DYNAMIC MECHANICAL BEHAVIOR OF BLACK CHERRY[1] (*PRUNUS SEROTINA* EHRH.)

P. R. Blankenhorn
School of Forest Resources and Material Sciences Department, the Pennsylvania State University, University Park, PA. 16802

D. E. Kline
Material Sciences Department, the Pennsylvania State University, University Park, PA. 16802

F. C. Beall
School of Forest Resources, the Pennsylvania State University, University Park, PA. 16802

(Received 27 October 1972)

ABSTRACT

The dynamic mechanical properties of black cherry (*Prunus serotina* Ehrh.) have been investigated as a function of temperature at audio frequencies. Relaxation processes are evident near 200, 360, and 510 K. The process near 200 K was investigated as a function of initial moisture content (based on mass measurements prior to testing). At moisture contents greater than about 20%, the damping peak is centered near 185 K. This relaxation shifts with moisture content, and at moisture contents below 6%, the peak is centered near 225 K. The relaxation in the 360 K region is also associated with initial moisture content. For oven-dry black cherry specimens, the dynamic mechanical properties in the 360 K region are nearly temperature-independent. The relaxation near 510 K is believed to be associated with thermal degradation of wood constituents that are known to degrade in that temperature region.

Additional Keywords: *Prunus serotina*, thermodynamic properties, dynamic modulus of elasticity, internal friction, moisture content.

INTRODUCTION

In the study of wood, the dynamic mechanical properties are used to gain an understanding of the mechanical behavior and molecular structure. These data can provide information concerning the rigidity, structural peculiarities, relaxation behavior, and microscopic mechanical behavior of wood. Dynamic mechanical properties of wood can be typically investigated over a range of frequencies, moisture contents and temperatures. The potential usefulness of this method has been partially demonstrated by some researchers (Bernier and Kline 1968a; Jayne 1955; Jayne 1959; James 1961; Pentoney 1955).

The dynamic mechanical properties (DMP) of wood as a function of frequency, measured at room temperature, have been investigated, and it was found that the internal friction (Q^{-1}) varied with frequency (Jayne 1955; Pentoney 1955; Fukada 1951). Hearmon (1958) found that shear and rotatory inertia effects reduced the frequency of flexural vibration particularly in the higher modes of vibration, as compared to those frequencies predicted by theory. Kollmann and Krech (1960) reported that a change in the internal friction with frequency (1–8 kHz frequency range) was not detectable for spruce (*Picea* sp.) specimens, and that the increase in Q^{-1} was due to the change in the aspect ratio of their specimens. The actual contribution of shear to the internal friction in free trans-

---

[1] The authors are indebted to Dr. Wayne K. Murphey for suggestions concerning the research. The paper that won second place in the 23rd Annual Wood Award Competition (Dr. P. R. Blankenhorn) contained some of the data (100 to 300 K temperature region) presented in this article, but that paper was not published. This work was authorized for publication on 9 November 1972 as paper no. 4328 in the journal series of the Pennsylvania Agricultural Experiment Station. This work was supported in part by the Pennsylvania Science and Engineering Foundation.

verse vibration has not yet been determined. In the present investigation, shear effects would be minimized since all specimens were tested in the fundamental mode and the specimen length is ~ 16 times the diameter.

Some of the effects of moisture content on internal friction at room temperature have also been investigated. Moslemi (1968) reported that a moisture gradient did not significantly affect internal friction values. Diener et al. reported that cherry bark appeared to dissipate about four times as much energy as cherry wood (10^{-4} to 10^2 Hz). Pentoney (1955) and Kollmann and Krech (1960) obtained internal friction data at one temperature for a wide range of moisture contents. The minimum internal friction values at room temperature occurred at about 6% moisture content (MC), and Q^{-1} values increased with both increasing and decreasing moisture content (Pentoney 1955; Kollmann and Krech 1960; Suzuki 1962).

Because of the dynamic mechanical behavior of the wood-water complex at room temperature, it was postulated that relaxations in the DMP at other temperatures as a function of moisture content may influence the DMP values at room temperature. Fukada (1951) obtained DMP as a function of temperature (243 to 373 K) for only the oven-dry condition. Bernier and Kline (1968a) demonstrated that a moisture content of 6% had an effect on the DMP of birch (*Betula alleghaniensis* Britton) at low temperatures (< 300 K) as compared to oven-dry wood. James (1961) measured the DMP of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) as a function of moisture content (1.8% to 27.2%) and temperature (255 to 366 K). It was found that at less than 7.2% MC and near 255 K there appeared to be an internal friction peak of unknown nature. It is the purpose of this study to present results and analyze the behavior of the dynamic mechanical properties of black cherry (*Prunus serotina* Ehrh.) as a function of temperature (100 to 600 K) and moisture content (up to 20%).

