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DYNAMIC SHOCK ABSORBING PROPERTY OF REDWOOD FOR TRANSPORT/STORAGE CASKS

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ABSTRACT

The impact compressive tests for redwood were performed supposing the actual drop test condition and the energy absorbing property data were obtained. These tests include the static/dynamic conditions. In the dynamic test, the deformation speed according to the behavior of woods under the 9m drop test is simulated. It was confirmed that these woods could be the suitable materials for energy absorbing and useful for the design of effective shock absorber.
As for the redwood, the impact crush tests were performed not only in room temperature but also -20 and 70 ^{o}C and the energy-absorbing characteristic including the dependency of temperature was evaluated. The dynamic compressive stress of redwood with -20 ^{o}C is approximately maximum 30% larger and the value with 70 ^{o}C is approximately maximum 25% smaller than that of room temperature. These values are smaller than the compressive stress data published in literature, it has a little of influence on the design of the shock absorbing covers. These tested properties and the influence on the design of the shock absorbing covers are discussed in the paper.

INTRODUCTION

Transport/storage cask is required to be designed in order to endure the 9m drop test, therefore the shock absorbing covers are set at the both ends of cask to reduce the impact acceleration. For the shock absorbing covers, wood materials are often usually used. Wood material is the excellent energy absorbing material because it has relatively high specific strength and large compressive deformation. As it is required that the impact force under 9m drop test for the loaded contents such as fuel assemblies should be reduced, the detailed and accurate shock absorbing properties of wood materials become more and more important in order to design the effective shock absorber.
The general compressive strength properties of wood and its temperature dependencies are well described in the Wood Handbook[1)]. But these data seem not to be dynamic crush properties and the kinds of woods are not specified for the temperature dependency data.
The impact compressive tests for redwood were performed supposing the actual drop test condition and the energy absorbing property data were obtained. These tests include the static/dynamic conditions. And for the redwood, the impact crush tests were performed not only in room

temperature but also -20 and 70 ^{o}C and the energy-absorbing characteristic including the dependency of temperature was evaluated.

TEST CONDITION AND METHOD

The compressive strength properties of the redwood were measured on both static and dynamic conditions. In the static compressive test, test specimens have been compressed at low stroke speed with a universal testing machine. In the dynamic compressive test, the weight fell down on the target test specimen from 9 meters height. These tests were performed with three different temperatures which were -20 ^{o}C, room temperature and 70 ^{o}C. The temperature condition of -20 ^{o}C was the assumption of the lowest environmental condition of the Japanese transportation, and the temperature condition of 70 ^{o}C was the conservative assumption of wood in the shock absorbing covers heated by decay heat of fuels. Test specimens and test conditions are shown in Table 1.

Table 1. Test sample and conditions

Item	Test condition
Kind of the wood	Redwood
Direction of grain	Parallel / Perpendicular to grain
Density of wood	0.3 – 0.45 g/cm^{3}
Moisture content	5 – 12 %
Temperature of wood	-20 ^{o}C / Room temperature / 70 ^{o}C
Compressive condition	Static / Dynamic

Static Test Condition

Table 2 shows the condition of static compressive test. The shape and the size of the test specimen are shown in Figure 1 and a picture of test specimen is shown in Figure 2. And the test equipment and the aspect of static testing are shown in Figure 3.

The set of test specimen was composed of compressive core wood, ring wood and steel pipe. The size of compressive core wood was Φ40mm×43mm and it was restrained around with the same wood ring. Steel pipe covered outer side of wood ring which prevented the wood from crush scattering. The purpose of this test specimen's structure is to evaluate accurately the compressive property of actual wood surrounded and restrained by the same wood. The steel base rod was inserted into the center of specimen, part of Φ40mm×43mm, and only the core specimen of center has been compressed by universal testing machine with the enough slow speed.

The specimens tested with temperature of -20 ^{o}C and 70 ^{o}C were put in polyethylene's bag to prevent wood from being dried during cooled and heated in a constant temperature furnace or refrigerator. These test specimens were heated or cooled with enough time and the temperature of test specimens were controlled by the thermo-couples inserted in the representative wood sample and confirmed that test specimens were to be specific temperature.

