Smithsonian Center
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Harry A. Alden, Ph.D., Microscopist
And
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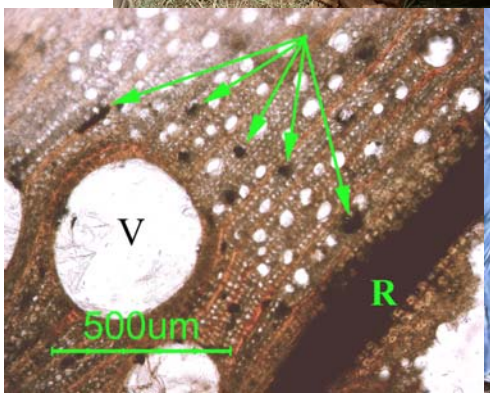

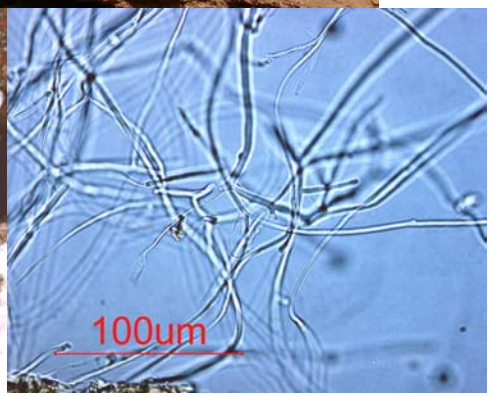

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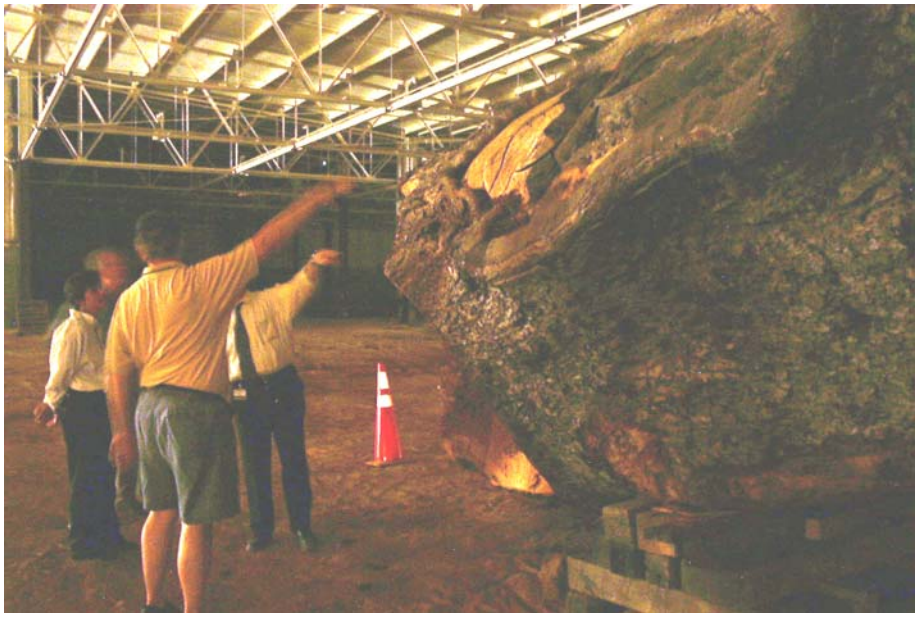
This is the preliminary report, produced 72 hours after the Wye Oak was transported to its current location, of the analysis and recommendations for its treatment and preservation. The final report will be submitted as soon as the wood samples from it have dried properly and mechanical-anatomical tests can be performed.

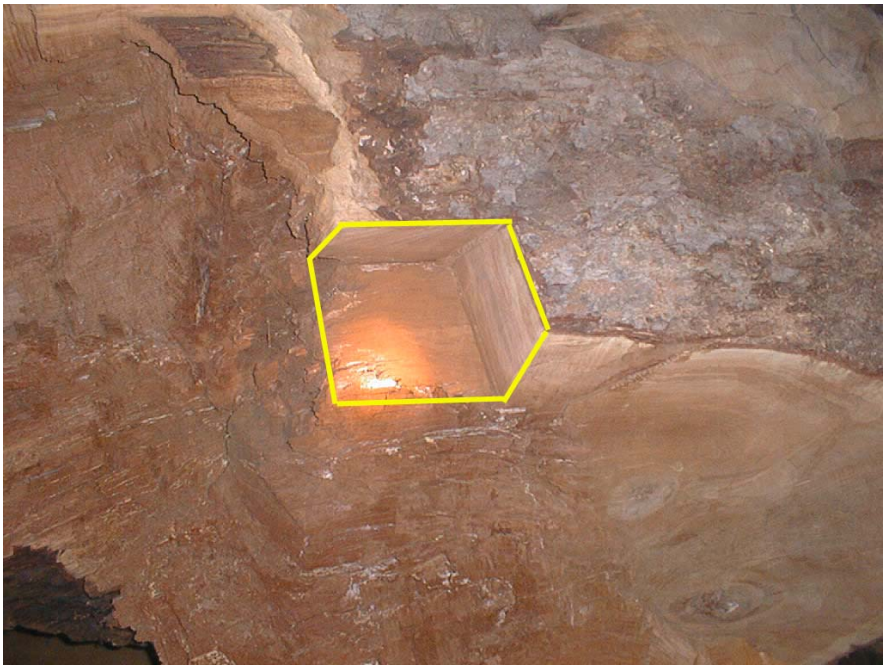


Dr. Harry Alden (SCMRE – foreground), discusses the extent of fungal damage to the butt section of the Wye Oak with Carolyn V. Watson (MD, DNR) and Thomas Schanno (MD, DGS).

Dr. Marion Mecklenberg (SCMRE , right, discusses soundness & checking of branch cuts with Stark McLaughlin (MD, DNR), left.

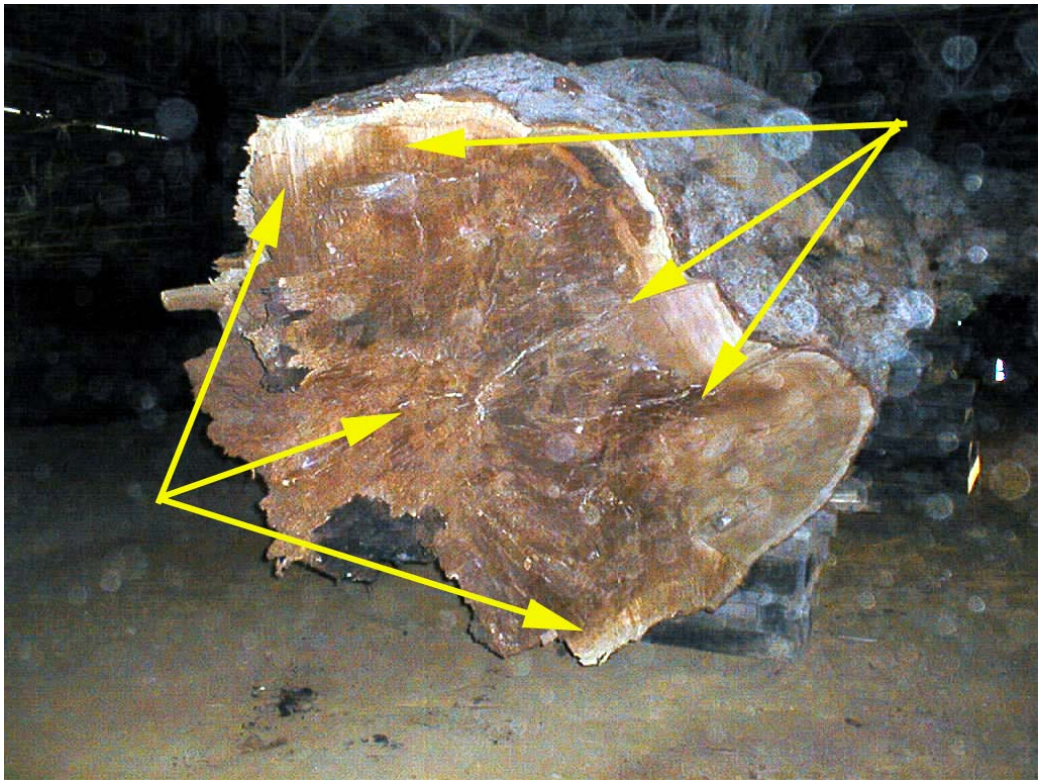
Microscopic analysis of wood from The Wye Oak

The wood from the Wye Oak (*Quercus alba*) has been evaluated on a microscopic level, to determine the extent of fungal penetration.



Area of sample taken for mechanical tests at SCMRE, about the size of a shoebox, containing both sound wood and brown-rot infected heartwood.

