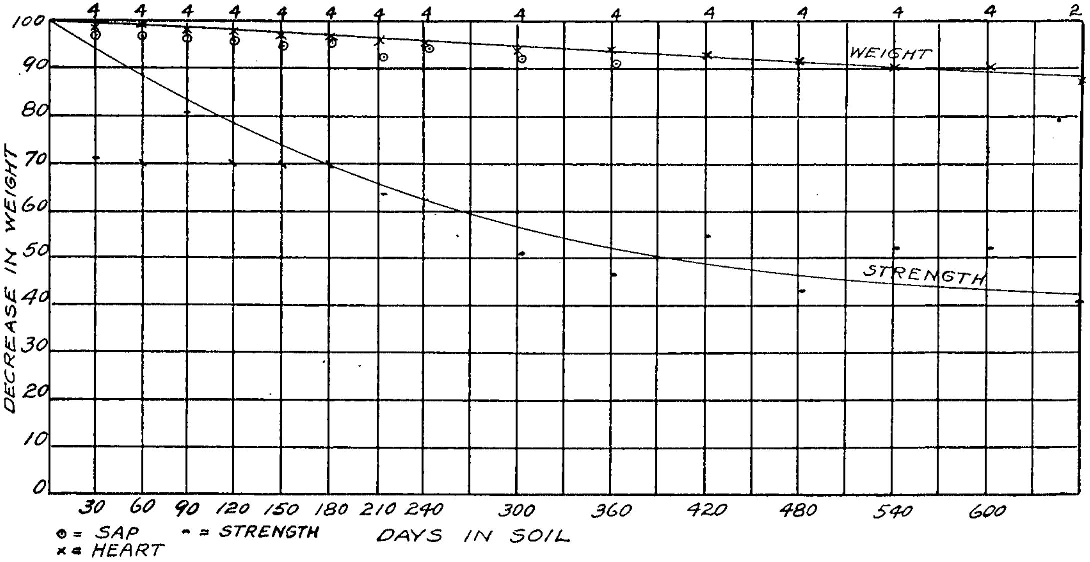
BLACK OR YELLOW LOCUST (*Robinia pseudoacacia*)

Material from tree grown on college campus.
81 pieces ½x1x8 inches. Growth rings per inch, 3 to 6.

Average breaking strength based upon 3 pieces, 472 lbs.
Average weight of sapwood based upon 10 pieces 51.2 gms.
Average weight of heartwood based upon 10 pieces, 48.6 gms.

In comparison with the wood of honey locust, as shown by this test, the wood of black locust is neither as heavy nor as strong as that of the former species. But little difference, however, appears in durability over the same period of time.

The growth rate was somewhat greater in the black locust than in the honey locust.



ELM (*Ulmus americana*)

Material from college campus. Number and size of pieces: 20 sap, 38 heart, ½x1x8 inches.

Average growth rings per inch: Sap, 5.7; heart, 6.7; Range 3 to 15.

The relative durability of the wood tested is rather high. The loss in strength is relatively great, however, as shown by the graph.

The sapwood was found to be equal in strength, on the average, to the heartwood and did not show as rapid a decline in strength due to decay as the heartwood. This result was evidently due to the clearer and straighter grain in all of the sapwood pieces. The highest individual strength test was exhibited by one piece of heartwood.

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