The compressive test in each temperature was performed just after the test specimens set in the test equipment from the temperature controlled furnace or refrigerator.

Table 2. Conditions of static compressive test

	condition
Test equipment	Universal testing machine (UH-F1000kN)
Stroke speed	10 mm/min

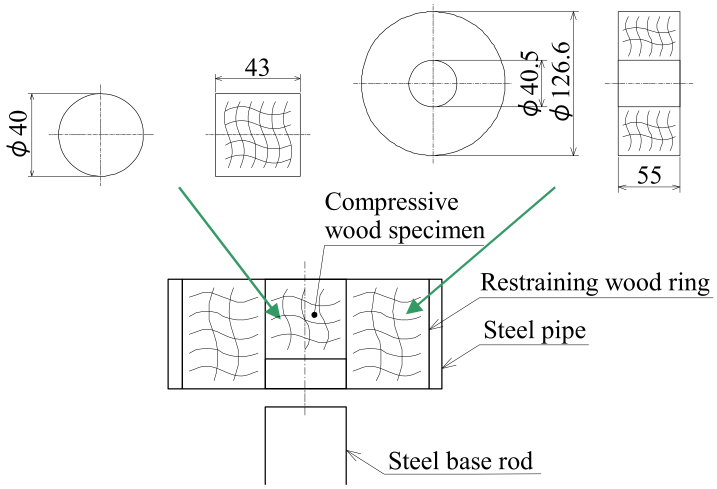


Figure 1. Dimensions of test sample

Figure 2. Picture of test sample

Figure 3. Equipment of static compressive test

<u>Dynamic Test Condition</u>

Figure 4 shows the outline of the dynamic compressive test equipment and the installation condition of the test specimen. The drop test condition of the IAEA regulation was simulated by dropping weight from the height of 9m. The weight was dropped on the test specimen set up on the load cell. The condition and size of test specimen were the same in case of static test.

The compressive displacement of wood was measured by searching the position on the bottom surface of the weight with the laser sensor. The compressive load was measured with the load cell that had been set up under the test specimen. These displacement and load data were obtained in a digital oscilloscope and then the relation between the dynamic compressive stress and the displacement of wood was obtained by processing data. The weight of the drop weight block was 40.5kg.

The specimens tested with temperature of -20 °C and 70 °C were prepared in the same way of static test. The compressive test in each temperature was performed just after the specimens set in the test equipment from the temperature controlled furnace or refrigerator.
And an internal temperature of the wood was confirmed to have no significant change during the testing period from taken out of the temperature controlled equipment until dropping the weight.