The sound heartwood and sapwood is comparable to all technical specifications of woods in the White Oak Group studied at the USDA Forest Products Laboratory (FPL), Madison, WI. A technical information sheet is provided in Appendix A.

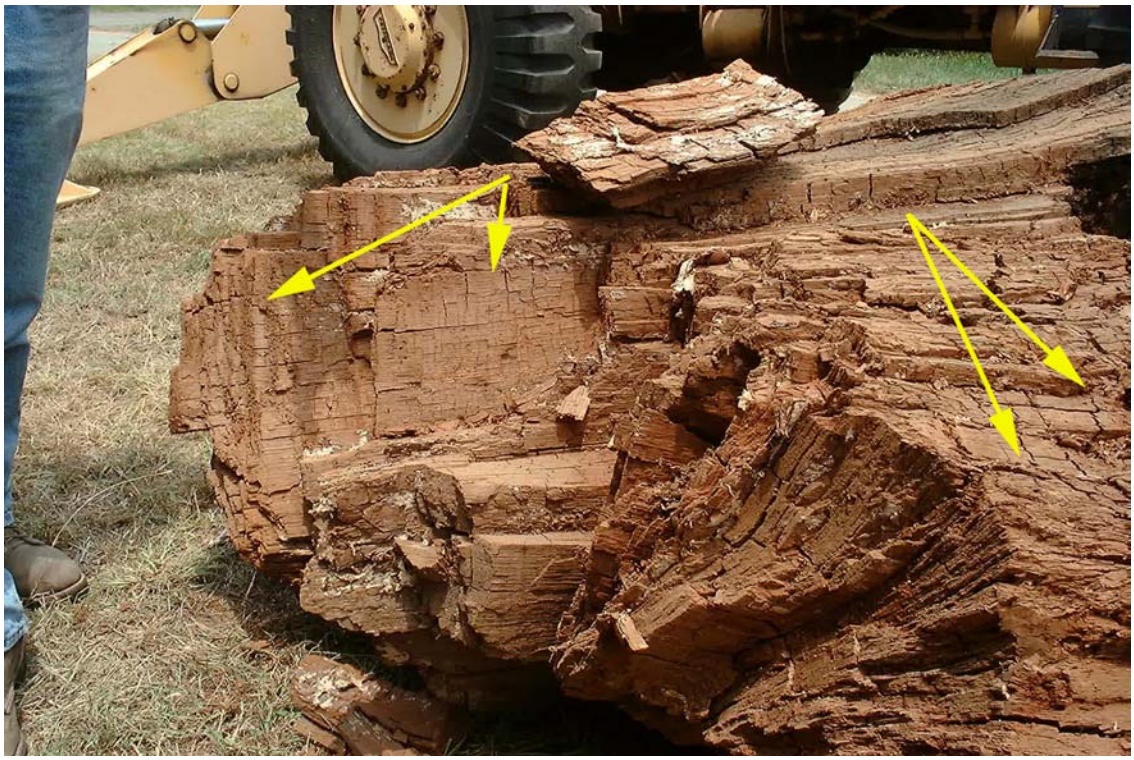


Broken base of the Wye Oak,
showing extensive infiltration of brown-rot fungus (between arrows).

The other areas of the bole that are a red brown color, with small white patches and that contain cracks are areas infiltrated by fungal hyphae (the white patches). There may be several types of fungi involved, but the main type is most likely brown rot, which is identified by the distinctive red brown color and the presence of cubiodal checks or cracks.

The microscopic structure (shown below, Figs. 1 – 4) validates this analysis. Most of the tissues of the wood (vessels or pores, rays and parenchyma) contain numerous fungal hyphae (black areas in the micrographs). One of the white patches was surgically removed and mounted on a microscope slide (Figs. 5 & 6) to reveal the micro-structure. This, along with sterile culture of the hyphae by a trained mycologist, should permit the identification of the fungus involved.

Sample of base of the Wye Oak completely infiltrated with brown-rot fungus.



Close-up of previous picture, showing fungal hyphae (white patches) and cubiodal checking (arrows) symptomatic of brown-rot infection.

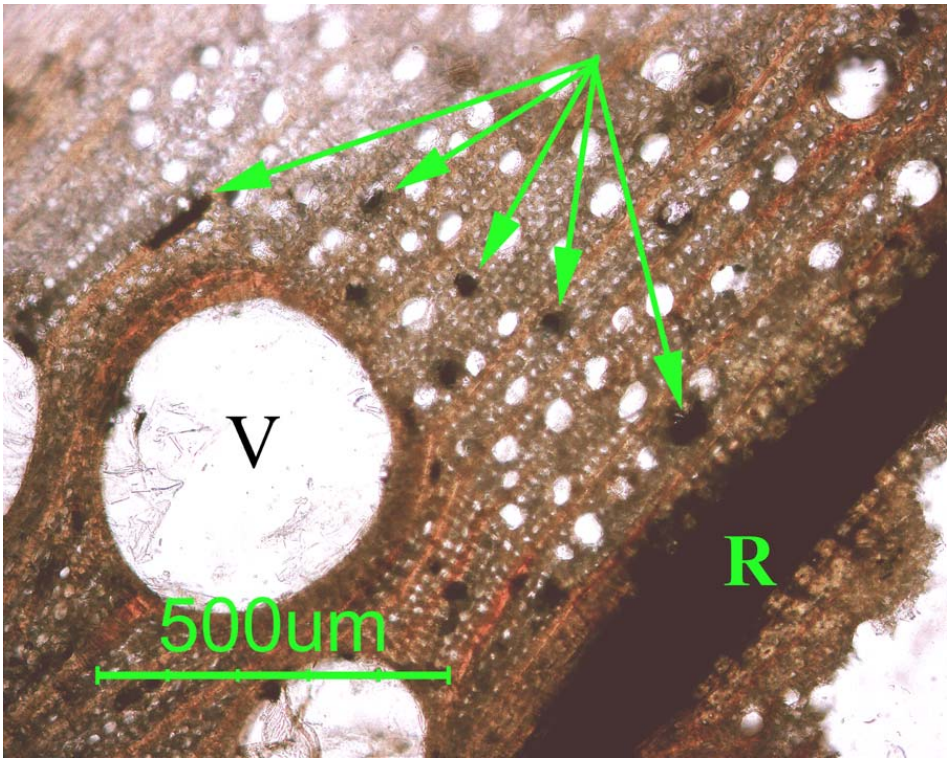


Figure 1. Cross section of wood from the Wye Oak, showing a wide ray (R), a large earlywood vessel (V) and numerous small latewood vessels occluded with fungal hyphae (arrows).

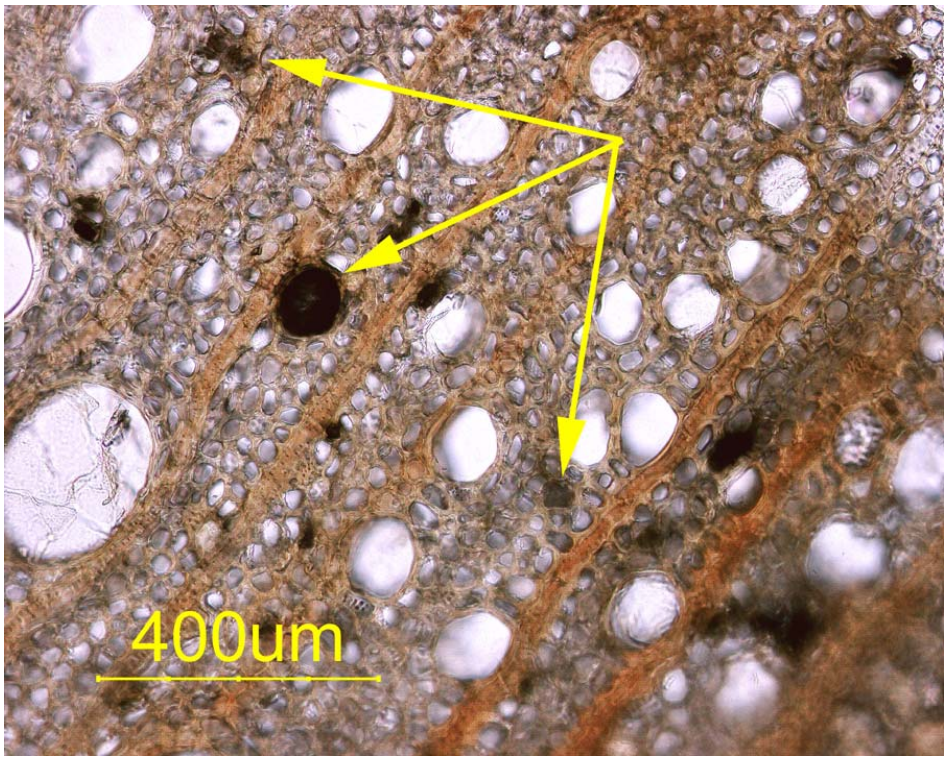


Figure 2. Cross section of wood from the Wye Oak, showing latewood vessels occluded with fungal hyphae (arrows).