EXPERIMENTAL

Apparatus

In the present investigation, dynamic elastic modulus and internal friction were measured as a function of temperature in a transverse dynamic mechanical properties apparatus (Kline 1956) at audio frequencies. In this apparatus, a specimen is suspended horizontally by two strings near the nodes of the primary mode of transverse vibration. One string is attached to a magnetostrictive transducer used to excite the specimen. The other string is attached to the stylus of a piezoelectric crystal pickup cartridge used as a detector. The internal friction of specimens (Q^{-1}) is determined from the half-power level, Δf, of the resonance curve and the resonant frequency, f_o; i.e., $Q^{-1} = \Delta f/f_o$. The dynamic elastic modulus (E') is determined from the resonant frequency and the relationship $E' = (1/12.7)(l^4\rho/R^2)f_o^2$. In this relationship, E' is the elastic modulus in dynes/cm^2, l is the specimen length in cm, ρ is the specimen density in g/cm^3, which is obtained from mass and average geometric dimensions prior to testing, and R is the radius of gyration for the specimen about an axis perpendicular to the specimen length.

A block diagram of the dynamic mechanical properties transverse testing apparatus is shown in Fig. 1. The oscillator voltage is amplified and used to drive the transducer which excites the specimen. The temperature can be varied in the test chamber from 80 to 800 K. Typically, the temperature is steadily increased at a rate of about 1 K/min while nitrogen gas is slowly passed into the chamber. Specimen response is detected, amplified, filtered, and recorded (AC level recorder and digital counter). The dual-trace oscilloscope is used to compare the input signal and specimen response to detect distortion and harmonics. Details concerning the apparatus, accuracy of measurement, etc. are given by Blankenhorn (1972) and Kline (1956).

Strings are placed near the theoretical nodes. Previous measurements have shown that the string position on the specimen

TABLE 1. *Properties of black cherry specimens conditioned at room temperature and humidity.**

Specimen	Mass* (g)	Length (cm)	Average Diameter (cm)	Moisture* Content (%)	Q^{-1} Peak Temperature (K)	Resonant Frequency 100 K (Hz)	Resonant Frequency 275 K (Hz)	E' x 10^{-10} (dynes/cm^2) 100 K	E' x 10^{-10} (dynes/cm^2) 275 K
A	2.799	10.656	0.656	20.5	183	2407	1998	17.1	11.8
	2.493	10.652	0.631	7.3	208	2361	2088	17.1	13.3
	2.421	10.649	0.625	4.2	225	2334	2102	16.7	13.6
	2.482	10.657	0.631	6.8	214	2322	2083	16.4	13.2
E	2.856	10.939	0.661	20.0	185, 385, 510	2360	1901	17.5	11.4
	1.567	10.874	0.558	4.0	250	1379	1094	6.4	4.0
F**	2.161	11.061	0.629	2.7	226	2127	1917	13.6	11.0
	2.185	11.062	0.627	3.8	226, 505	2131	1912	13.9	11.3
	1.692	11.060	0.577		250	1864	1661	11.5	9.2
G	2.532	10.732	0.645	23.2	185	2177	1766	13.8	9.1
	2.408	10.727	0.642	17.1	187	2186	1806	13.5	9.2
	2.372	10.727	0.639	15.4	190	2175	1823	13.3	9.4
	2.350	10.726	0.639	14.3	196	2167	1822	13.1	9.3
	2.301	10.723	0.634	11.9	199	2137	1858	12.9	9.7
	2.166	10.717	0.625	5.4	225	2119	1897	12.6	10.1
A'	2.002	10.744	0.641	15.0	192, 360	2554	2174	15.4	11.2
	1.734	10.719	0.610	2.0	245	2482	2234	15.3	12.4
	1.664	10.722	0.601		255	2423	2212	14.8	12.3

*These specimens were machined and frozen. Prior to a DMP test, a specimen was removed from the freezer, allowed to remain at room temperature for less than a half-hour, weighed and tested. Moisture contents reported are based on mass measurements prior to testing. After each test, the specimen was again frozen.

**This specimen was oven-dried in a vacuum oven at 330 K for 24 hr prior to being conditioned at room temperature and humidity.

will influence the damping values. In the initial machining of the specimens, all of the specimen lengths were equal to 10.7 cm ± 2 mm. All specimens were then marked for the string position, which was at about 1.3 cm from each end. Continuous DMP tests conducted on a given specimen were made with the strings positioned in very nearly the same location. All specimens in the present study were oriented in a manner such that the longitudinal and radial directions of the specimens were normal to the strings.

Specimens

The black cherry specimens were selected to be defect-free and were machined in the form of rods approximately 0.6 cm in diameter and 10.7 cm long. Grain was oriented along the specimen length. Specimens designated with letters are from the same cherry tree, and the specimen designated with the symbol *A'* is from a second cherry tree. In addition to specimens from three different cherry trees, specimens from other hardwood species (white ash, hard maple, and black walnut) have been tested, and the data presented here are considered to be representative of all the data obtained. All specimens were selected from trees harvested in central Pennsylvania. Specimens listed in Table 1 were allowed to dry from the green condition at room temperature prior to testing with no procedure to eliminate the moisture gradient, while other specimens (Tables 2 and 3) were conditioned to minimize the moisture gradient.

After initial machining, specimens to be dried at room temperature were frozen in sealed polyethylene bags. A specimen to be tested was removed from the freezer and allowed to remain at room temperature for less than a half-hour, weighed, and tested. After the test the specimen was again frozen. This procedure was continued until all DMP testing of each specimen was completed.

