NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report No. 32-1022

Effects of Decontamination, Sterilization, and Preconditioning Treatments on Energy-Dissipating Properties of Balsa Wood

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ABSTRACT

The effects of various decontamination, sterilization, and preconditioning treatments on the energy-dissipating properties of balsa wood have been measured. There was found to be a wide scatter in the properties of as-received balsa wood. Treatments of 5 hr at 260°C or 500 hr at 125°C caused significant degradation of the specific energy. Decreases to approximately 50% of the as-received value were measured. Other treatments did not have a serious effect on the specific energy, but did cause linear-dimension changes and variations in crushing stress that could be undesirable in some impact-limiting applications. Restrictive selection criteria may have to be established for the use of balsa wood as an energy-dissipating material.

AUTHOR

I. INTRODUCTION

The results of an earlier investigation (Ref. 1) demonstrated the feasibility of using balsa wood as an energy-dissipating material to protect payload devices during lunar or planetary landing. The effects of environmental and physical changes on the behavior of balsa wood have also been determined (Ref. 2). Developing the technology needed to build a usable impact limiter and gathering the required engineering design data are being accomplished under a separate investigation.[1]

The planetary quarantine requires that all materials to be landed on the surface of Mars must be sterilized. The present state of the art of energy-dissipating materials that could be used to protect a payload to be landed on the surface of Mars, such as called for by the present *Voyager* schedule, may dictate the use of balsa wood for this purpose. Although Ref. 1 provided a limited amount of data on the relation between moisture content, temperature, and the energy-dissipation capacity of balsa wood, the study did not involve the temperatures or the dwell times being presently proposed for sterilization treatments. The present investigation was therefore initiated to determine the effects of heat sterilization and ethylene oxide decontamination environments on the energy-dissipating properties of balsa wood.

[1] *Fabrication and Testing of Spherical Balsa Wood Impact Limiters to Impact Velocities of 500 ft/sec*, JPL Contract No. 951261 with Aeronutronic Div., Philco Corp., subsidiary of Ford Motor Co., Newport Beach, Calif.

II. MATERIAL TESTED

Because balsa wood is a natural product, it is not possible to closely control or readily vary its physical properties. However, by establishing selection criteria it was possible to obtain timbers of good quality and uniform characteristics.

The selection criteria were qualitative in nature and were applied to the timbers and the test specimens. These criteria stipulated that the balsa wood should be clear and free of visual defects, such as decay and splits, and should have straight grain orientation and uniform growth rings. The timbers met the specifications for grades A and AA, as established by the U. S. War Production Board in 1944 (Ref. 3).

The rough timbers, 4 in. by 5 in. by 10 ft long, were from the same stock as that used for the work reported in Ref. 2. Although the bulk density of each of the timbers was near 8 lb/ft^3, the measured density of the individual test specimens cut from these timbers ranged from 6 to 10 lb/ft^3, indicating significant variation along the length of the timbers. The nominal moisture content of the as-received timbers was about 8%.

The test specimens were 3-in. cubes cut from the timbers in such a way that the grain orientation was parallel to the sides of the test cube. Each specimen was assigned an identification number that indicated from which timber it was cut.

III. TREATMENTS GIVEN

Although the primary goal of this investigation was to determine the effects of sterilization treatments, earlier data (Ref. 1) indicated that moisture content had a significant effect on the energy-dissipating properties of balsa wood. Since all heat-sterilization cycles were such as to drive off most, if not all, of the natural moisture, some specimens were given conditioning treatments prior to testing that were intended to allow a study of the effects of removal of natural moisture by various other means, and to provide baseline data for comparison purposes. Also, the effects of variations in temperature and time for the heat-sterilization cycles were studied. Some specimens were given a combination of drying, ethylene oxide decontamination, and heat-sterilization treatments such as might be expected to occur in an actual use situation.

A detailed description of each of the conditioning treatments used in this study is given in Table 1.