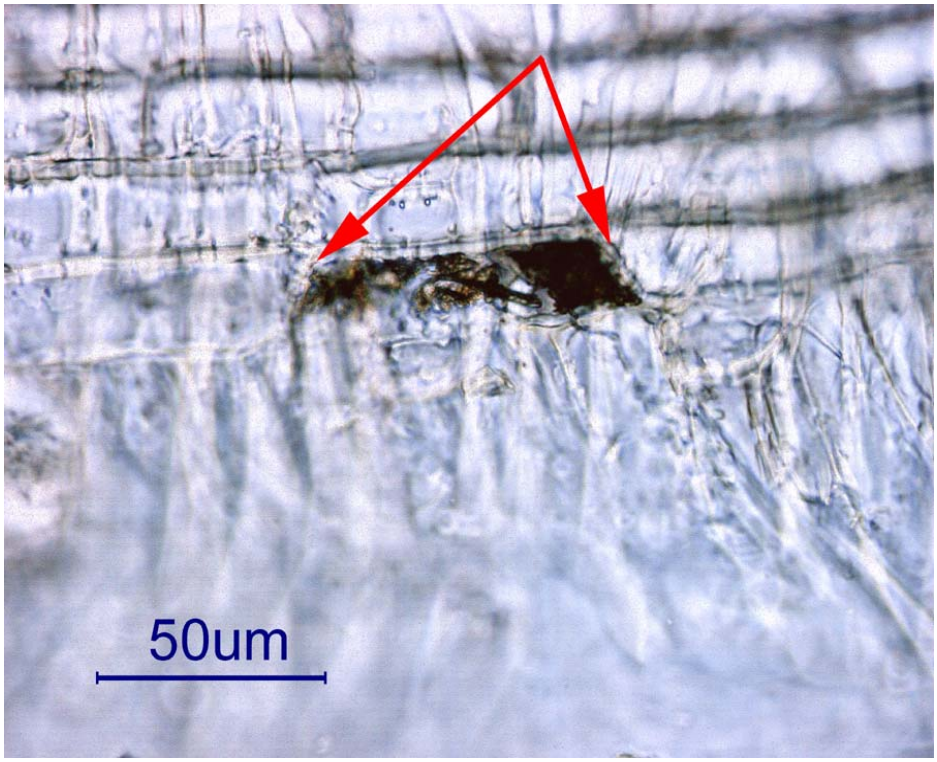


Figure 3. Radial section of wood from the Wye Oak, showing a ray parenchyma cell (arrows) packed with fungal hyphae.

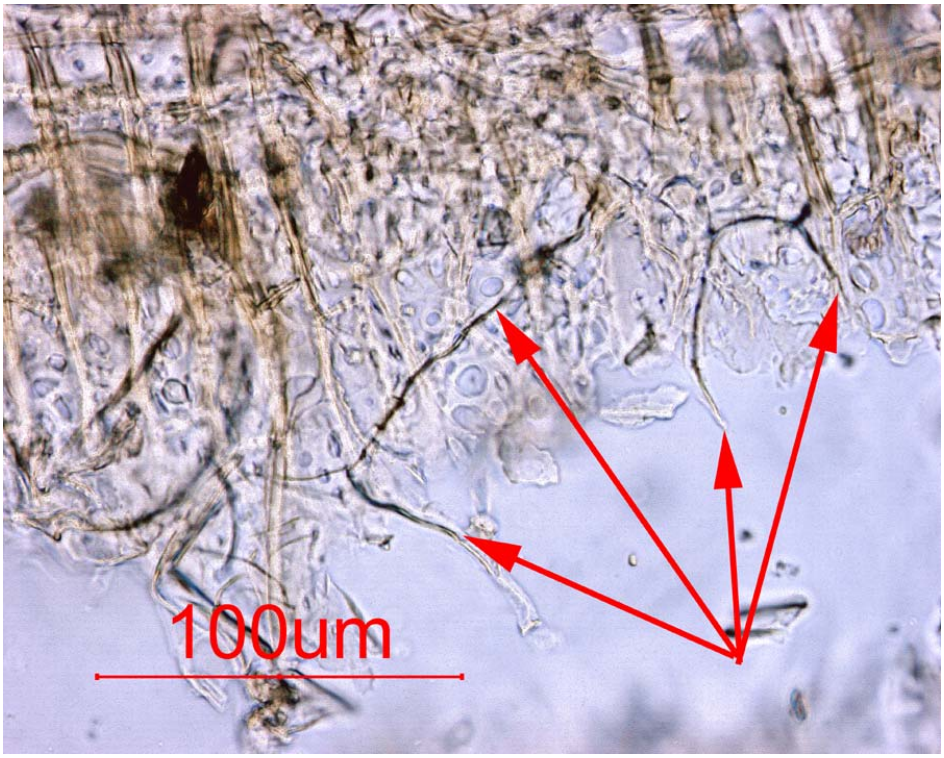


Figure 4. Radial section of wood from the Wye Oak, showing fungal hyphae distributed in a large earlywood vessel (arrows).

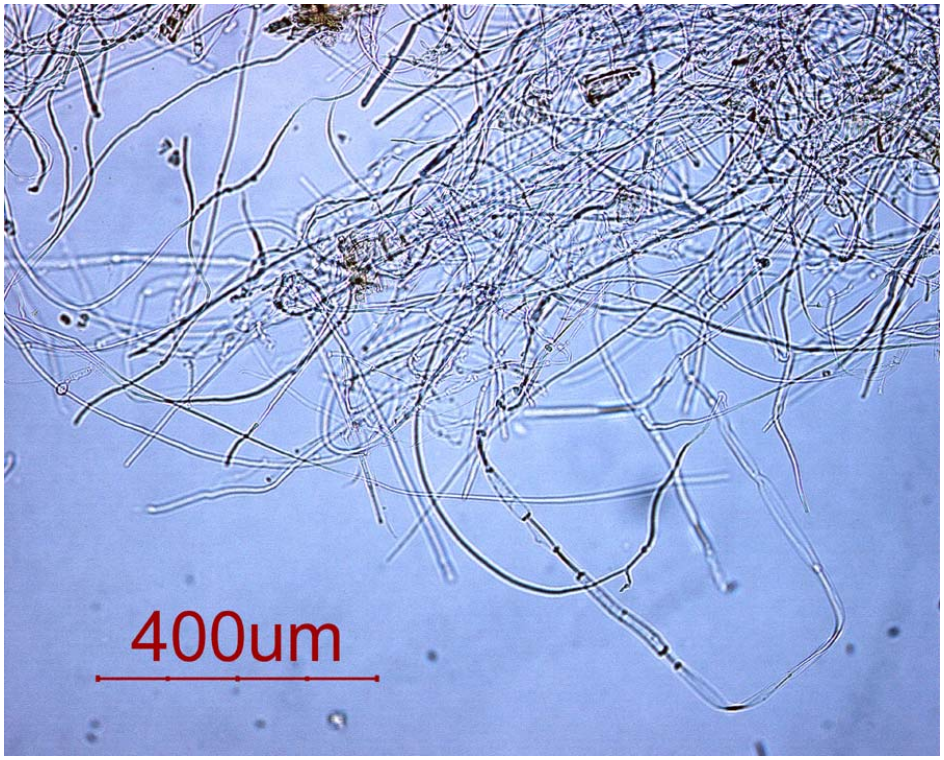


Figure 5. Isolated fungal hyphae taken from within wood from the Wye Oak.