A specimen to be conditioned in a temperature- and humidity-controlled chamber was dried from green to constant weight with the chamber set at an EMC about 2% lower than the desired moisture content. The chamber was then set at the desired moisture content, and the specimen was con-

TABLE 2. *Properties of black cherry specimens conditioned in a temperature- and humidity-controlled chamber.*

Specimen	Mass* (g)	Length (cm)	Average Diameter (cm)	Moisture* Content (%)	Q^{-1} Peak Temperature (K)	Resonant Frequency 100 K (Hz)	Resonant Frequency 275 K (Hz)	$E' \times 10^{-10}$ (dynes/cm^2) 100 K	$E' \times 10^{-10}$ (dynes/cm^2) 275 K
B	2.379	10.710	0.642	14.7	190	2454	2077	16.7	11.9
C	2.183	10.491	0.638	10.3	202	2500	2169	15.3	11.5
	1.986	10.480	0.618	0.4	225	2413	2227	14.7	12.5
D	2.107	10.514	0.638	6.8	211	2379	2110	13.4	10.6

*Moisture content calculations are based on mass measurements prior to DMP testing.

ditioned for about 15 hr, removed from the chamber, weighed, and tested.

The characteristics for the black cherry specimens dried at room temperature and humidity from the green condition can be found in Table 1. One of the purposes of Table 1 is to list the specimen initial moisture content (based on specimen mass prior to DMP testing) and the temperature where the internal friction peak appears to be centered. It is evident from this table that as the moisture content decreases from about 20% to 6%, the temperature where the Q^{-1} peak is centered increases. The data for the black cherry specimens conditioned in a humidity- and temperature-controlled chamber are listed in Tables 2 and 3. The initial specimen moisture content and Q^{-1} peak temperature data listed in Table 2 are similar to those in Table 1.

Some of the DMP tests were conducted from 100 to 275 K in order to control the loss of moisture from the wood. The absolute change in moisture content was less than about 0.5% during the low temperature testing. After testing, oven-dry masses for all specimens were obtained by placing the specimens in a vacuum oven at 330 K for 24 hr.

RESULTS

Dynamic mechanical properties of black cherry

Dynamic elastic modulus and internal friction data for black cherry specimen *A* are presented in Fig. 2 for the 100 to 300 K temperature region. The data are typical of the DMP data of black cherry specimens (*A, G, E,* and *A'*) that were dried at room temperature from the green condition. The *E'* data (Fig. 2) for all moisture contents (20.5% to 6.8%) show evidence of relaxations[2] as a function of temperature. The relaxation in *E'* near 200 K is very pronounced for 20.5% MC. The internal friction data associated with 20.5% MC have a value of about 2.3×10^{-3} at 100 K and after

---

[2] A mechanical relaxation is essentially the nonelastic behavior of a material, or stress and strain are functions of each other and time. Mechanical relaxation phenomenon are generally investigated by stress relaxation, creep, or DMP studies. A more detailed explanation is given by Woodward and Sauer (1965).

TABLE 3. *Properties of black cherry specimens I, J, and K conditioned in a temperature- and humidity-controlled chamber.*

Specimen	Mass* (g)	Length (cm)	Average Diameter (cm)	Moisture* Content (%)	Q^{-1} Peak Temperature (K)	Resonant Frequency 300 K (Hz)	Resonant Frequency 400 K (Hz)	$E' \times 10^{-10}$ (dynes/cm^2) 300 K	$E' \times 10^{-10}$ (dynes/cm^2) 400 K
I	2.358	10.562	0.644	14.9	367	2068	2055	11.1	10.9
J	2.299	10.499	0.646	13.8	360	2080	2069	10.6	10.5
K	2.193	10.522	0.632	9.3	360	2126	2052	11.6	10.8

*Moisture content calculations are based on mass measurements prior to DMP testing.

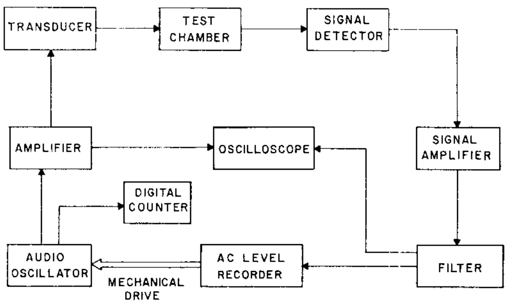

FIG. 1. Block diagram of DMP transverse testing apparatus.

a slight hump near 160 K, reach a peak value of about 29 × 10^{-3} near 185 K. Damping data for the other tests are higher at 100 K but lower at 300 K compared to the data taken at 20.5% MC, and the actual shape of the Q^{-1} peak changes markedly with different moisture contents. The Q^{-1} curve tends to broaden and shift with decreasing moisture content. The E' and Q^{-1} data for a moisture content of 6.8% were obtained after the specimen had been oven-dried and allowed to recondition at room temperature and humidity.

