PRETREATMENT WITH ULTRASONIC ENERGY—ITS EFFECT UPON VOLUMETRIC SHRINKAGE OF REDWOOD[1]

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ABSTRACT

Redwood heartwood samples 1.2 inches in cross section were subjected to ultrasonic irradiation prior to oven-drying. There was a small but consistent reduction in volumetric shrinkage due to the pretreatment when the test cell was subjected to continuous vacuum during irradiation. It is believed that cavitation of the wood liquid was responsible for the effect. However, since the sample moisture contents were considerably less than the maximum moisture content for redwood, the effect was evidently due to something other than the elimination of Tiemann liquid tension stress. It is suggested that the denaturing is of the kind, but not to the extent, of that believed to occur in the freezing of wet redwood.

INTRODUCTION

The report by Morris (1969) discusses the nature of wave energy, methods of producing it, and the general effects produced in liquids, solids, and gases. The listing of potential applications to wood products includes the drying of wood, fiber, and paper. In his résumé dealing with drying, the obtaining of internal heating in cork and an increase in heat-transfer coefficient are referenced. Morris suggests the possibility of increasing the drying rate in wood products by using wave energy for "reducing temperature and moisture gradients of boundary layers." Presumably this would be accomplished through a continuous irradiation of the product by ultrasonic energy throughout the drying process. This is probably also the method of the French patent (Jarreau 1953) that makes the claim: "Improvement, by ultrasonic waves, in rate of seasoning without deformation and in resistance to insect and chemical attack."

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OBJECTIVE

The purpose of this exploratory investigation was to determine if exposing collapse-susceptible redwood to ultrasonic energy would affect the amount of volumetric shrinkage during subsequent drying and to compare the effect of ultrasonic irradiation with that of prefreezing (Erickson 1968, 1969; Erickson et al. 1966).

EXPERIMENTAL MATERIALS

Areas containing collapse-susceptible tissue were located by cutting cross sections from green pieces of dimension lumber, end-coating the sections, and then oven-drying at 105 C to bring about collapse. The original board was reconstructed, and the collapse-susceptible streaks in the green pieces were outlined by extension from the oven-dried sections. It has been observed for redwood that collapse commonly occurs in dark streaks that extend from knots along the grain (Erickson and Sauer 1969).

The experimental samples 5/16 inch along the grain were serially cut from pieces 1.2 inches in cross section, which contained the streaks of collapse-susceptible tissue. Figure 1 illustrates the procedures employed for locating the streaks and cutting the samples.

The test treatments were assigned consecutively to the serially cut samples. Once completed, the assignment was repeated,