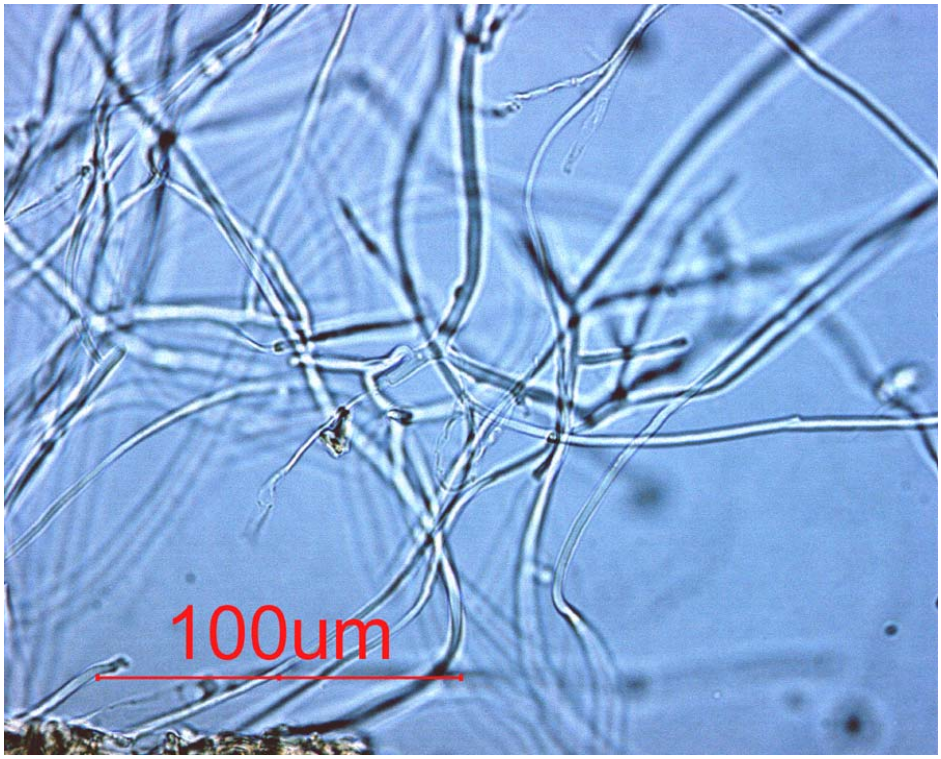
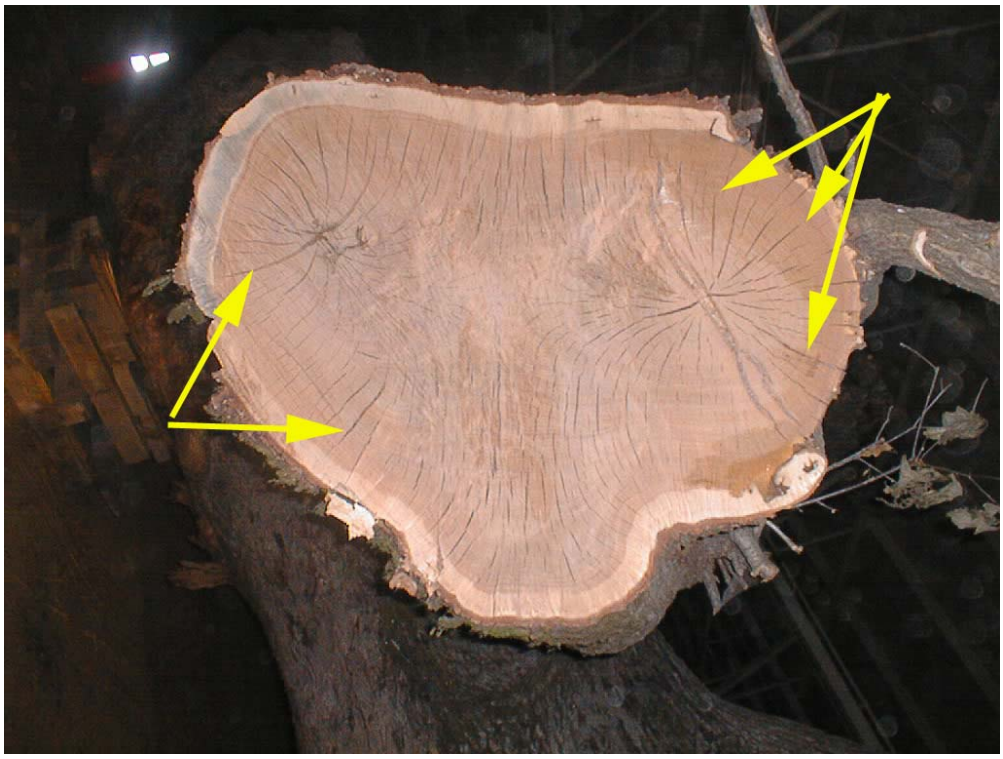


Figure 6. Isolated fungal hyphae taken from within wood from the Wye Oak.

Recommendations For Storage And Preservation
Of The Bole Of The Wye Oak

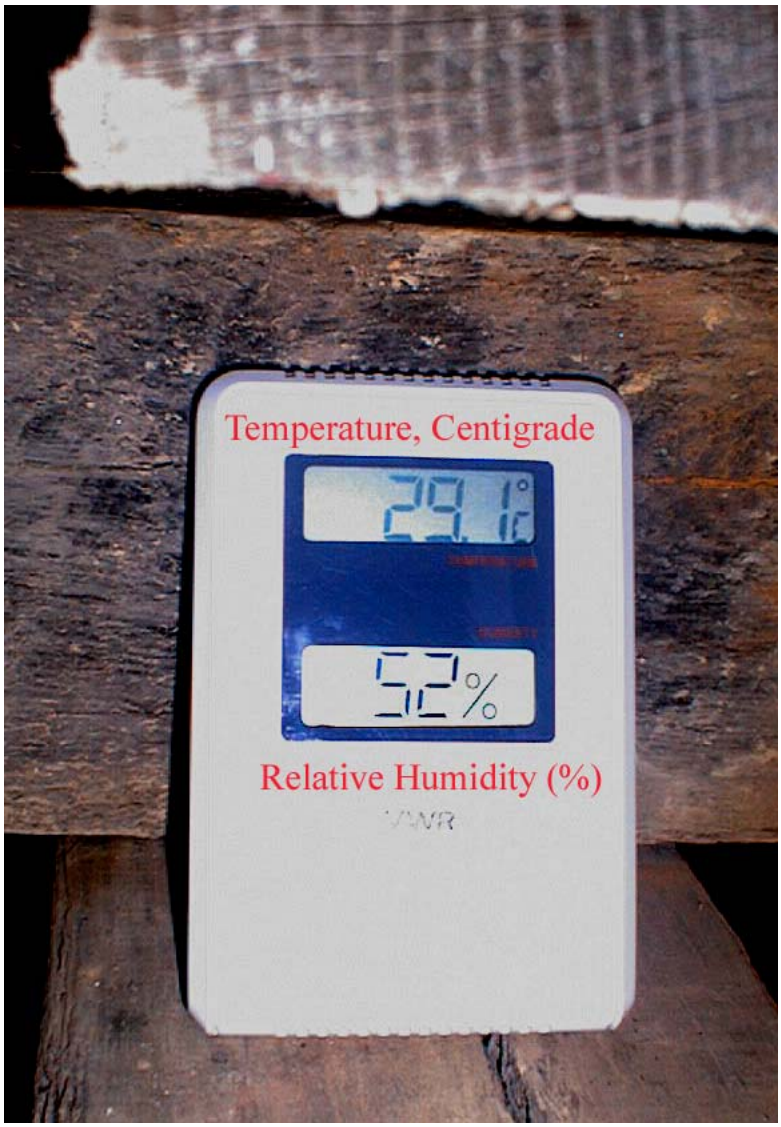
The real concern of the drying of the Wye Oak is the slow removal of the water from the green wood. If not controlled it will cause severe checking of the exposed end grain wood. This has already occurred to some extent at the places where the branches were either cut off or broken during the tree‘s fall.



Brach cut of main bole of the Wye Oak, showing extensive surface checking (arrows).

The loss of water to a point of equilibrium at an average Relative Humidity (RH) of 60% means a potential shrinkage of as much as 7%, which represent strains well in excess of the breaking strains of the wood in the tangential direction (Fig. 7). Cracking occurs simply as a consequence of the non-uniform removal of the water as it leaves wood through the end grain surface faster than in any other direction. “Capping” the exposed end grain will go a long way in reducing the non-uniform moisture loss. This can be done by using wax to seal the chainsaw cuts and by using heavy plastic sheeting taped to seal the exposed broken surfaces.

The current storage environment is actually ideal in most respects. The exposed earth floor and the relatively high water table actually serve to buffer the environment.



VWR monitoring device, showing temperature (29.1 ^{o}C – 84.4 ^{o}F) and relative humidity (52 %) in the storage building on the day of inspection.

When the heat in the building rises and the tendency for the ambient RH is to drop, additional moisture is "wicked" into the atmosphere from the floor. Conversely, cooling causes the ambient RH to rise and the floor begins to absorb the excess moisture. The average RH in the building over the year will remain about 55%-65%. The loss of moisture from the "capped" tree will be relatively slow. Perhaps between 10 to 20 years before 100% of the green water is removed.