Table 1. Balsa wood treatments

Treatment number	Details of treatment	Treatment number	Details of treatment
1	Held for 17 hr in a vacuum of 10^{-5} torr at room temperature	10	Held for 5 hr in nitrogen at 260°C, followed by treatment 8
2	Held for 498 hr in air at 125°C	11	Treatment 8, followed by six 96-hr cycles in nitrogen at 135°C
3	Held for 6 hr in air at 145°C	12	Treatment 1, followed by treatment 11
4	Held for 108 hr in air at 145°C	13	Held for 5 hr in nitrogen at 260°C, followed by treatment 11
5	Held for 108 hr in nitrogen at 145°C	14	Treatment 1, followed by one 96-hr cycle in nitrogen at 135°C
6	Held for 498 hr in sealed container at 125°C	15	Treatment 1, followed by impregnation with G. E. 103 Dri-Film silicone resin
7	Held for 108 hr in sealed container at 145°C	16	Treatment 1, followed by impregnation with G. E. 103 Dri-Film silicone resin, followed by 108 hr in air at 145°C
8	Six 30-hr cycles at 50°C and 50% RH in an 88% Freon–12% ethylene oxide mixture		
9	Treatment 1, followed by treatment 8		

IV. TESTING PROCEDURE

All testing conducted during this investigation was carried out at room temperature and ambient pressure. The actual test apparatus used was the same as that described in Ref. 2. The testing procedure consisted of recording the force-vs-displacement curve when a cylindrical plunger of 1-in.^{2} cross-sectional area is pushed into the test specimen at a speed of 1 in./min. For this series of tests, the direction of penetration was parallel to the grain of the specimen, and a side constraining force of approximately 15 lb was used.

Each specimen was carefully weighed and measured prior to any conditioning treatment and again immediately prior to testing. In those cases where a conditioning treatment was given, care was taken to protect the specimen from adverse effects caused by exposure to the ambient room conditions. All tests were performed as quickly as possible after removal from the conditioning environment. Careful visual examinations of the test specimens were conducted at each stage of the conditioning and testing.

After testing and inspection, each specimen was placed in a circulating-air oven and dried overnight at 120°C. The weight of the dried specimen and the weight prior to testing provided the data needed to compute the moisture content of the specimen.

The area under the force–displacement curve for the total crushing cycle is the mechanical energy dissipated during crushing. Dividing the mechanical energy dissipated by the weight of the test specimen gives the specific energy. This is a useful design parameter, which can be used to compare various materials. Dividing the force by the area of the element being crushed gives the crushing stress. This is also a useful parameter in comparing different energy dissipators since it provides a measure of the deceleration level. The mean crushing stress is defined as

$$\sigma_{mean} = \frac{\text{area under force–displacement curve}}{\text{total displacement} \times \text{area of element crushed}}$$

The ratio of the maximum to the minimum crushing stress is called the crushing-stress ratio α. This parameter is useful in the study of impact-limiter dynamics. The most significant material efficiency parameter is the thickness efficiency β, defined as

$$\beta = \frac{\text{height before crushing} - \text{height after crushing}}{\text{height before crushing}}$$

All of these parameters, as well as density, moisture content, weight loss, and linear-dimension changes, were determined for each specimen tested.

V. RESULTS AND DISCUSSION

The test data obtained during this investigation are given in Table 2. The last digit of the specimen number indicates the timber from which the specimen was taken. The reported weight loss was based on the as-received weight of the specimen. A negative weight-loss value means that the specimen increased in weight during the conditioning and/or testing. The minimum linear shrinkage always occurred in a direction parallel to the grain, and the maximum perpendicular to the grain. A negative linear-shrinkage value means that the specimen expanded.

The force–displacement curves shown in Fig. 1 are representative of all of the curves recorded during this study. Since the area of the plunger was 1 in.^{2}, the force and crushing stress have the same numerical value. In Fig. 1 the data are shown as crushing stress. Besides showing the different stress levels resulting from specific conditioning treatments, these curves show another important characteristic of the balsa wood. The curve for the as-received specimen is smooth with no sudden changes in stress, which is a very desirable characteristic for an energy-dissipating material. The variations in stress shown by the curve for the vacuum-dried specimen, and to a lesser extent for the other specimens, are undesirable. Such variations would produce changes in the deceleration level that would be experienced by a payload protected by such a material.