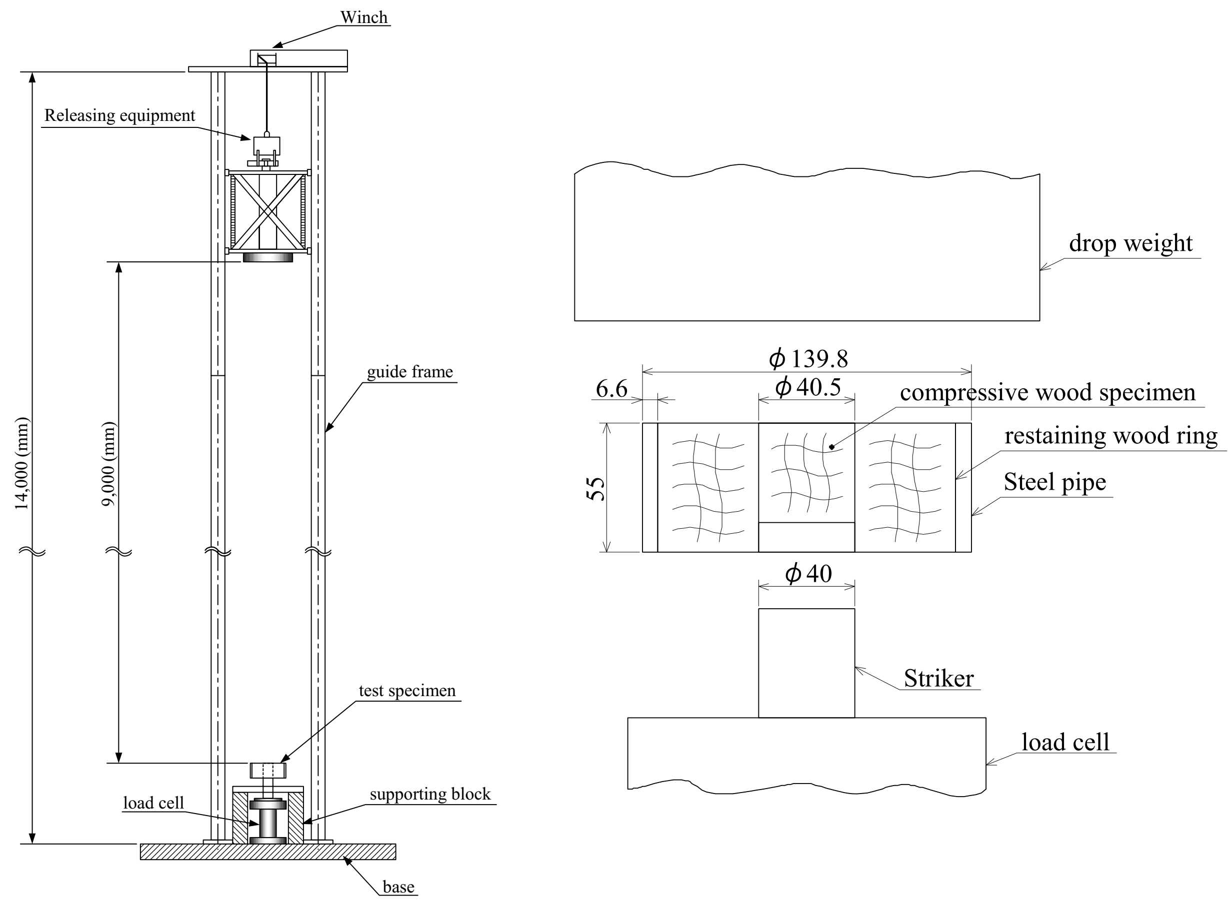


Figure 4. Equipment of dynamic compressive test

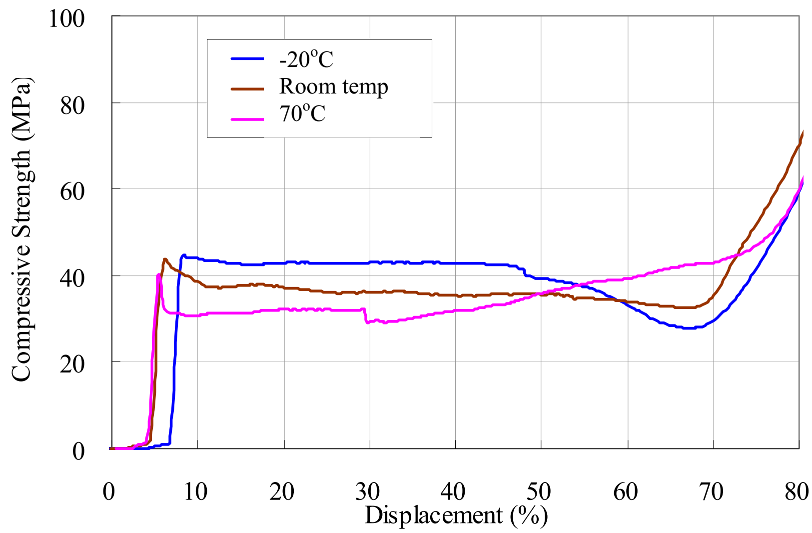
TEST RESULTS

Static Condition

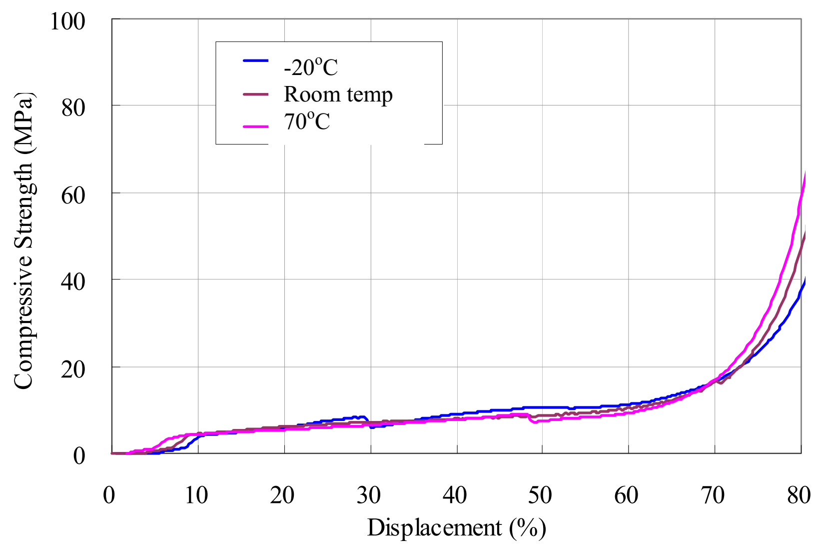
It was confirmed that the compressive strength of the wood at -20 °C increased slightly and the strength of the wood at 70 °C decreased slightly compared with the strength of room temperature in both directions parallel and perpendicular to grain.

Table 3. Relative change in compressive strength from room temperature on static condition