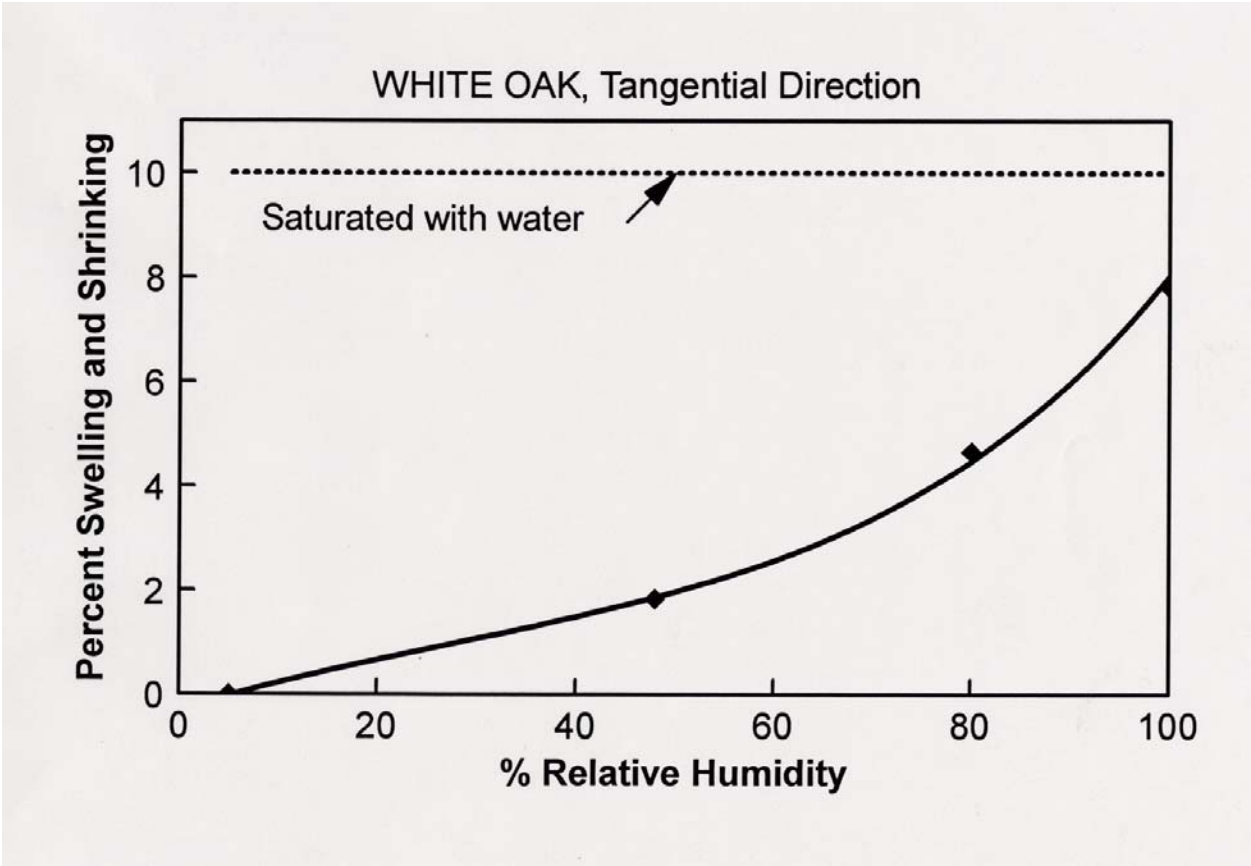


Figure 7. Moisture isotherm graph of White Oak (Quercus alba).

Appendix A: Technical Information Sheet
From: Alden, H. 1995. Hardwoods of North America.
USDA Forest Service. General Technical Report FPL-GTR-83.

Data for White Oak (*Quercus alba*) is highlighted in red.

***Quercus* spp.**
Fagaceae
Oak

Worldwide, the oaks (*Quercus* spp.) consist of 275 to 500 species that can be separated into three groups based on their microanatomy: the live or evergreen oak group, the red oak group *(Erythrobalanus)*, and the white oak group *(Leucobalanus)*. Species within each group look alike microscopically. The word *quercus* is the classical Latin name of oaks, said to be derived from Celtic fine and tree.

The commercial North American species are as follows:

Red Oak Group (*Erythrobalanus*)

Quercus coccinea	bastard oak, black oak, buck oak, red oak, **scarlet oak**, Spanish oak, spotted oak
Quercus falcata	American red oak, bottomland red oak, **cherrybark oak**, Elliott oak, red oak, Spanish oak, **southern red oak**, swamp red oak, swamp spanish oak, turkeyfoot oak, water oak
Quercus kelloggii	black oak, **California black oak**, Kellogg oak, mountain black oak
Quercus laurifolia	Darlington oak, diamond-leaf oak, **laurel oak**, laurel-leaf oak, swamp laurel oak, water oak, obtusa oak
Quercus nigra	American red oak, blackjack, pin oak, possum oak, punk oak, red oak, spotted oak, **water oak**
Quercus nuttallii	**nuttall oak**, pin oak, red oak, red river oak, striped oak
Quercus palustris	**pin oak**, red oak, Spanish oak, Spanish swamp oak, Spanish water oak, swamp oak, swamp Spanish oak, water oak
Quercus phellos	black oak, laurel oak, peach oak, pin oak, red oak, swamp willow oak, water oak, **willow oak**, willow swamp oak
Quercus rubra	American red oak, black oak, buck oak, Canadian red oak, common red oak, gray oak, eastern red oak, leopard oak, Maine red oak, mountain red oak, **northern red oak**, red oak, Spanish oak, spotted oak, southern red oak, swamp red oak, water oak, West Virginia soft red oak
Quercus shumardii	American red oak, Schneck oak, Schneck red oak, **shumard oak**, Shumard red oak, southern red oak, spotted bark, spotted oak, swamp red oak, Texas oak, Texas red oak
Quercus velutina	American red oak, blackjack, **black oak**, dyer oak, jack oak, quercitron, quercitron oak, redbush, red oak, smoothbark oak, spotted oak, tanbark oak, yellowbark, yellow oak, yellowbark oak

White Oak Group (*Leucobalanus*)

Quercus alba	American white oak, Arizona oak, Arizona white oak, forked-leaf white oak, Louisiana white oak, mantua oak, ridge white oak, stave oak, true white oak, West Virginia soft white oak, **white oak**
Quercus bicolor	blue oak, cherry oak, curly swamp oak, swamp oak, **swamp white oak**, white oak
Quercus garryana	Brewer oak, Garry oak, Oregon oak, **Oregon white oak**, Pacific post oak, Pacific white oak, post oak, prairie oak, shin oak, western oak, western white oak, white oak
Quercus lyrata	American white oak, **overcup oak**, swamp post oak, swamp white oak, water white oak
Quercus macrocarpa	blue oak, **bur oak**, burr oak, mossycup oak, mossy-overcup oak, overcup oak, scrub oak, white oak, white mossycup oak, white overcup oak
Quercus michauxii	American white oak, basket oak, cow oak, swamp oak, **swamp chestnut oak**
Quercus muehlenbergii	chestnut oak, **chinkapin oak**, chinquapin oak, dwarf chestnut oak, dwarf chinkapin, pin oak, rock oak, rock chestnut oak, running white oak, scrub oak, shrub oak, white oak, yellow oak, yellow chestnut oak
Quercus prinus	American white oak, basket oak, **chestnut oak**, chestnut rock oak, chestnut swamp oak, cow oak, mountain oak, rock oak, rock chestnut, rock chestnut oak, swamp oak, tanbark oak, white oak, white chestnut oak
Quercus stellata	American post oak, barren white oak, bastard oak, bastard white oak, box oak, box white oak, brash oak, Delta post oak, Durand oak, iron oak, pin oak **post oak**, ridge oak, rough oak, rough white oak, southern oak, turkey oak, white box oak, white oak
Live Oak Group	
Quercus virginiana	dwarf live oak, encino, **live oak**, rolfs oak, scrub live oak, Virginia live oak, Virginia oak

Distribution: Widely distributed throughout the United States.

The Tree: Oaks can reach a height of 125 ft (38 m), with large diameters.

General Wood Characteristics: The sapwood of oak is white to very light brown, while the heartwood is light to dark brown in the white oak group and reddish brown in the red oak group. Oak wood has a course texture; it is heavy, straight-grained, hard, tough, very stiff, and strong. Fast-grown oak, with wide rings, is stronger and heavier than slow-grown oak.