Table 2. Balsa wood test data

Conditioning treatment	Spec. No.	Density, lb/ft³	Moisture content, %	Stress, psi				Stress ratio	Thickness efficiency	Specific energy, ft-lb/lb	Weight loss, %	Shrinkage, 0.001 in./in.		Remarks
				Initial peak	Crushing							Min.	Max.	
					Max.	Mean	Min.							
As received	8-1-1	6.45	8.5	900	870	728	582	1.49	0.832	13500	—	—	—	
	8-6-1	6.33	7.2	—	875	729	585	1.50	0.833	13800	—	—	—	
	8-14-1	8.34	7.2	1140	1135	896	695	1.63	0.813	12600	—	—	—	
	8-23-1	8.89	8.4	1955	1910	1535	1275	1.50	0.777	19300	—	—	—	
	8-29-1	7.48	9.5	—	1440	1200	1065	1.35	0.780	18000	—	—	—	
	8-43-2	8.52	8.2	2025	2010	1710	1430	1.41	0.774	22400	—	—	—	
	8-45-2	8.93	8.2	1995	1950	1720	1545	1.26	0.768	21300	—	—	—	
	8-84-3	7.03	7.1	—	1840	1360	990	1.86	0.814	22700	—	—	—	
	8-94-3	8.33	7.8	1980	1950	1550	1260	1.55	0.795	21300	—	—	—	
	8-103-3	8.40	5.6	2190	2190	1632	1250	1.75	0.800	22400	—	—	—	
	8-112-4	9.60	9.1	1980	1980	1530	1190	1.66	0.795	18200	—	—	—	
	8-113-4	9.82	9.2	2010	2010	1580	1400	1.44	0.792	18300	—	—	—	
	8-114-4	9.43	9.1	1935	1935	1560	1400	1.38	0.780	18600	—	—	—	
	8-115-4	9.34	6.0	2210	2210	1710	1310	1.69	0.790	20900	—	—	—	
	8-116-4	9.63	6.0	2140	2140	1640	1270	1.68	0.790	19300	—	—	—	
	8-117-4	9.28	6.1	2160	2160	1770	1480	1.46	0.790	21700	—	—	—	
	8-118-4	9.56	6.1	2205	2205	1820	1490	1.48	0.778	21400	—	—	—	
	8-119-4	9.66	6.1	2340	2340	1855	1500	1.56	0.784	21700	—	—	—	
	8-120-4	9.50	6.1	2030	2030	1580	1185	1.72	0.790	19000	—	—	—	
	8-152-5	6.34	7.6	1250	1250	923	700	1.79	0.837	17600	—	—	—	
	8-153-5	6.46	8.2	1180	1180	974	795	1.49	0.830	18000	—	—	—	
As received	8-154-5	9.04	8.2	1620	1620	1230	990	1.63	0.813	15900	—	—	—	
1	8-54-2	7.95	0	—	2590	1640	1220	2.12	0.867	25800	6.3	2	11	
1	8-55-2	8.22	0	—	2855	2150	1540	1.85	0.813	30600	7.2	3	11	
1	8-74-3	6.36	0	—	1880	1244	945	1.99	0.875	24500	7.9	3	11	Split
1	8-75-3	6.47	0	—	2020	1410	800	2.52	0.847	26500	7.9	3	11	
1	8-77-3	6.32	0	—	1860	1267	920	2.02	0.843	24400	8.0	2	11	
2	8-50-2	7.02	0	1920	1965	1080	610	3.22	0.893	19800	16.2	3	27	Split
2	8-51-2	7.43	0	1480	1530	1170	930	1.65	0.867	19600	17.1	3	29	Split
2	8-52-2	7.23	0	1880	1940	1250	890	2.18	0.848	21100	16.5	2	27	Split
2	8-85-3	6.74	0	1800	1540	826	610	2.52	0.896	15800	15.8	2	22	Split
2	8-86-3	6.32	0	1650	1640	757	480	3.42	0.900	15500	15.8	2	19	Split
2	8-87-3	6.50	0	1480	1620	1040	680	2.38	0.867	20000	16.0	2	20	Split
3	8-56-2	8.07	0	1950	1460	1320	1110	1.31	0.817	19300	6.8	1	7	
3	8-99-3	7.36	0	2010	2010	1290	765	2.63	0.847	21400	6.3	0	5	
3	8-100-3	8.17	0	2360	2570	1732	1260	2.04	0.840	25600	6.5	1	5	
4	8-46-2	8.57	0	2985	2850	2220	1320	2.16	0.824	30800	9.1	1	11	Split
4	8-47-2	7.84	0	—	1860	1290	1000	1.86	0.840	19900	9.5	2	14	
4	8-49-2	8.02	0	2000	2100	1635	1240	1.69	0.830	24300	9.7	1	13	