Material	Direction of wood	Test temp. (°C)	Moisture Content (%)	Average compressive stress (MPa) (Range of strain 10-50 %)	Relative change
Red wood	Parallel to grain	-20	7	43	1.17
		R.T.	9	36	1.00
		70	7	32	0.87
	Perpendicular to grain	-20	9	7.4	1.07
		R.T.	9	6.9	1.00
		70	7	6.6	0.95



(a) Direction of parallel to grain

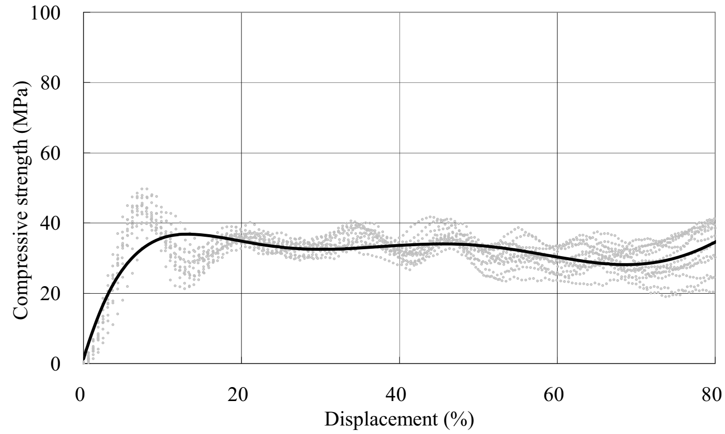


(b) Direction of perpendicular to grain

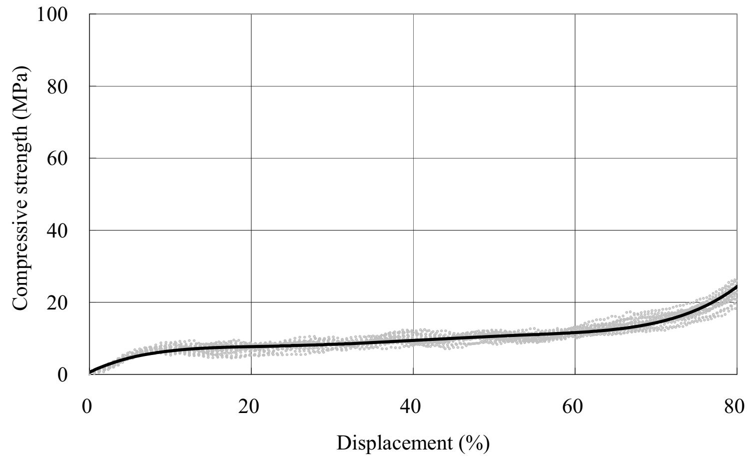
Figure 6. Compressive strength property of redwood on static condition