Weight[a]

Species	MC	SG	Weight lb/ft^3	Weight kg/m^3
Red Oak Group				
Quercus coccinea	Green	0.60	62	993
(scarlet oak)	12%	0.67	47	753
	Ovendry	0.71	NA	NA
Quercus falcata	Green	0.52	62	993
(southern red oak)	12%	0.59	41	657
	Ovendry	0.62	NA	NA
Quercus falcata var. *pagodifolia*	Green	0.61	68	1,089
(cherrybark oak)	12%	0.68	47	753
	Ovendry	0.71	NA	NA
Quercus laurifolia	Green	0.56	65	1,041
(laurel oak)	12%	0.63	44	705
	Ovendry	0.70	NA	NA
Quercus nigra	Green	0.56	63	1,009
(water oak)	12%	0.63	44	705
	Ovendry	0.68	NA	NA
Quercus palustris	Green	0.58	63	1,009
(pin oak)	12%	0.63	44	705
	Ovendry	0.68	NA	NA
Quercus phellos	Green	0.56	67	1073
(willow oak)	12%	0.69	48	769
	Ovendry	0.69	NA	NA
Quercus rubra	Green	0.56	63	1,009
(northern red oak)	12%	0.63	44	705
	Ovendry	0.66	NA	NA
Quercus velutina	Green	0.56	62	993
(black oak)	12%	0.61	43	689
	Ovendry	0.67	NA	NA
White Oak Group				
Quercus alba	Green	0.60	62	993
(white oak)	12%	0.68	48	769
	Ovendry	0.71	NA	NA
Quercus bicolor	Green	0.64	69	1,105
(swamp white oak)	12%	0.72	50	801
	Ovendry	0.79	NA	NA
Quercus garryana	Green	0.64	69	1,105
(Oregon white oak)	12%	0.72	50	801
	Ovendry	0.75	NA	NA
Quercus lyrata	Green	0.57	NA	NA
(overcup oak)	12%	0.63	NA	NA
	Ovendry	NA	NA	NA
Quercus macrocarpa	Green	0.58	62	993
(bur oak)	12%	0.64	45	721
	Ovendry	0.67	NA	NA
Quercus michauxii	Green	0.60	65	1,041
(swamp chestnut oak)	12%	0.67	47	753
	Ovendry	0.76	NA	NA
Quercus prinus	Green	0.57	61	977
(chestnut oak)	12%	0.66	46	737
	Ovendry	0.67	NA	NA
Quercus stellata	Green	0.60	63	1,009
(post oak)	12%	0.67	47	753
	Ovendry	0.74	NA	NA

Live Oak Group

Quercus virginiana	Green	0.80	76	1,218
(live oak)	12%	0.88	62	993
	Ovendry	0.98	NA	NA

[a]References: specific gravity, green and 12%, (98), except for *Q. garryana* (59); specific gravity, ovendry, (59); weight, (59).

Mechanical properties[a]

Property	Green		Dry	
Red Oak Group				
Quercus coccinea (scarlet oak)				
MOE	1.48×10^6 lbf/in^2	10.204 GPa	1.91×10^6 lbf/in^2	13.169 GPa
MOR	10.4×10^3 lbf/in^2	71.708 MPa	17.4×10^3 lbf/in^2	119.973 MPa
$C_{\parallel}$	4.09×10^3 lbf/in^2	28.201 MPa	8.33×10^3 lbf/in^2	57.435 MPa
$C_{\perp}$	0.83×10^3 lbf/in^2	5.723 MPa	1.12×10^3 lbf/in^2	7.722 MPa
WML	15.0 in-lbf/in^3	103.425 kJ/m^3	20.5 in-lbf/in^3	141.348 kJ/m^3
Hardness	1,200 lbf	5,337.60 N	1,400 lbf	6,227.20 N
$Shear_{\parallel}$	1.41×10^3 lbf/in^2	9.722 MPa	1.89×10^3 lbf/in^2	13.031 MPa
Quercus falcata (southern red oak)				
MOE	1.14×10^6 lbf/in^2	7.860 GPa	1.49×10^6 lbf/in^2	10.274 GPa
MOR	6.90×10^3 lbf/in^2	47.576 MPa	10.9×10^3 lbf/in^2	75.156 MPa
$C_{\parallel}$	3.03×10^3 lbf/in^2	20.892 MPa	6.09×10^3 lbf/in^2	41.991 MPa
$C_{\perp}$	0.55×10^3 lbf/in^2	3.792 MPa	0.87×10^3 lbf/in^2	5.999 MPa
WML	8.0 in-lbf/in^3	55.160 kJ/m^3	9.4 in-lbf/in^3	64.813 kJ/m^3
Hardness	860 lbf	3,825.28 N	1,060 lbf	4,714.88 N
$Shear_{\parallel}$	0.93×10^3 lbf/in^2	6.412 MPa	1.39×10^3 lbf/in^2	9.584 MPa
Quercus falcata var. *pagodifolia* (cherrybark oak)				
MOE	1.79×10^6 lbf/in^2	12.342 GPa	2.28×10^6 lbf/in^2	15.721 GPa
MOR	10.8×10^3 lbf/in^2	74.466 MPa	18.1×10^3 lbf/in^2	124.800 MPa
$C_{\parallel}$	4.62×10^3 lbf/in^2	31.855 MPa	8.74×10^3 lbf/in^2	60.262 MPa
$C_{\perp}$	0.76×10^3 lbf/in^2	5.240 MPa	1.25×10^3 lbf/in^2	8.619 MPa
WML	14.7 in-lbf/in^3	101.357 kJ/m^3	18.3 in-lbf/in^3	126.179 kJ/m^3
Hardness	1,240 lbf	5,515.52 N	1,480 lbf	6,583.04 N
$Shear_{\parallel}$	1.32×10^3 lbf/in^2	9.101 MPa	2.00×10^3 lbf/in^2	13.790 MPa
Quercus laurifolia (laurel oak)				
MOE	1.39×10^6 lbf/in^2	9.584 GPa	1.69×10^6 lbf/in^2	11.653 GPa
MOR	7.90×10^3 lbf/in^2	54.471 MPa	12.6×10^3 lbf/in^2	86.877 MPa
$C_{\parallel}$	3.17×10^3 lbf/in^2	21.857 MPa	6.98×10^3 lbf/in^2	48.127 MPa
$C_{\perp}$	0.57×10^3 lbf/in^2	3.930 MPa	1.06×10^3 lbf/in^2	7.309 MPa
WML	11.2 in-lbf/in^3	77.224 kJ/m^3	11.8 in-lbf/in^3	81.361 kJ/m^3
Hardness	1,000 lbf	4,448.00 N	1,210 lbf	5,382.08 N
$Shear_{\parallel}$	1.18×10^3 lbf/in^2	8.136 MPa	1.83×10^3 lbf/in^2	12.617 MPa
Quercus nigra (water oak)				
MOE	1.55×10^6 lbf/in^2	10.687 GPa	2.02×10^6 lbf/in^2	13.928 GPa
MOR	8.90×10^3 lbf/in^2	61.366 MPa	15.4×10^3 lbf/in^2	106.183 MPa
$C_{\parallel}$	3.74×10^3 lbf/in^2	25.787 MPa	6.77×10^3 lbf/in^2	46.679 MPa
$C_{\perp}$	0.62×10^3 lbf/in^2	4.275 MPa	1.02×10^3 lbf/in^2	7.033 MPa
WML	11.1 in-lbf/in^3	76.535 kJ/m^3	21.5 in-lbf/in^3	148.243 kJ/m^3