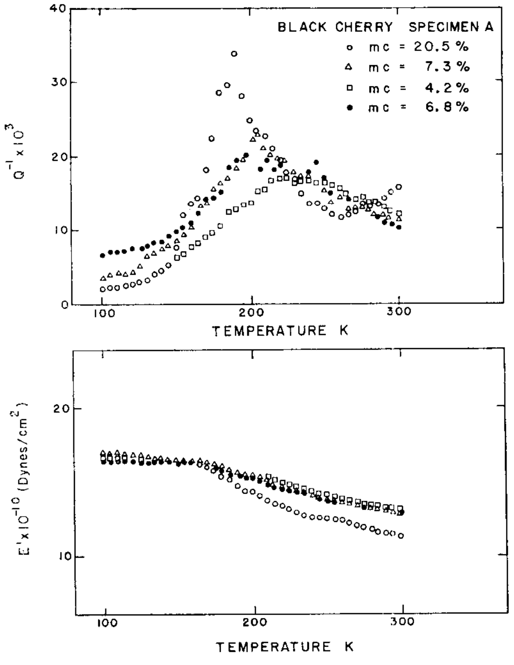

FIG. 2. Dynamic elastic modulus and internal friction of black cherry (specimen A) as a function of temperature.

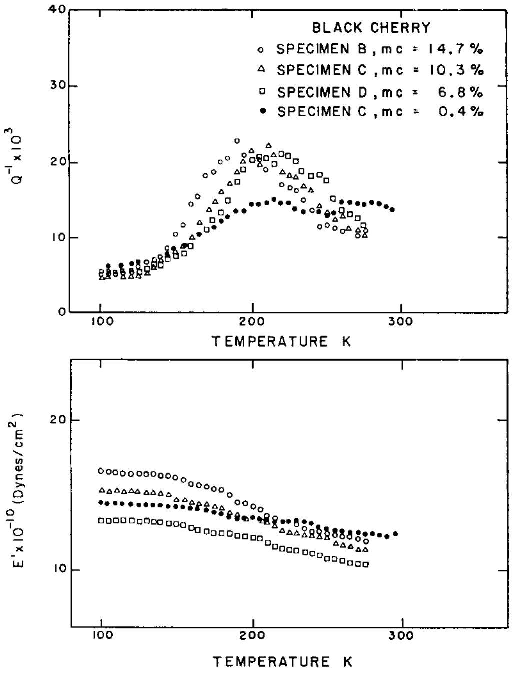

FIG. 3. Dynamic elastic modulus and internal friction of black cherry as a function of temperature.

In contrast to Fig. 2, DMP in Fig. 3 are given for a series of black cherry specimens (*B*, *C*, and *D*) that were placed in the conditioning chamber prior to testing from 100 to 275 K. These specimens were tested to see if conditioning in a temperature- and humidity-controlled chamber affected the

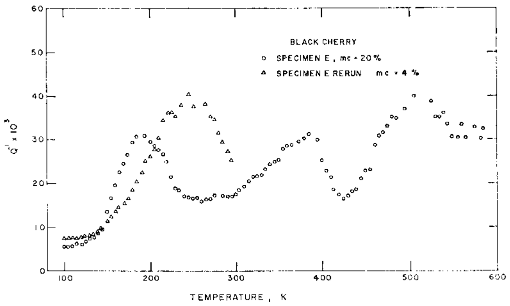

FIG. 4. Internal friction of black cherry specimen *E* as a function of temperature.

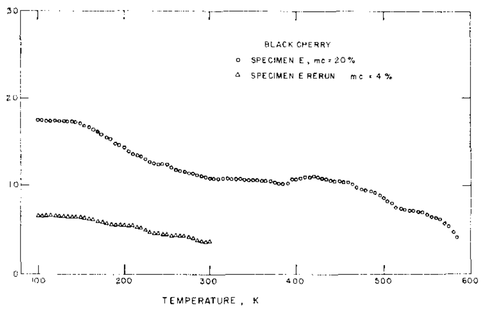

FIG. 5. Dynamic elastic modulus of black cherry specimen *E* as a function of temperature.

DMP results. For specimens *B*, *C*, and *D*, the Q^{-1} curves tend to broaden with decreasing moisture content (14.7% to 6.8%) similar to the data of specimens *A* and *G*. The modulus curves for the tests (except specimen *C* rerun at 0.4% MC) in Fig. 3 have a generally similar shape and display relaxations associated with the Q^{-1} peak much as in Fig. 2, but the overall levels differ. Data for specimen *C*, at 0.4% MC, exhibited a smaller relaxation than the data for the other tests at higher moisture contents. The Q^{-1} data increase from a value of about 6.0×10^{-3} at 100 K to a value of 14.5×10^{-3} near 225 K, where it remains relatively temperature-independent.

To illustrate the characteristics of results obtained over a wider temperature range (100 to 600 K), the internal friction and dynamic elastic modulus data for black cherry specimen *E* are presented in Figs. 4 and 5. Data for specimen *E* at 20.0% MC (100 to 585 K) reveal three relaxations in this temperature range near 200, 360, and 510 K. After this specimen was retested (100 to 300 K) with a moisture content of the wood char at about 4%, the data displayed a relaxation in the 250 K region and sharply lower rigidity in comparison with the first test at 20.0% MC. This appears to be typical behavior as will be discussed in another paper. In the second test of the specimen (100 to 300 K), the damping at 100 K was slightly higher than the first test at 20.0% MC and the height and temperature position of the Q^{-1} peak differs from that of the first test.