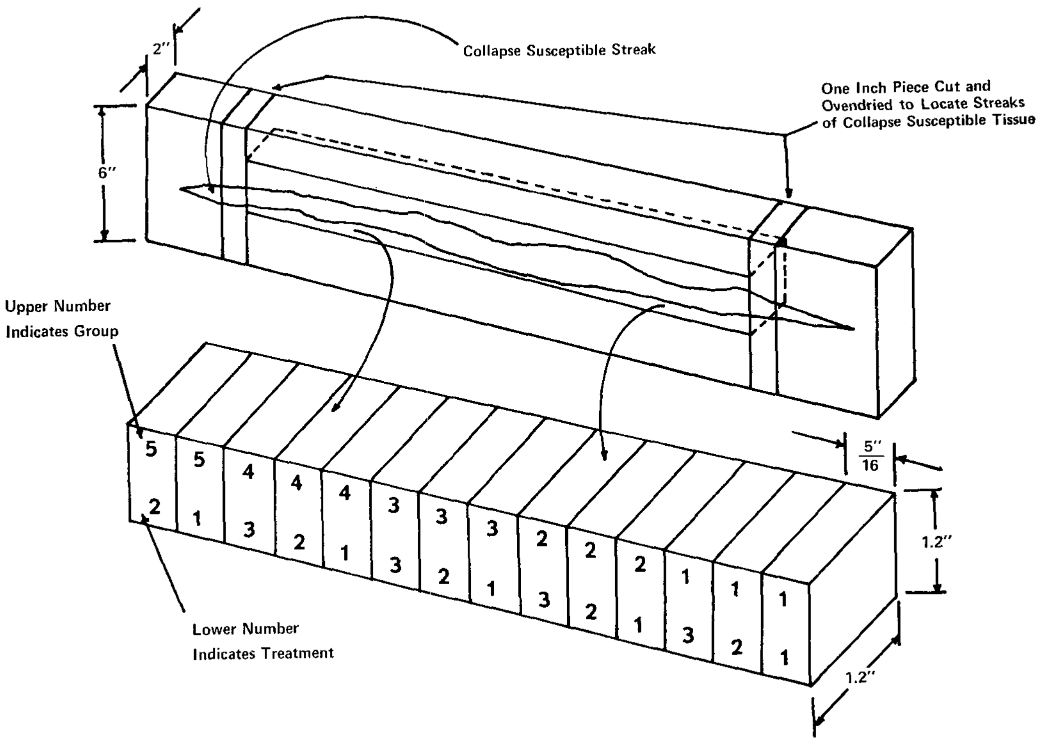

FIG. 1. The preparation of experimental samples from a portion of a board containing a streak of collapse-susceptible tissue.

with each cycle then being considered a group. Usually a group contained one sample per treatment.

The experimental equipment for ultrasonic treatment consisted of a Hewlett Packard Model CD variable frequency oscillator; a 200-watt power amplifier[2], an ultrasonic transducer with a resonant frequency of 24 kHz[3], a cavitation meter[3], and a vacuum pump.

Two methods were used for ultrasonic coupling of the wood sample to the transducer. In one method 10% aqueous cellulose gum (Hercules CHC – 7H) was spread over the face of the transducer, and the sample was held in place on the gum by a 1.5-kg weight. In the other method, the transducer and sample were immersed in a water bath with the sample again held in place on the radiating face of the transducer by a 1.5-kg weight. Provision was made for evacuating the test chamber in order to facilitate cavitation of the liquid. Figure 2 shows the test cell in detail.

[2] Type CRV-50121 driver amplifier. U. S. Navy surplus echo-sounding equipment.

[3] Macrosonics Corporation.

EXPERIMENTAL PROCEDURE

In an attempt to optimize the testing procedure, a series of six preliminary experiments was conducted. The results of this series, summarized in Table 1, indicated the following:

1. Prefreezing consistently gave the lowest volumetric shrinkages.
2. Samples irradiated at 19 to 20 kHz, under continuous vacuum, consistently gave lower volumetric shrinkages than the controls. This was true for both the water and cellulose gum coupling.
3. Average specific gravity values were fairly constant and did not appear to explain the differences in shrinkage.

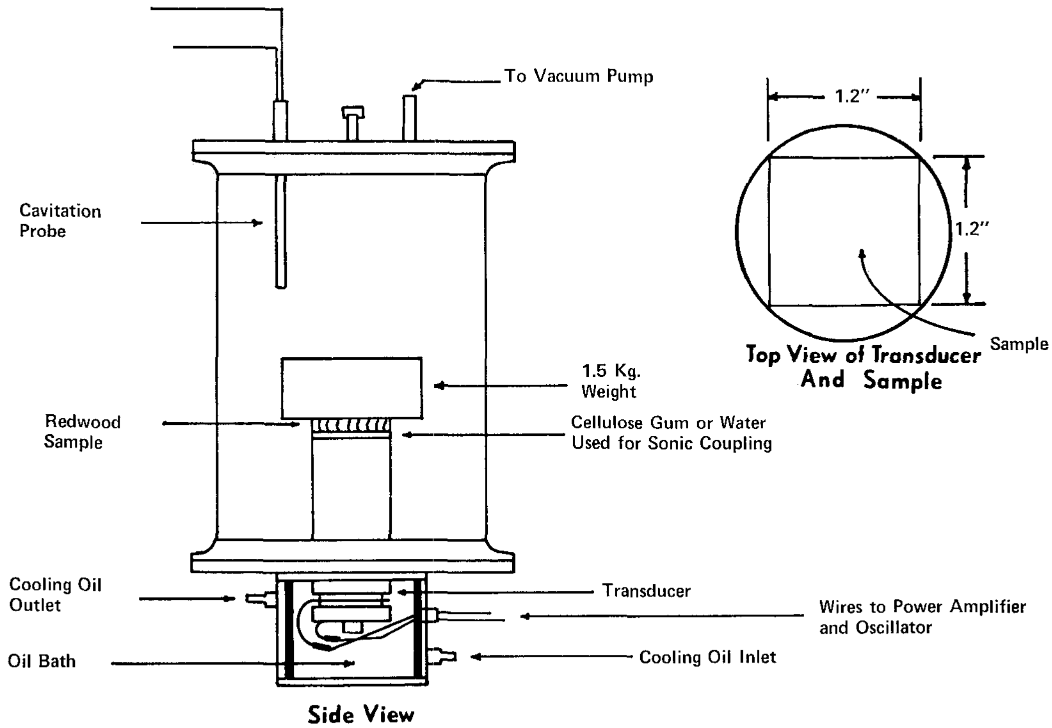

FIG. 2. A detailed sketch of the ultrasonic test cell.