<u>Dynamic Condition</u>

Compressive strength properties of redwood on dynamic condition at room temperature are shown in Figure 5. The average curve for each direction of wood were obtained for designing shock absorbing cover based on these data. Figure 6 shows one example of the dynamic test measurement data at -20 °C and 70 °C. Property at each temperature was very similar. It was confirmed that redwood was excellent for shock absorbing cover because compressive property was maintained almost constantly in the wide range of deformation and it can absorb a lot of energy in this range.

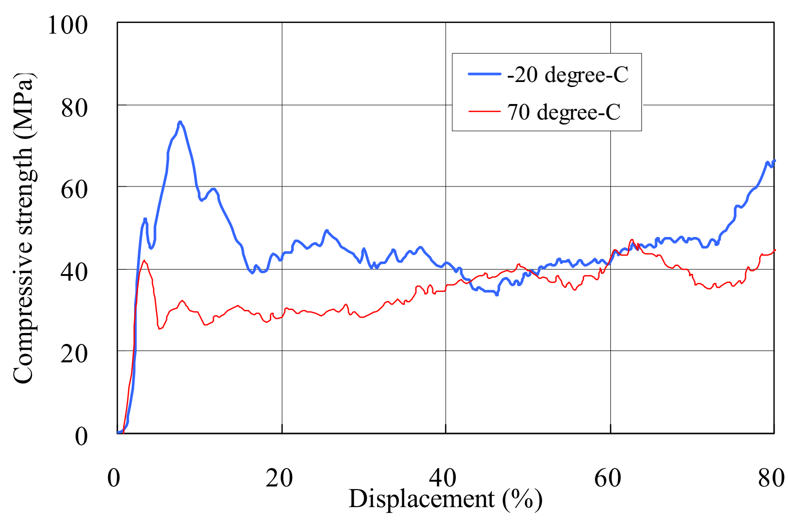


(a) Direction of parallel to grain

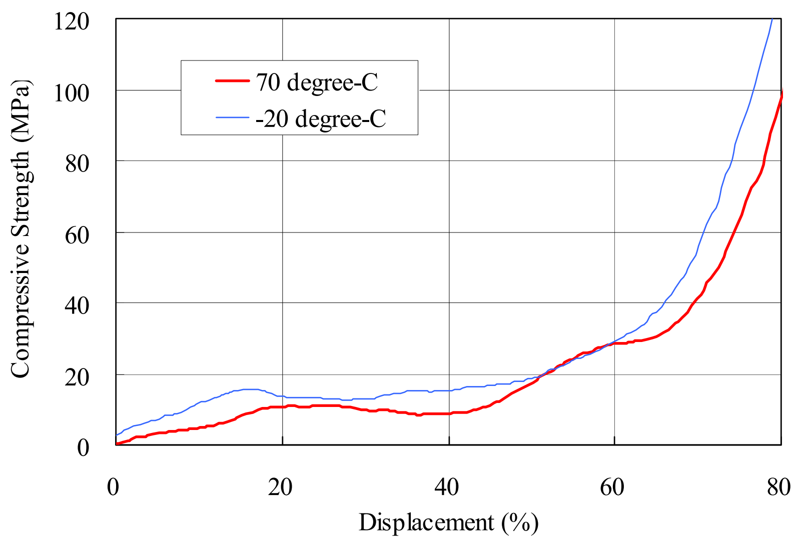


(b) Direction of perpendicular to grain

Figure 5. Compressive strength property of redwood on dynamic condition at room temperature



(a) Direction of parallel to grain



(b) Direction of perpendicular to grain

Figure 6. Dynamic compressive strength property at -20 °C and 70 °C

Table 4 shows the result of average strength of dynamic test. As for the direction of parallel to grain, the compressive strength at -20 °C was higher about 24% and the strength at 70 °C was lower about 8% than that of room temperature. On the other hand, for the direction of perpendicular to grain, the compressive strength at -20 °C was higher about 30% and the strength at 70 °C was lower about 15% than that of room temperature.