Table 2. (Cont'd)

Conditioning treatment	Spec. No.	Density, lb/ft³	Moisture content, %	Stress, psi				Stress ratio	Thickness efficiency	Specific energy, ft-lb/lb	Weight loss, %	Shrinkage, 0.001 in./in.		Remarks
				Initial peak	Crushing							Min.	Max.	
					Max.	Mean	Min.							
5	8-57-2	8.25	0	2270	2280	1575	1120	2.03	0.835	23000	8.3	1	12	
5	8-101-3	8.52	0	2340	2880	1870	1080	2.67	0.820	25900	7.7	1	9	
5	8-104-3	8.17	0	2270	2570	1650	850	3.03	0.846	24600	7.3	1	9	
6	8-33-2	7.10	*	1065	950	690	525	1.81	0.827	11600	19.5	−9	6	Split; pressure reached 147 psi
6	8-88-3	6.83	*	1300	1010	760	570	1.77	0.843	13500	17.2	−10	5	Pressure reached 146 psi
6	8-95-3	7.01	*	1440	1380	905	730	1.89	0.841	15600	17.8	4	5	Split; pressure reached 144 psi
7	8-7-1	5.96	*	1030	1000	714	570	1.75	0.863	14900	9.1	5	13	Container leaked
7	8-13-1	7.55	*	720	690	480	360	1.92	0.848	7750	11.1	0	2	Pressure reached 110 psi
7	8-38-1	6.64	*	950	850	583	390	2.18	0.840	10600	11.9	0	1	Pressure reached 120 psi
8	8-127-4	7.73	5.7	1905	1910	1530	1410	1.35	0.800	22700	−2.6	0	−3	Linear expansion and weight gain
8	8-128-4	7.85	5.6	1990	2000	1560	1150	1.74	0.813	23300	−2.5	0	−3	Linear expansion and weight gain
8	8-133-4	8.63	5.9	2220	2235	1740	1180	1.90	0.793	23000	−2.7	0	−3	Linear expansion and weight gain
9	8-121-4	9.76	5.5	2420	2455	1900	1460	1.68	0.810	22800	−2.5	−1	−10	Linear expansion and weight gain
9	8-122-4	8.89	5.5	2390	2410	1950	1530	1.57	0.787	24800	−2.3	−2	−9	Linear expansion and weight gain
9	8-123-4	9.03	5.4	2415	2430	1560	1790	1.36	0.787	19500	−2.6	−1	−9	Linear expansion and weight gain
10	8-131-4	6.75	4.3	1230	1350	885	640	2.11	0.873	16500	26.8	—	—	
10	8-136-4	6.82	5.4	965	1100	775	740	1.42	0.813	14200	26.8	—	—	
11	8-109-3	8.04	0	2300	2170	1720	1220	1.78	0.840	26000	6.6	1	9	
11	8-144-4	8.82	0	2760	2540	2060	1440	1.76	0.816	27600	7.5	1	12	
11	8-147-4	8.36	0	1940	1750	1590	1090	1.60	0.823	22600	—	1	11	
12	8-105-3	9.31	0	2920	2550	1820	1490	1.71	0.826	23300	6.3	1	3	
12	8-124-4	8.38	0	2460	2120	1860	1140	1.86	0.843	27000	7.7	1	6	
12	8-125-4	8.50	0	2880	2660	2370	1600	1.66	0.800	32300	7.1	1	5	
12	8-129-4	7.85	0	2710	2600	2250	1540	1.69	0.816	33500	7.1	1	9	
13	8-139-4	7.20	0	1730	1260	1140	590	2.16	0.876	19900	22.9	2	3	
13	8-141-4	6.86	0	1040	790	620	340	2.31	0.923	11900	30.0	3	27	
14	8-102-3	6.45	0	2910	2510	2200	1380	1.81	0.803	39400	—	—	—	
14	8-106-3	7.91	0	2370	1770	1580	950	1.87	0.850	24300	7.5	—	—	
14	8-107-3	8.30	0	2670	2240	1850	1180	1.90	0.840	27000	7.5	—	—	
14	8-140-4	5.88	0	1370	1350	1040	770	1.76	0.870	21900	8.0	—	—	
14	8-151-4	6.27	0	1170	980	960	700	1.39	0.880	19300	6.3	—	—	
15	8-80-3	6.86	—	—	2110	1210	780	2.50	0.853	21700	3	1	12	4.5% resin
15	8-92-3	7.68	—	—	2280	1292	920	2.48	0.870	21100	−1	2	10	8.0% resin
15	8-96-3	8.10	—	2415	2410	1640	1120	2.17	0.844	24600	−5	2	10	11.5% resin
16	8-97-3	7.70	—	1900	1860	1220	900	2.07	0.877	20000	1	2	15	11.5% resin