Hardness	1,010 lbf	4,492.48 N	1,190 lbf	5,293.12 N
Shear$_{\parallel}$	1.24 $\times 10^6$ lbf/in^2	8.549 MPa	2.02 $\times 10^3$ lbf/in^2	13.927 MPa
Quercus palustris (pin oak)				
MOE	1.32 $\times 10^6$ lbf/in^2	9.101 GPa	1.73 $\times 10^6$ lbf/in^2	11.928 GPa
MOR	8.30 $\times 10^3$ lbf/in^2	57.229 MPa	14.0 $\times 10^3$ lbf/in^2	96.530 MPa
C$_{\parallel}$	3.68 $\times 10^3$ lbf/in^2	25.374 MPa	6.82 $\times 10^3$ lbf/in^2	47.024 MPa
C$_{\perp}$	0.72 $\times 10^3$ lbf/in^2	4.964 MPa	1.02 $\times 10^3$ lbf/in^2	7.033 MPa
WML	14.0 in-lbf/in^3	96.530 kJ/m^3	14.8 in-lbf/in^3	102.046 kJ/m^3
Hardness	1,070 lbf	4,759.36 N	1,510 lbf	6,716.48 N
Shear$_{\parallel}$	1.29 $\times 10^3$ lbf/in^2	8.894 MPa	2.08 $\times 10^3$ lbf/in^2	14.341 MPa
Quercus phellos (willow oak)				
MOE	1.29 $\times 10^6$ lbf/in^2	8.894 GPa	1.90 $\times 10^6$ lbf/in^2	13.101 GPa
MOR	7.40 $\times 10^3$ lbf/in^2	51.023 MPa	14.5 $\times 10^3$ lbf/in^2	99.978 MPa
C$_{\parallel}$	3.00 $\times 10^3$ lbf/in^2	20.685 MPa	7.04 $\times 10^3$ lbf/in^2	48.541 MPa
C$_{\perp}$	0.61 $\times 10^3$ lbf/in^2	4.206 MPa	1.13 $\times 10^3$ lbf/in^2	7.791 MPa
WML	8.8 in-lbf/in^3	60.676 kJ/m^3	14.6 in-lbf/in^3	100.667 kJ/m^3
Hardness	980 lbf	4,359.04 N	1,460 lbf	6,494.08 N
Shear$_{\parallel}$	1.18 $\times 10^3$ lbf/in^2	8.136 MPa	1.65 $\times 10^3$ lbf/in^2	11.376 MPa
Quercus rubra (northern red oak)				
MOE	1.35 $\times 10^6$ lbf/in^2	9.308 GPa	1.82 $\times 10^6$ lbf/in^2	12.549 GPa
MOR	8.30 $\times 10^3$ lbf/in^2	57.229 MPa	14.3 $\times 10^3$ lbf/in^2	98.599 MPa
C$_{\parallel}$	3.44 $\times 10^3$ lbf/in^2	23.719 MPa	6.76 $\times 10^3$ lbf/in^2	46.610 MPa
C$_{\perp}$	0.61 $\times 10^3$ lbf/in^2	4.206 MPa	1.01 $\times 10^3$ lbf/in^2	6.964 MPa
WML	13.2 in-lbf/in^3	91.014 kJ/m^3	14.5 in-lbf/in^3	99.978 kJ/m^3
Hardness	1,000 lbf	4,448.00 N	1,290 lbf	5,737.92 N
Shear$_{\parallel}$	1.21 $\times 10^3$ lbf/in^2	8.343 MPa	1.78 $\times 10^3$ lbf/in^2	12.273 MPa
Quercus velutina (black oak)				
MOE	1.18 $\times 10^6$ lbf/in^2	8.136 GPa	1.64 $\times 10^6$ lbf/in^2	11.308 GPa
MOR	8.20 $\times 10^3$ lbf/in^2	56.539 MPa	13.9 $\times 10^3$ lbf/in^2	95.841 MPa
C$_{\parallel}$	3.47 $\times 10^3$ lbf/in^2	23.926 MPa	6.52 $\times 10^3$ lbf/in^2	44.955 MPa
C$_{\perp}$	0.71 $\times 10^3$ lbf/in^2	4.895 MPa	0.93 $\times 10^3$ lbf/in^2	6.412 MPa
WML	12.2 in-lbf/in^3	84.119 kJ/m^3	13.7 in-lbf/in^3	94.462 kJ/m^3
Hardness	1,060 lbf	4,714.88 N	1,210 lbf	5,382.08 N
Shear$_{\parallel}$	1.20 $\times 10^3$ lbf/in^2	8.274 MPa	1.91 $\times 10^3$ lbf/in^2	13.169 MPa
White Oak Group (*Leucobalanus*)				
Quercus alba (white oak)				
MOE	1.25 $\times 10^6$ lbf/in^2	8.618 GPa	1.78 $\times 10^6$ lbf/in^2	12.273 GPa
MOR	8.30 $\times 10^3$ lbf/in^2	57.229 MPa	15.2 $\times 10^3$ lbf/in^2	104.804 MPa
C$_{\parallel}$	3.56 $\times 10^3$ lbf/in^2	24.546 MPa	7.44 $\times 10^3$ lbf/in^2	51.299 MPa
C$_{\perp}$	0.67 $\times 10^3$ lbf/in^2	4.620 MPa	1.07 $\times 10^3$ lbf/in^2	7.378 MPa
WML	11.6 in-lbf/in^3	79.982 kJ/m^3	14.8 in-lbf/in^3	102.046 kJ/m^3
Hardness	1,060 lbf	4,714.88 N	1,360 lbf	6,049.28 N
Shear$_{\parallel}$	1.25 $\times 10^3$ lbf/in^2	8.618 MPa	2.00 $\times 10^3$ lbf/in^2	13.790 MPa
Quercus bicolor (swamp white oak)				
MOE	1.59 $\times 10^6$ lbf/in^2	10.963 GPa	2.05 $\times 10^6$ lbf/in^2	14.135 GPa
MOR	9.90 $\times 10^3$ lbf/in^2	68.261 MPa	17.7 $\times 10^3$ lbf/in^2	122.042 MPa
C$_{\parallel}$	4.36 $\times 10^3$ lbf/in^2	30.062 MPa	8.60 $\times 10^3$ lbf/in^2	59.297 MPa
C$_{\perp}$	0.76 $\times 10^3$ lbf/in^2	5.240 MPa	1.19 $\times 10^3$ lbf/in^2	8.205 MPa
WML	14.5 in-lbf/in^3	99.978 kJ/m^3	19.2 in-lbf/in^3	132.384 kJ/m^3
Hardness	1,160 lbf	5,159.68 N	1,620 lbf	7,205.76 N

Shear$_{\parallel}$	1.30 $\times 10^3$ lbf/in^2	8.963 MPa	2.00 $\times 10^3$ lbf/in^2	13.790 MPa
Quercus lyrata (overcup oak)				
MOE	1.15 $\times 10^6$ lbf/in^2	7.929 GPa	1.42 $\times 10^6$ lbf/in^2	9.791 GPa
MOR	8.00 $\times 10^3$ lbf/in^2	55.160 MPa	12.6 $\times 10^3$ lbf/in^2	86.877 MPa
$C_{\parallel}$	3.37 $\times 10^3$ lbf/in^2	23.236 MPa	6.20 $\times 10^3$ lbf/in^2	42.749 MPa
$C_{\perp}$	0.54 $\times 10^3$ lbf/in^2	3.723 MPa	0.81 $\times 10^3$ lbf/in^2	5.585 MPa
WML	12.6 in-lbf/in^3	86.877 kJ/m^3	15.7 in-lbf/in^3	108.252 kJ/m^3
Hardness	960 lbf	4,270.08 N	1,190 lbf	5,293.12 N
Shear$_{\parallel}$	1.32 $\times 10^3$ lbf/in^2	9.101 MPa	2.00 $\times 10^3$ lbf/in^2	13.790 MPa

Mechanical properties—con.

Property	Green		Dry	
Quercus macrocarpa (bur oak)				
MOE	0.88 $\times 10^6$ lbf/in^2	6.067 GPa	1.03 $\times 10^6$ lbf/in^2	7.102 GPa
MOR	7.20 $\times 10^3$ lbf/in^2	49.644 MPa	10.3 $\times 10^3$ lbf/in^2	71.019 MPa
$C_{\parallel}$	3.29 $\times 10^3$ lbf/in^2	22.685 MPa	6.06 $\times 10^3$ lbf/in^2	41.784 MPa
$C_{\perp}$	0.68 $\times 10^3$ lbf/in^2	4.689 MPa	1.20 $\times 10^3$ lbf/in^2	8.274 MPa
WML	10.7 in-lbf/in^3	73.777 kJ/m^3	9.8 in-lbf/in^3	67.571 kJ/m^3
Hardness	1,110 lbf	4,937.28 N	1,370 lbf	6,093.76 N
Shear$_{\parallel}$	1.35 $\times 10^3$ lbf/in^2	9.308 MPa	1.82 $\times 10^3$ lbf/in^2	12.548 MPa
Quercus michauxii (swamp chestnut oak)				
MOE	1.35 $\times 10^6$ lbf/in^2	9.308 GPa	1.77 $\times 10^6$ lbf/in^2	12.204 GPa
MOR	8.50 $\times 10^3$ lbf/in^2	58.608 MPa	13.9 $\times 10^3$ lbf/in^2	95.841 MPa
$C_{\parallel}$	3.54 $\times 10^3$ lbf/in^2	24.408 MPa	7.27 $\times 10^3$ lbf/in^2	50.127 MPa
$C_{\perp}$	0.57 $\times 10^3$ lbf/in^2	3.930 MPa	1.11 $\times 10^3$ lbf/in^2	7.653 MPa
WML	12.8 in-lbf/in^3	88.256 kJ/m^3	12.0 in-lbf/in^3	82.740 kJ/m^3
Hardness	1,110 lbf	4,937.28 N	1,240 lbf	5,515.52 N
Shear$_{\parallel}$	1.26 $\times 10^3$ lbf/in^2	8.687 MPa	1.99 $\times 10^3$ lbf/in^2	13.721 MPa
Quercus prinus (chestnut oak)				
MOE	1.37 $\times 10^6$ lbf/in^2	9.446 GPa	1.59 $\times 10^6$ lbf/in^2	10.963 GPa
MOR	8.00 $\times 10^3$ lbf/in^2	55.160 MPa	13.3 $\times 10^3$ lbf/in^2	91.704 MPa
$C_{\parallel}$	3.52 $\times 10^3$ lbf/in^2	24.270 MPa	6.83 $\times 10^3$ lbf/in^2	47.093 MPa
$C_{\perp}$	0.53 $\times 10^3$ lbf/in^2	3.654 MPa	0.84 $\times 10^3$ lbf/in^2	5.792 MPa
WML	9.4 in-lbf/in^3	64.813 kJ/m^3	11.0 in-lbf/in^3	75.845 kJ/m^3
Hardness	890 lbf	3,958.72 N	1,130 lbf	5,026.24 N
Shear$_{\parallel}$	1.21 $\times 10^3$ lbf/in^2	8.343 MPa	1.49 $\times 10^3$ lbf/in^2	10.273 MPa
Quercus stellata (post oak)				
MOE	1.09 $\times 10^6$ lbf/in^2	7.515 GPa	1.51 $\times 10^6$ lbf/in^2	10.411 GPa
MOR	8.10 $\times 10^3$ lbf/in^2	55.850 MPa	13.2 $\times 10^3$ lbf/in^2	91.014 MPa
$C_{\parallel}$	3.48 $\times 10^3$ lbf/in^2	23.995 MPa	6.60 $\times 10^3$ lbf/in^2	45.507 MPa
$C_{\perp}$	0.86 $\times 10^3$ lbf/in^2	5.930 MPa	1.43 $\times 10^3$ lbf/in^2	9.860 MPa
WML	11.0 in-lbf/in^3	75.845 kJ/m^3	13.2 in-lbf/in^3	91.014 kJ/m^3
Hardness	1,130 lbf	5,026.24 N	1,360 lbf	6,049.28 N
Shear$_{\parallel}$	1.28 $\times 10^3$ lbf/in^2	8.825 MPa	1.84 $\times 10^3$ lbf/in^2	12.686 MPa
Live Oak Group				
Quercus virginiana (live oak)				
MOE	1.58 $\times 10^6$ lbf/in^2	10.894 GPa	1.98 $\times 10^6$ lbf/in^2	13.652 GPa
MOR	11.9 $\times 10^3$ lbf/in^2	82.051 MPa	18.4 $\times 10^3$ lbf/in^2	126.868 MPa
$C_{\parallel}$	5.43 $\times 10^3$ lbf/in^2	37.440 MPa	8.90 $\times 10^3$ lbf/in^2	61.366 MPa
$C_{\perp}$	2.04 $\times 10^3$ lbf/in^2	14.066 MPa	2.84 $\times 10^3$ lbf/in^2	19.582 MPa