The continuous application of vacuum to the test cell during irradiation appeared essential to obtaining a shrinkage reduction during subsequent oven-drying. With cellulose gum coupling, however, the possibility existed that at least a part of the shrinkage reduction was due to a bulking effect. Consequently, to eliminate this confounding factor, it was decided to use the water bath coupling for all subsequent tests. The water bath also served as a heat sink, helping to keep the sample temperature relatively constant, while making it possible to observe cavitation in the immediate vicinity of the sample.

The occurrence and degree of cavitation were determined by inserting the probe of a cavitation meter into the water bath near the wood sample, or by visual and audible estimation of maximum bubble formation and noise level. Generally the highest meter readings were obtained in the 23- to 24-kHz range, which is the resonant frequency of the transducer. However, the highest visible and audible cavitation occurred in the 19- to 20-kHz range, and it also appeared to be the most effective frequency for reducing shrinkage. Possibly the lower range represented the resonant frequency of the liquid system, resulting in greater power transfer.

The liquid displacement method was employed for the determination of sample volumes. Green volumes were obtained by water displacement, and because of the fairly high initial moisture contents, there was little opportunity for errors due to absorption.

Initially the oven-dry volumes were determined by water displacement, following the application of a thin rub-coat of paste wax to the sample. This, however, seemed to cause an inordinately large number of air bubbles to form on the surfaces, confounding the determination of sample volume. It was then discovered that the oven-dry samples were relatively nonabsorbent with-

TABLE 1. *Average per cent volumetric shrinkage and specific gravity values by treatment for the series of six preliminary tests*

	Test											
	1		2		3		4		5		6	
Treatments	Vol. Shrink. %[1]	Spec. Grav. [2]	Vol. Shrink. %[1]	Spec. Grav. [2]	Vol. Shrink. %[1]	Spec. Grav. [2]	Vol. Shrink. %[1]	Spec. Grav. [2]	Vol. Shrink. %[1]	Spec. Grav. [2]	Vol. Shrink. %[1]	Spec. Grav. [2]
Controls	3.53	.50	8.99	.47	7.93	.53	5.97	.46	7.27	.49	7.31	.45
Prefrozen	2.87	.50	6.71	.46	4.67	.53	5.60	.45	6.43	.49	6.81	.44
No vacuum—gum coupling—19 to 20 kHz	4.05	.50										
Continuous vacuum —gum coupling—19 to 20 kHz			7.50	.48					6.75	.50	7.05	.46
Continuous vacuum —water coupling— 19 to 20 kHz					7.10	.51			6.97	.48	6.99	.44
Continuous vacuum —water coupling— 23 to 24 kHz							6.32	.44				
Vacuum alone							6.32	.45				

[1] Averages not always based on an equal number of samples.
[2] Based on oven-dry weight and green volume.

out the wax film, at least for the period of time required for making the measurement. With but one exception, all subsequent tests employed water displacement without a wax coating. In the one exception, mercury was substituted for water.

Based upon the findings and experience obtained in these tests, a series of three experiments was planned and carried out. A detailed description of these three experiments follows.

Number one consisted of four treatments, involving a total of 60 samples. In one of the ultrasonic treatments, 17 samples were subjected to a frequency of 23 to 24 kHz. In the second ultrasonic treatment, 13 samples were subjected to a frequency of 19 to 20 kHz. Both treatments used a water-bath coupling, continuous vacuum, and a treatment time of 5 min per sample. The remaining two treatments were prefrozen and control, with 15 samples per treatment. The prefreezing was at -20 C for 24 hr.

Number two consisted of three treatments. There were 25 samples in each of the two ultrasonic treatments plus 25 controls, with each treatment containing one sample from each of 25 groups. Both ultrasonic treatments employed water coupling and irradiation at a frequency of 19 to 20 kHz for a duration of 5 min per sample. They differed in that for one treatment vacuum was applied during irradiation, while for the other treatment a preliminary vacuum was applied and released just prior to irradiation.