*Because of the presence of significant quantities of recondensed substances, it was not reasonable to obtain a moisture content of the as-tested specimen.

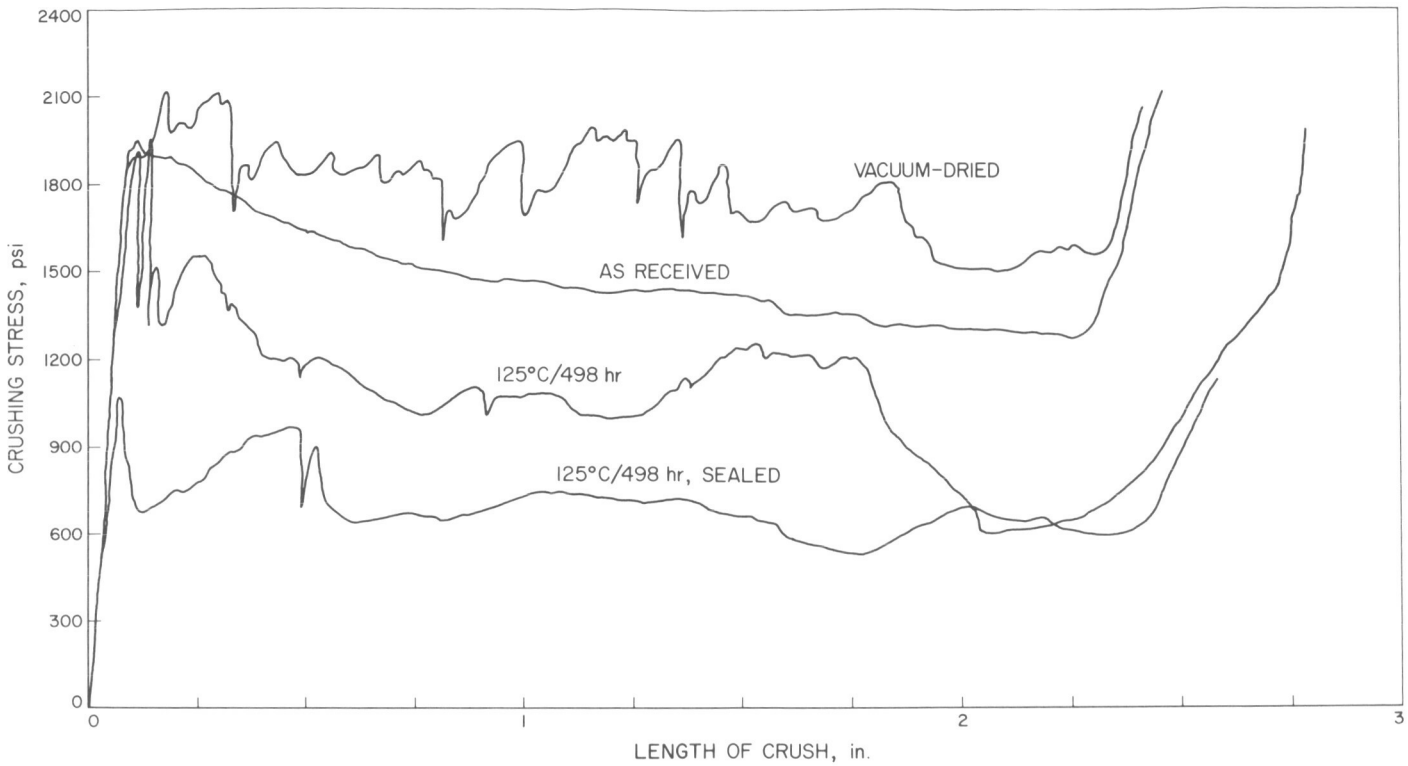

Fig. 1. Typical force–displacement curves for balsa wood during crushing

The curves for the specimens heated to 125°C show the stress reaching an initial peak during the very early portion of the displacement. While such a peak was typical for most specimens, it did not occur for every one. The value of stress corresponding to this peak is recorded in Table 2 under the heading of initial peak stress. Such peaking would produce a similar peaking in the deceleration level of an actual system.

