Evaluation of live oak submerged underwater for 50 years and proposed for use in rebuilding the U.S.S. *Constitution*

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Abstract

Live oak timber stored under fresh water in New Hampshire for over 50 years was evaluated for possible use as structural framing in repairs on the U.S.S. *Constitution*. The material was found to be unsuitable for structural uses onboard ship. Apparently anaerobic bacteria reduced specific gravity by 4 percent, maximum crushing strength by 17 percent, and modulus of rupture by 34 percent. Modulus of elasticity was unaffected. Still, this material may be suitable for some uses in which structural properties are not of prime importance.

The U.S.S. *Constitution*, "Old Ironsides," is the oldest active, and possibly the most famous, naval vessel commissioned by the U.S. Navy. To preserve our nation's maritime heritage, the U.S. Navy rebuilt the U.S.S. Constitution in 1930-31 and repaired it again in 1963-64. The Navy is once again considering retrofitting this great ship. If they do, a suitable source of material will be required.

The Navy saved the excess live oak (*Quercus virginiana*) from the 1930-31 retrofit. This material has been submerged in freshwater for the last 50 years near Portsmouth, N.H. In 1982, some of this material was retrieved and shipped to the Forest Products Laboratory (FPL) to determine if it is suitable for the possible retrofit of "Old Ironsides."

Objectives

This study evaluated a limited sample of live oak to determine if a 50-year submersion had affected physical and mechanical properties. The following were specifically evaluated:

1. The material and its present properties.
2. The feasibility of using this material for structural purposes.
3. The feasibility of using this material for display purposes either onboard the ship or at a naval museum in lieu of its use as structural material.

Material and methods

Twenty-one blanks, ranging in size from 1.25 to 4.5 inches in width and depth and from 6.25 to 23.00 inches in length, were received from the U.S. Navy and confirmed as live oak (*Q. virginiana*).They consisted of 18 that had been submerged for 80 years and 3 that were newer material (hereafter referred to as new) of unknown origin but which had not been stored underwater. The moisture content of all 21 blanks was in excess of the fiber saturation point, as measured by a resistance-type moisture meter. Except for a brief processing period, the material was kept in a cold room (36°F) and brought to room temperature shortly before actual testing.

Five randomly selected blanks were microscopically examined for biological organisms. Later, two additional blanks (for a total of seven) were also examined, because these two blanks possessed atypical mechanical properties.

Static bending and compression parallel-to-the-grain tests were chosen to evaluate this material because the Navy would like to use it as structural knees and breasthooks onboard the Constitution. Because of the small size and low quality of the submerged material, some blanks were unusable; of those remaining some were machined into bending specimens, some into compression specimens, and some into both.

Because of the small size of the blanks, the bending specimens were prepared to a substandard size of 0.75 by 0.75 by 12.0 inches. When tested over a 10.5-inch span, the substandard size provided the same 14:1 span-to-depth ratio specified by American Society for Testing

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and Materials (ASTM) Standard D 143 (1). Loads were applied on the radial face at a load head speed of 0.05 inch per minute, the same as the ASTM D 143 secondary standard strain rate. Because of the small size of the blanks, the compression specimens (1.0 by 1.0 by 4.0 in.) were prepared and tested according to ASTM D 143 secondary standard.

Results and discussion

Biological activity

The pathological examinations of the live oak blanks stored underwater showed some evidence of hyphae, but no evidence of clamp-type hyphal connections or cell wall boring, common indicators of fungal decay. The limited occurrence of fungal decay indicates an absence of oxygen during underwater storage, which apparently favored the growth of anaerobic bacteria within the wood. Some of the blanks stored underwater exhibited insect boring holes, but these holes were of the type that normally occur in living trees. The holes possibly provided an avenue of infection for some of the bacteria that proliferated during the underwater storage. Oval-shaped bacterial cells were found within the rays and vessels throughout the entire cross section of the infected wood. Additionally, the infected wood had distinct fermentative odors of volatile fatty acids, which are often indicative of bacterial activity in wood (5, 10).

Bacterial infection usually has little effect on strength properties (7). However, over extended exposure, anaerobic bacteria have reportedly substantially reduced the mechanical properties of various southern pines (4), of Douglas-fir (6), and of red pine, white pine, and tamarack (3). No specific information could be found as to the effect of bacteria and extended submersion on the strength of a dense hardwood like live oak.

To determine whether the mechanical properties of the study material had been affected by anaerobic biological activity, the test results were compared by analysis of variance to ASTM D 2555 published values for live oak (2). Because the size and quality of the original material dictated the cutting of several specimens from some blanks and none from others, an unbalanced experimental design resulted. Accordingly, pooled estimates of the variance were used to analyze the data because specimens cut from the same blanks (within-blank variation) had much lower variation than specimens cut from different blanks (between-blank variation). F-tests adjusted from the unbalanced nature of the data were used to compare the new material to the submerged material. All analyses were performed at the 95 percent confidence level, unless otherwise noted.

Abnormal specimens

A preliminary analysis of the data generated from the material stored underwater revealed that the specimens originating from blanks No. 4 and No. 5 exhibited average reductions in specific gravity (SG) of 13 percent, in modulus of rupture (MOR) of 57 percent, maximum crushing strength (MCS) of 49 percent, and modulus of elasticity (MOE) of 37 percent when compared to the remaining material that had also been stored underwater. Subsequent microscopic examination revealed that the specimens from blanks No. 4 and No. 5 contained high numbers (counts) of bacteria. However, the relative differences between the bacterial counts of material from blanks No. 4 and No. 5 and those of the other material stored underwater did not appear to entirely account for the low SG and strength values. The material from blanks No. 4 and No. 5 was apparently different, either in its initial mechanical properties or in its resistance to bacterial degradation, than the rest of the material stored underwater. Accordingly, material from blanks No. 4 and No. 5 has been excluded from subsequent analyses. But it should be remembered that some blanks were reduced in strength to a far greater degree than the effects discussed later in this report.