Number three consisted of two treatments applied to 24 end-matched pairs of samples. One sample from each pair was subjected to irradiation while the other was used as a control. Water-bath coupling was employed along with continuous vacuum. Irradiation was at a frequency of 19 to 20 kHz for a duration of 5 min per sample. Oven-dry volumes were determined by mercury displacement, rather than by water displacement as in experiments one and two. The use of mercury served as a check on the remote possibility that the apparent treatment effect was an artifact of using water for the displacement fluid.

TABLE 2. *Average per cent volumetric shrinkage and specific gravity values by treatment for the series of 3 experiments*

Treatment	Experiment Number					
	1		2		3	
	Vol. Shrink. %	Av.[1] Spec. grav.	Vol. Shrink. %	Av.[1] Spec. grav.	Vol. Shrink. %	Av.[1] Spec. grav.
Controls	9.98	0.37	6.55	0.44	5.33	[2]
Irradiation at 19 to 20 kHz, continuous vacuum, water bath coupling (high visible and audible cavitation)	8.84	0.36	6.20	0.43	5.06	[2]
Irradiation at 23 to 24 kHz, continuous vacuum, water bath coupling (maximum reading on cavitation meter)	9.51	0.38				
Irradiation at 19 to 20 kHz, vacuum applied and released before irradiation, water bath coupling			6.89	0.45		
Prefrozen	8.74	0.37				

[1] Based on oven-dry weight and green volume.
[2] Data unavailable.

RESULTS AND DISCUSSION

Table 2 compares the average shrinkage values by treatment for the three experiments. As in the series of preliminary tests, samples irradiated at 19 to 20 kHz under continuous vacuum consistently showed lower average shrinkage values than the controls. As one would expect, however, there was considerable variation among individual values, and the conclusion that there is a real effect needs statistical support. Experiments two and three, which contained the largest number of grouped samples, were subjected to analyses of variance tests, and the results are summarized in Table 3. The large natural variation in shrinkage is apparent from the F values for between groups, both of which are significant at the 1% level. In spite of this large natural variation, however, the F value for between treatments is significant at the 5% level for both experiments. These results are indicative of a small but real effect of ultrasonic irradiation upon volumetric shrinkage. This is particularly true for experiment three, which contained only the ultrasonic treatment and the serially matched controls.

TABLE 3. *Summary of F values determined for experiments two and three*

Experiment	Between Treatments	Between Groups
2	4.61*	5.02**
3	5.42*	13.61**

* Significant at the 5% level.
** Significant at the 1% level.

DISCUSSION

It is indeed possible to indulge in considerable speculation as to the mechanism by which irradiation with ultrasonic energy reduced shrinkage during drying. Bubble generation in cell lumens comes to mind, focusing attention upon the possible elimination of Tiemann-type liquid tension stress. It is generally held, however, that for this type of stress to be operative, the cell lumens must be completely filled with liquid. This seems rather unlikely, judging from the data for experiment two shown summarized in Table 4. Even the highest moisture contents given are considerably less than the maximum moisture content for redwood of normal specific gravity (Wood Handbook 1955), and at least half of the samples had initial moisture contents less than 100%.

Vaporous cavitation occurs when the low pressure portion of an ultrasonic pressure wave cycle drops below the vapor pressure of the liquid. The resulting vaporous bubbles collapse during the ensuing high pres-

TABLE 4. *Initial moisture content, specific gravity, and per cent volumetric shrinkage by individual sample for experiment two*