The thickness efficiency parameter β, which determines the quantity of material required to dissipate a given amount of energy, was very insensitive to the various treatments, as shown in Table 2.

Those treatments that involved heating the specimen usually had an effect on the visual appearance. As can be seen in Fig. 2, heating caused noticeable darkening throughout the specimen. Heating in a sealed container resulted in extreme darkening and the presence of recondensed volatiles, and the wood exuded a very pungent odor and had a punky feeling. Those treatments that involved ethylene oxide–Freon decontamination had no noticeable effect on the visual appearance. Impregnating with resin caused a change in the color of the specimen because of the color of the resin.

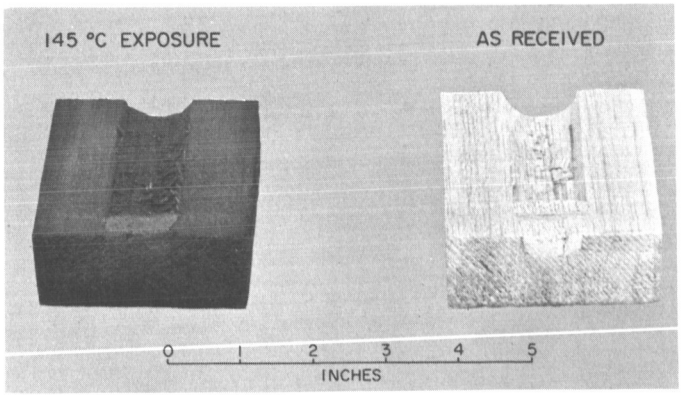

Fig. 2. Balsa wood specimens before and after heating

Using the specific energy as a comparison parameter, the test data given in Table 2 for the as-received specimens show a very wide scatter. This scatter does not correlate with density, moisture content, or any of the other observed parameters. It is not only evident from timber to timber, but is even present within a given timber. While such scatter may be inherent in balsa wood, it seems more likely that a portion of it may be due to lack of information on the growing conditions, the selection criteria, and the processing steps used prior to the selecting of the specific

timbers of this study. It is known that for other woods careful control and selection can lead to a high degree of uniformity in some properties.

Because of the wide scatter in the experimental data it does not appear to be reasonable to calculate average values and use these to draw conclusions. Instead, trends will be indicated, which take into consideration all of the available data. These should be clearly understood as trends and it should also be realized that they are based on a limited amount of data.

Vacuum drying, which removes all of the natural moisture (treatment 1), appears to increase the specific energy of balsa wood. The shrinkage appears to be uniform and is acceptable from a design and fabrication standpoint. However, the increase in the stress ratio and the significant increase in the stress variations that occur during crushing (Fig. 1) make the vacuum-dried material less desirable from an impact-limiter standpoint. The fact that one specimen split during testing could indicate a decrease in transverse strength, which would be undesirable.

From the limited data available it is not possible to identify any definite effects of time, temperature, or atmosphere on the specific energy (treatments 2, 3, 4, and 5). The increase in stress ratio and the variation in stress during crushing indicated for the vacuum-dried material were also observed, but to a lesser extent, for the heated specimens. Whether this is due to the removal of the moisture or damage to the wood structure cannot be determined. The only definite indication seems to be that long times at elevated temperature may have a significant effect on the transverse strength, since every specimen heated for 498 hr split during crushing. Only one of the specimens heated for a shorter time showed similar splitting.

Besides the significant visual changes that resulted from heating in a sealed container (treatments 6 and 7), there was a marked decrease in specific energy. The increase in stress ratio and the range of stress variation during crushing were not as large as for the specimens heated in an atmosphere. The specimens heated for the longer time split during crushing, while those heated for shorter times did not. The pressure buildup and the generation of condensable materials make heating within a sealed container unacceptable.