WML	12.3 in-lbf/in^3	84.809 kJ/m^3	18.9 in-lbf/in^3	130.316 kJ/m^3
Hardness	NA	NA	NA	NA
Shear$_{\|\|}$	2.21 $\times 10^3$ lbf/in^2	15.237 MPa	2.66 $\times 10^3$ lbf/in^2	18.340 Mpa

[a]Reference (98).

Drying and shrinkage[a]

Type of shrinkage	Percentage of shrinkage (green to final moisture content) 0% MC	6% MC	20% MC
Tangential			
Red Oak Group			
Quercus coccinea (scarlet oak)	10.8	7.8	3.2
Quercus falcata (southern red oak)	11.3	NA	NA
Quercus falcata var. *pagodifolia* (cherrybark oak)	10.6	NA	NA
Quercus laurifolia (laurel oak)	9.9	NA	NA
Quercus nigra (water oak)	9.8	7.4	3.1
Quercus palustris (pin oak)	9.5	7.6	3.2
Quercus phellos (willow oak)	9.6	NA	NA
Quercus rubra (northern red oak)	8.6	6.6	2.7
Quercus velutina (black oak)	11.1	7.8	3.2
White Oak Group			
Quercus alba (white oak)	10.5	7.2	3.0
Quercus bicolor (swamp white oak)	NA	NA	NA
Quercus lyrata (overcup oak)	12.7	NA	NA
Quercus macrocarpa (bur oak)	8.8	7.0	2.9
Quercus michauxii (swamp chestnut oak)	10.8	8.6	3.6
Quercus prinus (chestnut oak)	10.8	7.8	3.2
Quercus stellata (post oak)	9.8	7.8	3.3
Live Oak Group			
Quercus virginiana (live oak)	9.5	7.6	3.2
Radial			
Red Oak Group			
Quercus coccinea (scarlet oak)	4.4	3.7	1.5
Quercus falcata (southern red oak)	4.7	NA	NA
Quercus falcata var. *pagodifolia* (cherrybark oak)	5.5[b]	NA	NA
Quercus laurifolia (laurel oak)	4.0	NA	NA
Quercus nigra (water oak)	4.4	3.4	1.4
Quercus palustris (pin oak)	4.3	3.4	1.4
Quercus phellos (willow oak)	5.0	NA	NA
Quercus rubra (northern red oak)	4.0	3.2	1.3
Quercus velutina (black oak)	4.4	3.6	1.5
White Oak Group			
Quercus alba (white oak)	5.6	4.2	1.8
Quercus bicolor (swamp white oak)	NA	NA	NA
Quercus lyrata (overcup oak)	5.3	NA	NA
Quercus macrocarpa (bur oak)	4.4	3.5	1.5
Quercus michauxii (swamp chestnut oak)	5.2	4.2	1.7
Quercus prinus (chestnut oak)	5.3	4.4	1.8
Quercus stellata (post oak)	5.4	4.3	1.8
Live Oak Group			
Quercus virginiana (live oak)	6.6	5.3	2.2

Drying and shrinkage—con.

Type of shrinkage	Percentage of shrinkage (green to final moisture content)		
	0% MC	6% MC	20% MC
Volumetric			
Red Oak Group			
Quercus coccinea (scarlet oak)	14.7	11.0	4.6
Quercus falcata (southern red oak)	16.1	NA	NA
Quercus falcata var. *pagodifolia* (cherrybark oak)	16.1	NA	NA
Quercus laurifolia (laurel oak)	19.0	NA	NA
Quercus nigra (water oak)	16.1	13.1	5.5
Quercus palustris (pin oak)	14.5	11.6	4.8
Quercus phellos (willow oak)	18.9	NA	NA
Quercus rubra (northern red oak)	13.7	10.8	4.5
Quercus velutina (black oak)	15.1	11.4	4.7
White Oak Group			
Quercus alba (white oak)	16.3	12.6	5.3
Quercus bicolor (swamp white oak)	NA	NA	NA
Quercus lyrata (overcup oak)	16.0	NA	NA
Quercus macrocarpa (bur oak)	12.7	10.2	4.2
Quercus michauxii (swamp chestnut oak)	16.4	13.1	5.5
Quercus prinus (chestnut oak)	16.4	13.4	5.6
Quercus stellata (post oak)	16.2	13.0	5.4
Live Oak Group			
Quercus virginiana (live oak)	14.7	11.8	4.9

[a]References: 0% MC, (98); 6% and 20%, (90).
[b]Reference (90).

Kiln drying schedule[a]

Species	4/4, 5/4, 6/4 stock	8/4 stock	10/4 stock	12/4 stock	16/4 stock
Western oaks[b]	T3-B1	T3-B1	NA	NA	NA
Upland red oaks[c]	T4-D2	T3-D1	T3-C1	T3-C1	NA
Lowland red oaks[d]	T2-C1	Table 113	NA	NA	NA
Upland white oaks[e]	T4-C2	T3-C1	T3-B1	T3-B1	NA
Lowland white oaks[f]	T2-C1	Table 113	NA	NA	NA

[a]References (6, 86).
[b]California black, Oregon white, canyon live.
[c]Black, blackjack, cherrybark, northern pin, northern red, scarlet, Schumard, southern red, turkey, water.
[d]Cherrybark, laurel, nuttall, pin, Shumard, water, willow.
[e]Blue, bur, chestnut, chinkapin, Emory, Gambel, Mexican blue, post, white.
[f]Bur, live, overcup, swamp chestnut, swamp white, white.

Working Properties: Oak wood has good working properties. It machines and glues well and holds fasteners extremely well. It tends to split when nailed, unless predrilled. Oak finishes well, but shrinks considerably.

Durability: The oaks are rated with respect to resistance to heartwood decay as follows (98):

Very resistant	bur oak, chestnut oak, Gambel oak, Oregon oak, post oak and white oak
Moderately resistant	swamp chestnut oak
Slightly to nonresistant	black oak and red oak

Preservation: The heartwood of the white oak group is resistant to impregnation with preservatives, whereas that of the red oak group is more easily penetrated.

Uses: Ships, railroad crossties, timber bridges, tannin dyes, fuel wood, hardwood dimensions and flooring, furniture, veneer, plywood, barrels, kegs and casks (white oak group), truck and trailer beds, mining timbers, containers, pallets, caskets, boxes, paneling.

Toxicity: May cause allergic bronchial asthma, rhinitis, and dermatitis (40, 64, 105).

Additional Reading: 29, 55, 68, 74, 78.

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