TABLE 1. – *Results and analysis of live oak stored by submersion under fresh water near Portsmouth, New Hampshire, for 50 years.*

	Submerged				New				Analysis			
											Is submerged material significantly differentfrom (a<0.05)	
Property	No of blanks	No. of specimens	Mean value	Stand-ard devia-tion	No. of blanks	No. of specimens	Mean value	Stand-ard devia-tion	ASTM[a] D-2555 value	ASTM D-2555 stand-ard devia-tion	New material	ASTM values
Bending	5	14			2	5						
Specific gravity			0.767	0.020			0.846	0.015	0.810	0.081	yes	yes
Modulus of rupture (psi)			7,881	262			11,397	288	11,930	1,909	yes	yes
Modulus of elasticity ($\times 10^6$ psi)			1.289	.214			1.246	.054	1.575	.346	no	no
Compression	9	26			2	11						
Specific gravity			.786	.020			.803	.128	.810	.081	yes	yes
Maximum crushing strength, (psi)			4,485	503			5,183	260	5,430	977	no[b]	no[b]
Modulus of elasticity ($\times 10^6$ psi)			1.571	.409			1.421	.138	1.575	.346	no	no

FIX

[a] ASTM values are similar to Wood Handbook values.
[b] These differences were foundto be significant at a<0.10. FIX

Physical properties

The results of the bending and compression tests can be found in Table 1.

Specific gravity. — For both bending and compression the SG of the material stored underwater was significantly lower than the ASTM reported value of 0.81, while the SG of the new material was equivalent to the ASTM reported value. With the compression specimens, the differences in SG between material stored underwater and new material were much less than the differences in SG found with the bending specimens. However, F-tests adjusted for the unbalanced nature of the data showed that the material stored underwater had significantly lower SG than the new material for both bending and compression specimens.

Modulus of rupture. — The MOR of the material stored underwater was significantly lower than the ASTM reported value of 11,930 psi. The MOR of the new material was equivalent to the ASTM reported value. An F-test, adjusted for the unbalanced nature of the data, showed that the material stored underwater had significantly lower MOR than the new material.

Maximum crushing strength. — The MCS of the material stored underwater showed signs of being significantly lower (with a probability of $0.05 < a < 0.10$) than the ASTM reported value of 5,430 psi. The MCS of the new material was equivalent to the ASTM reported value. An F-test, adjusted for the unbalanced nature of the data, showed that the MCS of the material stored underwater also showed signs of being significantly lower than the MCS of the new material.

Modulus of elasticity. — The MOEs of both the new material and the material stored underwater were equivalent to the ASTM reported value of 1.575×10^6 psi. An F-test, adjusted for the unbalanced nature of the data, showed the MOEs of the new material and the material stored underwater to be equal. These results are not surprising because MOE has been shown to be one of the properties least affected by degradative-type treatments (9).

Conclusions

Live oak was prized as premium material for the construction of seafaring vessels because of its extraordinary density, strength, and resistance to biological degradation. However, the usefulness of this material can be affected by biological forces. The average mechanical properties of live oak (*Q. virginiana*) stored under fresh water for 50 years were affected in the following manner when compared to ASTM D 2555 values:

Modulus of rupture	–reduced by 34 percent
Maximum crushing strength	–reduced by 17 percent
Specific gravity	–reduced by 4 percent
Modulus of elasticity	–no effect

Extended underwater storage has apparently reduced the mechanical properties of the material examined here. The reduction in ultimate bending strength of 34 percent seems to severely limit the use of this material for structural applications. Still, the properties indicate that this material is adequate for shipboard or museum display purposes.

Literature cited

1. American Society for Testing and Materials. 1982. Standard methods for testing small clear specimens of timber. ASTM D 143-52, Part 22. Wood and Adhesives. ASTM, Philadelphia, Pa.
2. ________. 1982. Standard method for establishing clear wood strength values. ASTM D 2555-78, Part 22. Wood and Adhesives. ASTM, Philadelphia, Pa.
3. Bendtsen, B.A. 1974. Bending strength and stiffness of bridge piles after 85 years in the Milwaukee River. USDA Forest Serv. Res. Note FPL-0229. Forest Prod. Lab., Madison, Wis.
4. Scheffer, T.C., G.C. Duncan, and T. Wilkinson. 1969. Condition of pine piling submerged 62 years in river water. Wood Preserv. 47(1):22-24.
5. Schink, B., J.C. Ward, and J.G. Zeikus. 1981. Microbiology of wetwood: importance of pectin degradation and *Clostridium* species in living trees. Appl. Environ. Microbiol. 42(3):526-532.
6. Schniewind, A.P., B. Gammon, and B.A. Bendtsen. 1982. Strength of untreated Douglas-fir foundation piles after some 70 years' service. Forest Prod. J. 32(11/12):39-46.
7. Smith, R.S. 1975. Economic aspects of bacteria in wood. In: W. Liese (ed.). Biological Transformation of Wood by Microorganisms. Springer-Verlag, Berlin.
8. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1974. Wood Handbook: Wood as an Engineering Material. Agri. Handb. 72. rev. Govt. Print. Office, Washington, D.C.
9. Winandy, J.E., and R.M. Rowell. 1984. The chemistry of wood strength; Chapter V. In: R.M. Rowell (ed.). The Chemistry of Solid Wood. Adv. in Chemistry Series No. 207. Am. Chem. Soc., New York.
10. Zinkel, D.F., J.C. Ward, and B.F. Kukachka. 1969. Odor problems from some plywoods. Forest Prod. J. 19(2):60.