Ethylene oxide decontamination followed by a heat-sterilization treatment at 135°C had no significant effects on the behavior of the as-received material (treatment 11). For specimens that were vacuum-dried before being subjected to the combination decontamination plus heat (treatment 12), the specific energy was slightly higher than for the as-received material. However, most of this increase was very likely due to the vacuum drying. If the material was dried by heating to 260°C for 5 hr prior to decontamination and heat sterilization (treatment 13), the specific energy was decreased. In this case the decrease is most likely due to the high-temperature drying treatment rather than to the decontamination or sterilization treatments.

Reducing the heat-sterilization treatment to one cycle of 96 hr at 135°C on material that had been vacuum-dried (treatment 14) had no significant effect on the specific energy. One specimen treated in this way did give an exceptionally high value of specific energy; however, because of the scatter observed and the limited amount of data, this single value cannot be considered significant.

In an attempt to increase the specific energy and decrease the variation in crushing stress observed in the vacuum-dried material, it was decided to impregnate the balsa wood samples with a water repellent (treatment 15). A silicone resin was used for this purpose. The limited data show no significant increase in the specific energy. Heating the impregnated material (treatment 16) seemed to have no effect on its energy-dissipating properties.

VI. CONCLUSIONS

As stated earlier in this Report, the data available are too limited to allow the drawing of definite conclusions. It is only possible to identify certain items which seem to be indicated by the test results and which are to be given further consideration and investigation when using balsa wood as an impact-limiting material. Among these items are:

1. There is a wide scatter in the specific energy of balsa wood as measured during this investigation. More restrictive selection criteria may reduce this scatter; however, such criteria have not been determined.

2. Exposing balsa wood to ethylene oxide decontamination and heat-sterilization environments specified for *Voyager* capsule equipment does not cause a significant degradation in the specific energy as measured by the method used in this study.

3. Heating balsa wood to 260°C for short times (5 hr) or to 125°C for long times (498 hr) causes a marked decrease in specific energy.

4. Heating balsa wood in a sealed container to temperatures in the range used for heat sterilization causes a degradation of the energy-dissipating properties and generates unacceptable volatile products that produce a large pressure increase in the container.

5. Exposing balsa wood to drying or heating treatments of the type used in this study causes linear-dimension changes and increases crushing-stress variations.

It is reasonable to expect that it will be possible to develop engineering techniques that can accommodate the variations and degradations discussed. However, unless the need for such developments and the possible tradeoffs is recognized, serious prediction errors may result.

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2. Knoell, A. C., *Environmental and Physical Effects on the Response of Balsa Wood as an Energy Dissipator*, Technical Report No. 32-944, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1966.

3. *Rules for the Measurement and Inspection of Balsa Wood — U.S. War Production Board*, Balsa Ecuador Lumber Corporation, New York, 1944.

APPENDIX

The degradation in specific energy that occurs in balsa wood as a result of long-time exposure at temperatures in the lower range of those considered acceptable from a sterilization standpoint indicates the necessity of considering various means of heating large cross sections in a minimum time. A preliminary estimate indicates that the time required to heat a 16-in.-thick section of balsa wood to 135°C, if the heat is supplied from one side only, could approach 100 hr or longer. Because of the low thermal conductivity of balsa wood, cooling times would be equally long.

During the course of the study presented in this Report, it was decided to investigate the feasibility of a method of heating that might significantly reduce the time at temperature. Because of the highly porous structure of balsa

