Detection and analysis of the stress relaxation properties of thin wood composites using cantilever-beam bending

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Abstract

At present, the discussion on the stress relaxation properties of wood and wood materials is usually investigated in tension, mid-point bending and dual cantilever bending methods. This paper aims to study the stress relaxation properties of thin wood composites using a cantilever-beam bending method. According to the stress relaxation tests, we found this detection method could be feasible. From the stress relaxation plots the initial rate is fast and then slows down after some time. We compared the stress relaxation and the relaxation coefficient for specimens from particleboard, high density fiberboard, medium density fiberboard, and wood fiber plastic boards. We looked at 2 hours test vs 3 hour test to determine if it might be possible to determine stress relaxation over a 2 hour time span. The stress curves for the high-density fiberboard and the particle board are more consistent between specimens. The test stress curves of the medium density fiberboard are a little less consistent. The wood fiber plastic specimens were harder less consistent in the data to determine the relaxation coefficient. The relaxation coefficient value corresponded to the stress relaxation, where minimal stress relaxation occurred in the specimens then the coefficient value was also lower and if the stress relaxation was higher, then the coefficient value was also higher. This is preliminary work to determine the potential for obtaining the relaxation characteristics using a simple log model. There is a need to further study the stress relaxation for composite boards using a different model but the cantilever bending method may be a useful method for determining this characteristic.

Keywords: thin wood composites, cantilever-beam bending, stress relaxation, relaxation coefficient

Introduction

Thin wood composites defined in this paper includes fiberboard, particleboard, wood-fiber plastic, reconstituted veneer, pulp molded products that measure between 1 to 5mm (Zhang et al. 2010). These composites materials can be used widely for products such as box boards, container boards, non-load-bearing building panels of building materials, architectural, and decorated panels. The performance or structural needs are different for each application requiring an understanding of the mechanical properties of these wood composites. The main mechanical properties of thin wood composites include static elastic modulus, dynamic elastic modulus, storage modulus, loss modulus, shear modulus, and stress relaxation properties. Detecting these mechanical properties of thin wood composites has a very important meaning in production and application fields.

In the past, stress relaxation of wood and wood materials has been investigated by many scientists (Attic et al. 1968, Cheng 1985, Feng and Zhao 2010, Larson 1999). Three kinds of testing methods were mainly used by them, including tension test (Cao et al. 2006, Xie and Zhao 2004), mid-point bending test (Ikuho et al. 2002) and dual cantilever bending test (Ebrahimzadeh et al. 1993). The key mechanism of the test methods is to give and keep an initial deflection to the specimen, and then measure the stress reduced with the time. However, using cantilever-beam bending method, to detect the stress relaxation properties of wood or wood materials has not found. This paper aims to similarly introduce a detection method on the stress relaxation properties of thin wood composites based on the cantilever beam bending theory.

SUMMARY ON STRESS RELAXATION OF WOOD COMPOSITES

The stress relaxation occurs in wood composites when a static displacement is applied to a board or panel where the strain is constant (constant displacement) and the stress continues but at a decreasing rate. The curves of constant strain and decreasing stress rate are shown in Figure 1 (Feng and Zhao 2010). The stress relaxation is a static viscoelasticity phenomena, that changes with the environmental conditions (Cheng 1985). The major factors that influence stress relaxation are temperature, moisture content, strain levels, density, and grain direction. Brown et al used eight species of dried lumber and determined that the approximate relaxation coefficient *m* was inversely proportional to density as measured using horizontal grain pressure gauge (Cheng 1985).

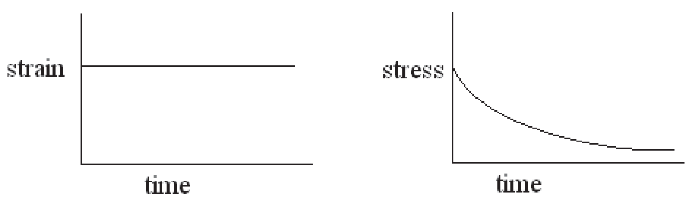


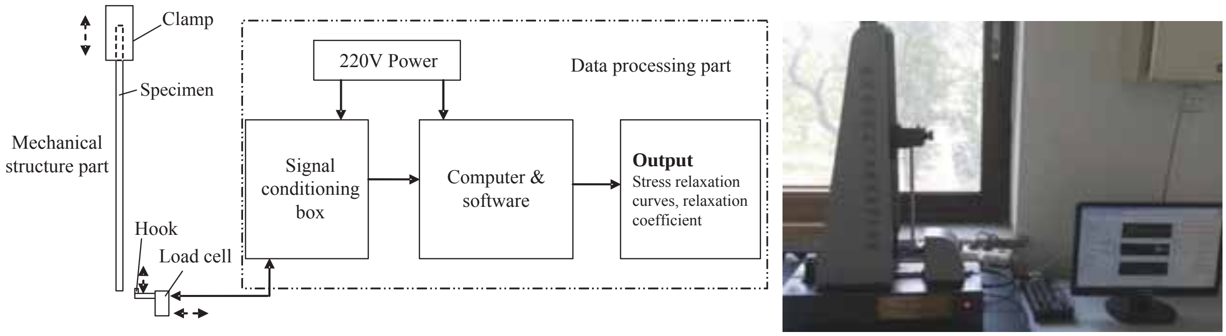
Figure 1—Constant Strain and Stress relaxation of wood materials