	Moist. Cont. %[3]	Vol. Shrink. %	Spec. Grav. [4]	Moist. Cont. %[3]	Vol. Shrink. %	Spec. Grav. [4]	Moist. Cont. %[3]	Vol. Shrink. %	Spec. Grav. [4]	Moist. Cont. %[3]	Vol. Shrink. %	Spec. Grav. [4]
		1			2			3			4	
Ultrasonics[1]	72.2	4.53	.38	87.2	5.96	.38	80.0	5.28	.38	73.4	5.02	.37
Control	90.2	5.10	.39	76.9	5.20	.39	70.1	5.77	.38	65.4	5.20	.37
Ultrasonics[2]	93.7	5.21	.38	80.2	5.70	.38	74.6	5.79	.36	68.3	6.20	.36
		5			6			7			8	
Ultrasonics[1]	64.8	6.54	.40	67.8	6.03	.38	116.1	5.22	.45	141.1	5.84	.44
Control	71.1	9.38	.39	62.4	7.06	.42	133.3	6.71	.46	132.8	7.38	.45
Ultrasonics[2]	63.4	5.72	.42	88.6	8.20	.45	141.3	6.24	.44	147.9	7.36	.42
		9			10			11			12	
Ultrasonics[1]	146.6	5.30	.42	157.2	6.33	.39	166.8	6.14	.38	157.2	6.33	.38
Control	——	6.54	.44	146.5	5.76	.41	151.4	6.99	.39	151.6	5.54	.40
Ultrasonics[2]	143.7	6.37	.42	164.8	7.28	.38	167.6	6.42	.38	165.9	7.43	.37
		13			14			15			16	
Ultrasonics[1]	137.7	6.02	.42	134.3	7.37	.43	69.3	6.95	.38	76.0	4.83	.39
Control	132.5	6.52	.43	126.8	6.92	.44	65.9	4.45	.40	73.4	4.94	.41
Ultrasonics[2]	167.6	6.42	.41	130.5	7.61	.43	74.5	5.67	.39	78.8	5.02	.39
		17			18			19			20	
Ultrasonics[1]	90.3	6.27	.42	82.9	7.81	.50	84.9	7.50	.39	108.2	5.77	.46
Control	85.9	6.62	.43	75.1	8.52	.55	80.4	5.57	.41	128.4	5.85	.47
Ultrasonics[2]	79.7	6.86	.45	73.2	8.08	.59	84.9	6.26	.42	139.9	6.55	.45
		21			22			23			24	
Ultrasonics[1]	135.0	6.19	.46	129.8	5.89	.48	90.5	8.23	.51	100.7	8.20	.57
Control	128.4	6.15	.48	127.8	6.44	.48	109.4	8.78	.54	71.5	9.26	.68
Ultrasonics[2]	135.6	6.59	.46	135.6	6.76	.47	111.4	8.05	.54	71.2	9.99	.70
		25										
Ultrasonics[1]	96.6	6.73	.46									
Control	116.5	7.16	.51									
Ultrasonics[2]	112.6	8.70	.53									

[1] Vacuum applied during the ultrasonic treatment.
[2] Preliminary vacuum prior to the ultrasonic treatment.
[3] Calculated on the basis of oven-dry weight.
[4] Calculated on the basis of oven-dry weight and green volume.

sure portion of the cycle, with the release of a significant amount of energy at a concentrated point. This can have energetic effects upon the immediate surroundings, as in the erosion of ships' propellors or physical and chemical changes in wood-water systems (Morris 1969). We believe that this type of mechanism is responsible for the shrinkage reduction. Exactly what happens is not known, but we suggest that the process can be characterized as a denaturing of some component of the woody tissue colloidal system. The suggested denaturing is perhaps of the kind, but not of the extent, believed to occur in the freezing of redwood (Erickson et al. 1966; Erickson 1968). Possibly irradiation at higher power might further decrease the amount of shrinkage.

Equipment limitations prevented the study of this possibility.

SUMMARY AND CONCLUSIONS

The purpose of this exploratory research was to determine if treatment with ultrasonic irradiation would produce a measurable reduction in the volumetric shrinkage of wood upon subsequent oven-drying. High-moisture-content redwood heartwood was selected as the experimental material because of extreme shrinkage (collapse) susceptibility, and experience of the authors in study and control of shrinkage and collapse in this material (Erickson et al. 1966).

The results of the study showed a slight but consistent decrease in shrinkage upon oven-drying, corresponding with ultrasonic treatment at 19 to 20 kHz. It was found that in order for the treatment to be successful, the ultrasonic irradiation must be under conditions that will apparently produce cavitation of the water in the specimen.

It is well known that the interchange of energy resulting from vaporous cavitation of a liquid is such that it will cause chemical reactions to take place in the liquid. It is suggested that in a similar manner the wood undergoes a change, caused by cavitation, that modifies its shrinkage behavior upon drying. It is not evident what the specific nature of the change might be, but it is reasonable to assume that it would be one that affects the colloidal characteristics of the wood system.

RECOMMENDATIONS FOR FUTURE WORK

The results reported in this technical note are of very limited nature, and serve only to indicate a slight reduction in volumetric shrinkage of redwood heartwood due to pretreatment with ultrasonic energy. It is recommended that additional research be done in order to investigate the effect of varying sample size, irradiation frequency, duration of treatment, and power level. Redwood sapwood should also be examined in order to determine if the extractives are involved in obtaining the ultrasonic effect. A microscopic examination of the ultrasonically treated, wet wood should be conducted.

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