In order to demonstrate the effects of

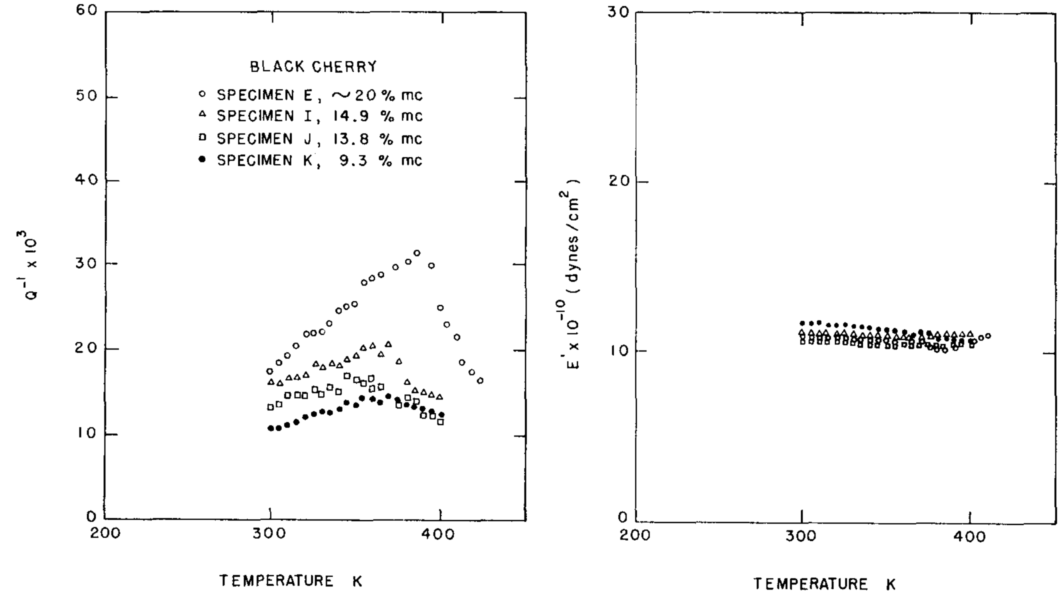

FIG. 6. Dynamic elastic modulus and internal friction of black cherry specimens *E*, *I*, *J*, and *K* as a function of temperature.

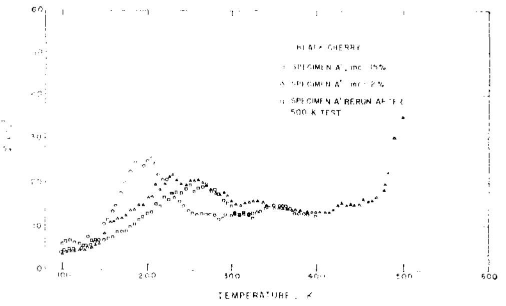

FIG. 7. Internal friction of black cherry specimen A' as a function of temperature.

moisture content on the dynamic elastic modulus and internal friction in the temperature region of 300 to 400 K, data from four cherry specimens (E, I, J, and K) are shown in Fig. 6. Specimens I, J, and K were conditioned in a temperature- and humidity-controlled chamber. The data for specimen E (Figs. 4 and 5) in the temperature range of 300 to 400 K are shown on this curve in order to make a comparison. As the moisture content decreased from 20% for specimen E to 9.3% for specimen K, the internal friction peak decreased in size and shifted in temperature position. Modulus data of all specimens displayed slight complementary relaxation associated with these internal friction peaks. The initial moisture content values reported for these specimens are based on mass measurements obtained prior to DMP testing because as the specimens were tested from 300 to 400 K, the specimens were changing moisture content. It is realized that in testing above 300 K, the specimen moisture content is decreasing rapidly, but the data are presented in order to demonstrate that a difference in the initial moisture content at 300 K produces an effect in the relaxation in the 300 to 400 K region. After testing to 400 K, specimens I, J, and K were weighed and oven-dried, and the moisture contents of these specimens were less than 1%.

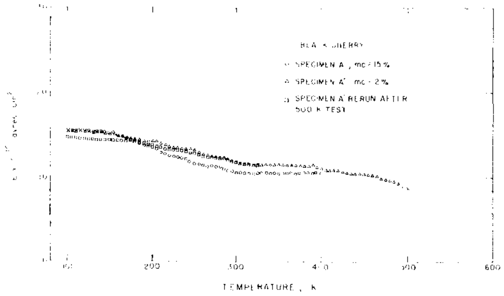

FIG. 8. Dynamic elastic modulus of black cherry specimen A' as a function of temperature.