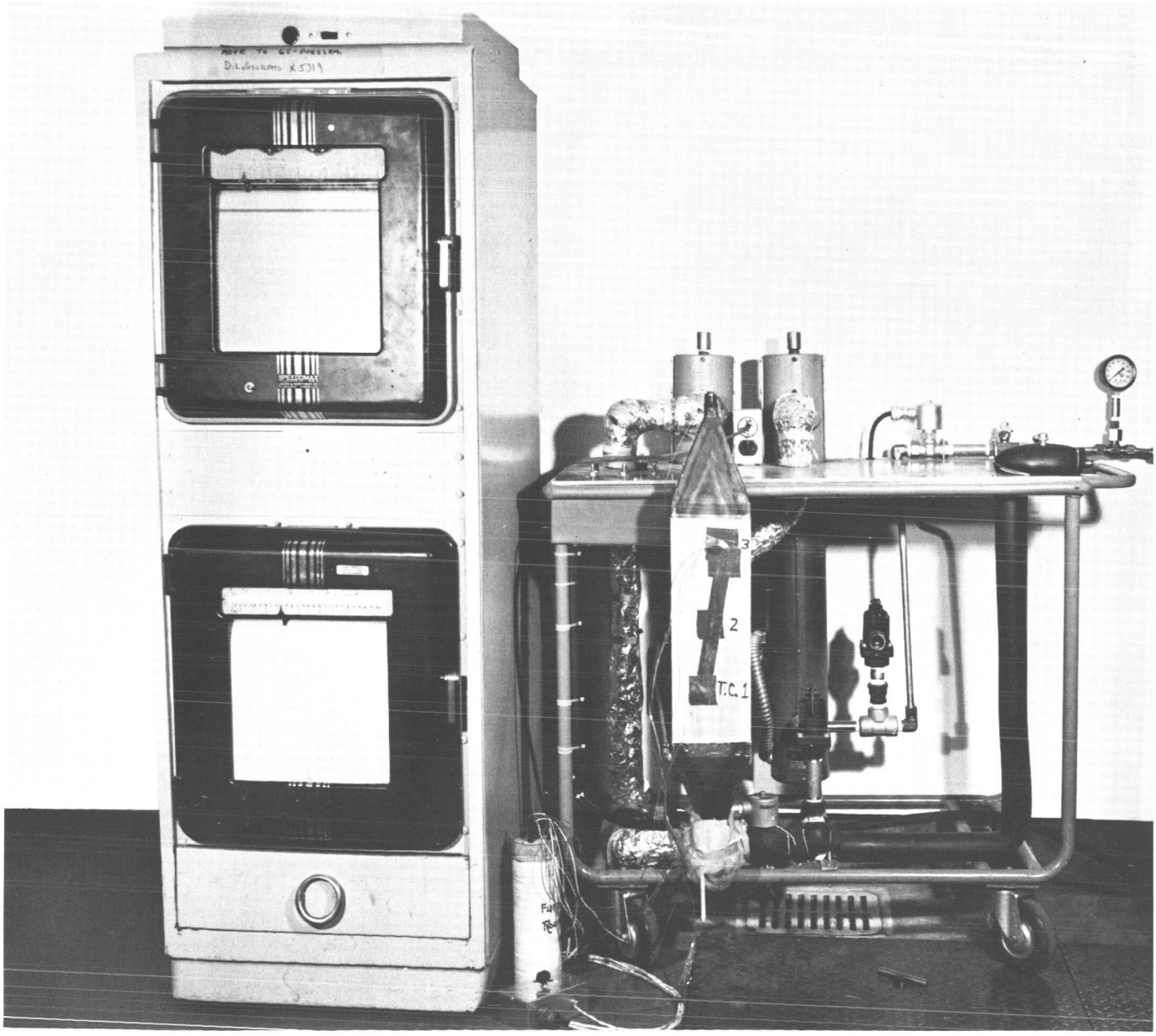

Fig. A-1. Hot-gas heating apparatus

wood, especially along the grain direction, it was considered possible to heat a thick section by forcing a heated gas through the balsa wood.

The equipment used for this investigation is shown in Fig. A-1. A balsa wood timber, 4 in. by 5 in. by 16 in. long, was fitted with a metal plenum chamber on each end, as can be seen near the middle of the photograph. Thc 16-in. length was parallel to the grain direction. Thermocouples were spaced on 4-in. centers along the central axis of the timber. Gaseous nitrogen was heated in the exchanger, shown in the middle background of the photograph. The heated nitrogen was piped to the chamber fastened to the lower end of the timber. At pressures as low as 2 to 4 psi, large flow rates could be maintained. Continuous recording of the output of the thermocouples located in the timber gave an indication of the efficiency of this method of heating.

Because of the large flow rate of gas that could be maintained at very low pressure, the capacity of the heat exchanger used was insufficient to maintain a constant gas temperature at the inlet. However, it was clearly evident that by passing heated gas parallel to the grain it is possible to heat thick sections of balsa wood to sterilization temperatures in a minimum amount of time.