Table 5 and Table 6 show the relative change rate to temperature of compressive strength published in "Wood Handbook" of United States Department of Agriculture[1)] and the results presumed by linear interpolation or extrapolation in the tested temperatures. According to Wood Handbook, it is shown that there is almost a linear relation of compressive strength to temperature in the range from -100 °C to 100 °C. Compared the relative change rates in Table 4 with those in Table 5 and Table 6, it was confirmed that the change rates in this test was a little smaller than the values presumed from wood handbook. Though the published data of moisture content 0%, 0%-6% at -20 °C are smaller than the tested result, it seems that the moisture content influences strength of wood.

And another published data of redwood [2)] and the results presumed by linear interpolation or extrapolation in the tested temperatures from these data are shown in Table 7. It was confirmed that the relative change rates of strength in this test was smaller than the published data compared the results in Table 4 and Table 7.

There is a significant correlation between the change rate of compressive strength and the moisture content according to Table 5 and Table 6. It is surmised that the strength of redwood becomes higher in low temperature because of the freeze of moisture contented in wood cell, and lower in elevated temperature because of the decrease of density caused by vaporization of moisture.

Table 4.Relative change in compressive strength from room temperature on dynamic condition

Material	Direction of wood	Test temp. (°C)	Moisture Content (%)	Average compressive stress (MPa) (Strain 20-50 %)	Relative change
Red wood	Parallel to grain	-20	8	42 [1]	1.24
		R.T.	9	34 [2]	1.00
		70	7	31 [1]	0.92
	Perpendicular to grain	-20	9	17 [1]	1.30
		R.T.	9	13 [2]	1.00
		70	7	11 [1]	0.85

Note 1) These values are the average of 4 data.
Note 2) These values are the average of 15 data.

Table 5.Relative change in compressive strength of parallel to grain from 20°C for clear wood [1]

	Published data [1]			Linear inter/extrapolated		
M.C.(%) \ Temp.(°C)	-50	20	50	-20	20	70
0	1.2	1.0	0.90	1.11	1.0	0.83
12 - 45	1.5	1.0	0.75	1.29	1.0	0.58

Table 6.Relative change in compressive strength of perpendicular to grain from 20°C for clear wood [1]

	Published data [1]			Linear inter/extrapolated		
M.C.(%) \ Temp.(°C)	-50	20	50	-20	20	70
0 - 6	-	1.0	0.8	1.26	1.0	0.67
>10	-	1.0	0.65	1.47	1.0	0.42

Table 7. Relative change in compressive strength of parallel to grain from room temperature for redwood [2]

	Published data [2]			Linear inter/extrapolated		
M.C.(%) \ Temp.(°C)	-29	20	66	-20	20	70
12	1.4	1.0	0.7	1.33	1.0	0.67

CONCLUSIONS

The static and dynamic tests of redwood were performed, it was confirmed that the compressive strength of redwood are available for the shock absorbing cover of transport cask. The compressive tests at -20 °C, room temperature and 70 °C were performed and the dependency of the compressive strength to the temperature has been obtained. It was estimated that the strength of redwood becomes higher at -20 °C, it becomes lower at 70 °C compared with that of room temperature. The increasing or decreasing rates of the strength were almost equal or lower than the data of published literature.

REFERENCES

1) Wood Handbook Wood as an Engineering Material, U.S. department of Agriculture, Forest Service, Forest Products Laboratory, 1999.
2) Characterizing Large Strain Crush Response of Redwood, Sandia National Laboratories, SAND96-2966, 1996.