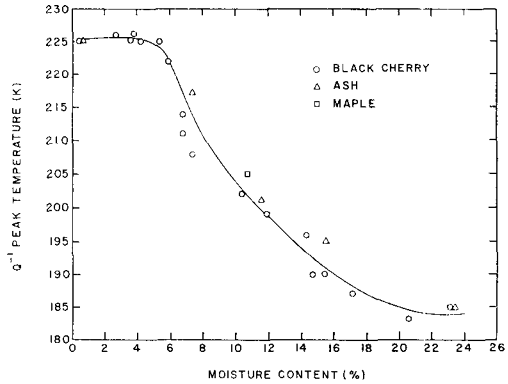

FIG. 9. Internal friction peak temperature vs moisture content for black cherry, white ash, and hard maple.

Other cherry specimens from different cherry trees have been tested and to illustrate that similar DMP results are obtained from another cherry tree, the DMP of cherry specimen A' are given in Figs. 7 and 8. Internal friction results for the first test (Fig. 7), from 100 to 400 K and a moisture content of about 15%, reveal a large peak centered near 192 K. In the second test (100 to 500 K), the low temperature internal friction peak is centered near 245 K and the onset of another internal friction maximum is evident near 500 K. After testing to 500 K, the internal friction in the third test (100 to 325 K) has a peak centered near 255 K. In the first test (15% MC) from 100 to 400 K, the modulus (Fig. 8) has a relaxation near 200 K. The modulus displays a relaxation near 250 K and the onset of a relaxation near 500 K on the second test from 100 to 500 K. In the third test, the modulus has a relaxation in the 255 K region.

DISCUSSION

Dynamic mechanical behavior of black cherry

The effects of moisture content and heat treatment on the dynamic mechanical behavior of cherry from 100 to 300 K were investigated in detail (Blankenhorn 1972). The data presented here (also see Blankenhorn 1972) show that when cherry specimens that have not been oven-dried are tested from 100 to 550 K, the DMP exhibit three main relaxations. These are located near 200, 360, and 510 K, as shown in Figs. 4 and 5 (20% MC). Cherry specimen *F*, that was oven-dried prior to testing, exhibited only two main relaxations near 225 and 510 K.

The internal friction peaks observed at 185 K for specimen *A* (20.5% MC) and specimen *G* (23.2% MC) are quite similar in that they are relatively large, occur in the same temperature range, and exhibit a slight hump near 160 K. This hump has also been observed in white ash (*Fraxinus americana* L.) for a moisture content of 23.4% (Kline et al. 1972). The nature of this hump is unknown, but it may be related to the onset of some internal mobility in sorbed water.

No apparent difference is evident in comparing the DMP data in the temperature region of 100 to 300 K of specimens *A*, *B*, *C*, *D*, and *G*. Specimens *A* and *G* were conditioned at room temperature resulting in a significant moisture gradient (see specimen section), and specimens *B*, *C*, and *D* were conditioned in a humidity- and temperature-controlled chamber to minimize the moisture gradient. This result is similar to the results of Moslemi (1968) in that he reported that the internal friction data, in the frequency range of 60 Hz at room temperature for white oak (*Quercus alba* L.) and yellow poplar (*Liriodendron tulipifera* L.) were not affected by a moisture gradient in the wood.

The low temperature data reported here for cherry are also similar to the internal friction data in the audio frequency range of birch (Bernier and Kline 1968a), Douglas-fir (James 1961), white ash (Kline et al. 1972), and hard maple (*Acer* sp.) (Blankenhorn et al. unpublished results). The internal friction peak for all cherry specimens at moisture contents greater than about 19% is centered at 185 K. Stepanov et al. (1968) reported in a study using a nuclear magnetic resonance (NMR) procedure that water molecules begin to attain appreciable internal mobility near 195 K. Also Kimura et al. (1972) using broad-line NMR reported that the proton movement of adsorbed water in cellulose changes markedly in the temperature region of 180–200 K. This region is the same temperature range of the internal friction peaks reported here for cherry. The NMR frequencies are somewhat higher than those of this investigation, and differences in the peak temperature are to be expected.

At moisture contents below about 6%, the remaining adsorbed water is more tightly bound in an effective monolayer and probably requires more energy (higher temperatures) to observe its effects. These data are consistent with those of James (1961), who observed higher internal friction values for low moisture contents and lower Q^{-1} values for higher moisture contents at 255 K.

In the investigation of viscose rayon (regenerated cellulose) using longitudinal vibrations in the frequency range of 8 to 80 Hz, Dunell and Price (1955) reported an internal friction peak near 230 K. They attributed this peak to motion in the amorphous regions and/or -CH_2OH side groups. Other polymers such as polyimides and polyamides display sorbed water effects in the DMP in the temperature region of 100 to 300 K. Bernier and Kline (1968b) reported a prominent relaxation associated with sorbed moisture in polyimide near 230 K, and upon drying the inflection was essentially eliminated.

Woodward and Sauer (1965) reviewed some of the literature available on the DMP of a variety of polyamides. On some of the polyamides, detailed DMP studies of the effects of temperature and moisture content have been reported. It was found that generally as the moisture content increased from 0 to 6%, the internal friction peak height in the temperature region of 155 K decreased and the internal friction peak near 300 K shifted to lower temperatures (Woodward and Sauer 1965). In polymers such as polyimides and polyamides, a moisture content of about 1% can produce significant effects in the dynamic mechanical properties in the 100 to 300 K region (Bernier and Kline 1968b; Woodward and Sauer 1965). In a polyamide such as nylon (Woodward and Sauer 1965), the maximum amount of sorbed water is ~ 6% or so. On the other hand, in wood the fiber saturation point can be near 30%. Effects in the dynamic mechanical properties of wood from 100 to 300 K, for moisture contents of less than 6% have been observed. As the moisture content in wood decreases, the relaxation due to moisture (100 to 300 K) becomes less prominent. This result is similar to the results for other polymers, but the actual moisture content is different for the different materials.

Internal friction data for relatively dry cherry specimens suggest that water-related damping may not be the only contributor to the area under the low temperature internal friction peak. Significant internal friction is present in these dry specimens in the temperature region of 100 to 300 K. Internal friction data for cherry specimen *C* at 0.4% MC (Fig. 3) show that the Q^{-1} increases between 130 and 210 K, after which the data are relatively flat up to 300 K. Similar DMP behavior for the oven-dry condition has been observed for white ash (Kline et al. 1972). It is interesting to note that 130 K is the same temperature region in which the internal energy dissipation begins to increase with increasing temperature for specimens at all moisture contents.

In every case the relatively large internal friction peak (MC > 6%) observed below 300 K has a modulus relaxation associated with it. The differences in the overall levels of E' of different cherry specimens reported (for instance Fig. 3) are ascribed to the variability from specimen to specimen and possibly to the effects of the different moisture contents (James 1961; Tang and Hsu 1972). On the other hand, data for specimen *A* and *G* illustrate that the overall levels of E' for a given specimen in the temperature region reported are not changed drastically by different moisture contents. It is interesting to note that all specimens at all moisture contents investigated displayed an increase in rigidity at 100 K as compared to that at 275 K. In dry specimens, this would be expected because of thermal contraction of the lattice and increased influence of van der Waals forces. When water is present, the modulus data suggest that below about 180 K the water acts as a rigid filler leading to a higher elastic modulus.

The relationship of the low temperature internal friction peak to Q^{-1} values at room temperature is evident in Fig. 2. At a moisture content of 6.8%, the room temperature value of Q^{-1} is lower than it is at 7.3%, 4.2%, or 20.5%. In Fig. 3 the trends at 275 K are similar to the trends at 275 K in Fig. 2. These data agree with those presented by Pentoney (1955) and Kollmann and Krech (1960), who measured the internal friction at room temperature for different wood species at various moisture contents, and those of Bernier and Kline (1968a) for birch and James (1961) for Douglas-fir, who measured the DMP as a function of temperature and moisture content. In a similar manner, the trends in the magnitude of internal friction values at 300 K as the moisture content is increased from 9% to 20% in Fig. 6 are similar to those of Pentoney (1955), Kollmann and Krech (1960), and James (1961). It thus seems evident that room temperature Q^{-1} values are related to relaxations whose damping peaks occur at other temperatures.

The relation between the temperature of the main Q^{-1} peak maximum below 300 K and the initial moisture content is presented in Fig. 9. The internal friction peak temperature was determined by drawing a line through the slopes on both sides of the low temperature Q^{-1} peak data. The temperature at the intersection of these lines is designated the Q^{-1} peak temperature. In Fig. 9 the curve drawn through the data points is meant to be only a general indication of the trend in the data. The relationship of the Q^{-1} peak temperature versus moisture content permits the prediction of the Q^{-1} peak temperature for a given moisture content for black cherry and some other hardwood species (Kline et al. 1972; Blankenhorn et al. unpublished results). There appear to be three regions to this curve. At moisture contents below 6%, the peak temperature is near 225 K. Above about 20% MC, the peak temperature is near 185 K. Between 6% and 20% MC, the temperature where the internal friction peak is centered is a function of moisture content.

The internal friction peak near 360 K and its associated relaxation were investigated to ascertain if moisture content is related to the relaxation mechanism. As the temperature increased, the internal friction for all specimens (Fig. 6) displayed evidence of a relaxation peak. Although the moisture content changes in tests above 300 K, the data show that a more pronounced relaxation is evident with higher initial moisture content at 300 K. The modulus for these specimens displays evidence of a slight relaxation associated with this peak. These internal friction data are similar to those data of James (1961) for Douglas-fir. He reported that as the moisture content increased from 7% to 27%, the internal friction values near 366 K also increased, and that evidence of the onset of a peak near 366 K is more pronounced at higher moisture contents. For specimen *F*, that was oven-dried prior to testing and tested at moisture contents below 6%, the internal friction from 300 to 400 K is relatively temperature-independent. It appears that the relaxation in the 360 K region is dependent upon moisture content.

The dynamic mechanical properties of black cherry in the temperature region of 100 to 300 K are changed irreversibly if the specimens have received heat treatment temperature histories of greater than 500 K. The temperatures at which the thermal degradation of the different wood constituents becomes appreciable are reported to be: above 473 K for hemicellulose; above 513 K for cellulose; and above 533 K for lignin (MacKay 1967; Beall and Eickner 1970). The relaxation in the DMP of cherry near 510 K is believed to be associated with the thermal degradation of the wood constituents, and the possible recombination of the degradation products into a carbon structure since the tests were conducted in a nitrogen atmosphere. Because of these facts, a detailed explanation of the process near 510 K has not been proposed. It is intended that a paper will be published separately concerning the effects of carbonization (> 600 K) in a nitrogen atmosphere on the DMP of wood.

CONCLUSION

The dynamic mechanical behavior of black cherry (*Prunus serotina* Ehrh.) in the audio frequency range was investigated as a function of temperature from 100 to 600 K. With appreciable initial moisture contents, there are three main relaxations for black cherry specimens in the temperature region of 100 to 600 K. These occur at about 200, 360, and 510 K. A detailed investigation of the relaxation near 200 K showed that this relaxation is largely related to the presence of sorbed water. The temperature at which the low temperature internal friction peak is centered increases as the initial moisture content decreases. Below 6% moisture content, the peak temperature is near 225 K, and above 20% moisture content, the peak temperature is near 185 K. In the 360 K region, the relaxation is associated with initial moisture content. Internal friction values at room temperature are related to relaxations that occur at other temperatures. The relaxation near 510 K may be associated with the thermal degradation of the wood constituents that are known to occur in that temperature region.

REFERENCES

BEALL, F. C., AND H. W. EICKNER. 1970. Thermal degradation of wood components: a review of the literature. U.S. Forest Service Research Paper. FPL 130:1–26.

BERNIER, G. A., AND D. E. KLINE. 1968a. Dynamic mechanical behavior of birch compared with methyl methacrylate impregnated birch from 90 to 475 K. For. Prod. J. 18(4):79–82.

BERNIER, G. A., AND D. E. KLINE. 1968b. Dynamic mechanical behavior of a polyimide. J. Appl. Polym. Sci. 12:593–604.

BLANKENHORN, P. R. 1972. Dynamic mechanical behavior of black cherry (*Prunus serotina* Ehrh.). Ph.D. Thesis. Pennsylvania State University, University Park, Pa.

DIENER, R. G., F. H. BUELOW, AND G. E. MASE. 1968. Viscoelastic analysis of the behavior and properties of cherry bark and wood under static and dynamic loading. ASAE 2(3): 323–331.

DUNELL, B. A., AND S. J. W. PRICE. 1955. Dispersion of mechanical properties of viscose rayon at low temperature. J. Polym. Sci. 18: 305–306.

FUKADA, E. 1950. The vibrational properties of wood I. J. Phys. Soc. Jap. 5:321–327.

———. 1951. The vibrational properties of wood II. J. Phys. Soc. Jap. 6:417–421.

HEARMON, R. F. S. 1958. The influence of shear and rotatory inertia on the free flexural vibration of wooden beams. Brit. J. Appl. Phys. 9:381–388.

JAMES, W. L. 1961. Effect of temperature and moisture content on: internal friction and speed of sound in Douglas fir. For. Prod. J. 11(9):383–390.

JAYNE, B. A. 1955. A non-destructive test of glue bond quality. For. Prod. J. 5(5):294–301.

———. 1959. Indices of quality . . . vibrational properties of wood. For. Prod. J. 9(11):413–416.

KIMURA, M., H. HATAKEYAMA, M. USUDA, AND J. NAKANO. 1972. Studies on adsorbed water in cellulose by broad-line NMR. J. Appl. Polym. Sci. 16:1749–1759.

KLINE, D. E. 1956. A recording apparatus for measuring the dynamic mechanical properties of polymers. J. Polym. Sci. 22:449–454.

KLINE, D. E., R. P. KREAHLING, AND P. R. BLANKENHORN. 1972. Dynamic mechanical properties and structure of white ash (*Fraxinus americana* L.) wood. Pages 185–205 *in* Advances in polymer science and engineering. Plenum Press, New York.

KOLLMANN, F., AND H. KRECH. 1960. Dynamische Messung der elastischen Holzeigenschaften und Dampfung. Holz Roh-Werkst. 18(2):41–54.

MACKAY, G. D. M. 1967. Mechanism of thermal degradation of cellulose: a review of the literature. Canada Department of Forestry and Rural Development, Forestry Branch, Dept. Pub. 1201, O.D.C. 813(4):1–20.

MOSLEMI, A. A. 1968. A study of moisture content gradients in wood by vibrational techniques. Wood Sci. 1(2):77–85.

PENTONEY, R. E. 1955. Effect of moisture content and grain angle on the internal friction of wood. Compos. Wood 2:131–136.

STEPANOV, V. I., B. S. CHUDINOV, AND L. V. KASHKINA. 1968. Zh. Khim. ABIPC 39(10):8783.

SUZUKI, M. 1962. The effects of water-sorption and temperature on dynamic Young's modulus and logarithmic decrement of wood. J. Jap. Wood Res. Soc. 8(1):13–18.

TANG, R. C., AND N. N. HSU. 1972. Dynamic Young's moduli of wood related to moisture content. Wood Sci. 5(1):7–14.

WOODWARD, A. E., AND J. A. SAUER. 1965. Mechanical relaxation phenomena. Pages 637–723 *in* Physics and chemistry of the organic solid state. Interscience Publishers, New York.