TEST METHOD

Test apparatus

Test apparatus is based on the cantilever beam bending load and deformation theory. The test apparatus includes two main parts: the mechanical structure part and the data processing part. The apparatus composition is shown in Figure 2 (a), and the apparatus photo is shown in Figure 2 (b).

The mechanical structure part clamps the specimen in a hanging vertical position, a static displacement is made by displacing the end of the specimen using a hook. A load cell, connected with the hook, is used to measure the load applied to the end of the beam. The data processing part consists of a signal conditioning box, a computer and a data processing software. Function of the data processing part are sensing load signal, conditioning load signal, A/D change and processing the data. The signal box consists of a linear DC power, an amplifier of load cell, an A/D card, etc. The software, written by Labview (Deng and Wang 2004), is used to acquisition and process the data, to get the stress relaxation properties of the specimens.



(a) Composition diagram (b) Photo

Figure 2—Cantilever beam test apparatus

Test theory

As shown in Figure 3, the specimen was clamped as a cantilever beam. A perpendicular hook was used to set the initial distance at the end of the specimen, *y*, resulting in a displacement load, *P*. Based on the engineering mechanics (Liu 2004), maximum tension stress and compression stress occur at the two surfaces of cross section A-A, and there is an equation (1).

$$\sigma = \frac{6Pl}{bh^2} \tag{1}$$

Where, σ is the maximum stress (MPa), P is static load (N), l is cantilever length (mm), b is width of the specimen (mm), h is thickness of the specimen (mm). The maximum stress was determined at initial load at the given displacement, then continued to be measured as a function of time.

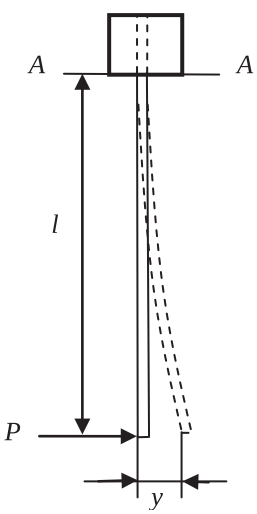


Figure 3—Static bending of a cantilever beam

Kitazawa used equation (2) to determine the stress relaxation rate of solid wood (Cheng 1985).

$$\sigma_t = \sigma_1(1 - m\log t) \tag{2}$$

In this formula, t represents time (min); σ_t represents the maximum stress at time t (MPa); σ_1 represents the maximum stress at time of 1 minute (MPa); m is relaxation coefficient. In the tests of this paper, the initial tension bending stress was set to approximately 10%-20% of modulus of rupture (MOR) of the materials. By rearranging equation (2) we can obtain the estimated relaxation coefficient m, equation (3).

$$m = \frac{1}{\log t}(1 - \frac{\sigma_t}{\sigma_1}) \quad (3)$$

Experimental materials

In this stress relaxation study, four kinds of specimens were used, including particleboard (PB), medium density fiberboard (MDF), high-density fiberboard (HDF) and wood fiber plastic board (WFP). The sizes, symbol and number of specimens are listed in Table 1. For the specimens can be clamped as cantilever-beams, total lengths of the specimens were equal to *l*+50 mm.

Table 1—Type, size, symbol and number of the specimens

Set	Type	Size of specimens ($h \times b \times l$, mm)	Symbol	Number of specimens
1	Particleboard	5×50×290	PB 5	5
2	Medium density fiberboard	4.6×50×290	HDF 4.6	5
3	High-density fiberboard	3.7×50×290	MDF 3.7	5
4	Wood fiber plastic board	2×50×180	WFP 2	5

RESULTS AND ANALYSIS

Test results

The following are the results from the cantilever bending beam test. Load was measured after an initial 20mm displacement was applied and held at the free end of the beam. After the initial displacement, load was continuously recorded for 2 to 3 hours. Beam stress was determined from the load using equation (1) and plotted as a function of time. Constant displacement testing resulted in stress that gradually decreased with time. While the displacement was the same for all boards in this study, there were slight differences in load to reach the 20 mm displacement and therefore there were slight differences in stress calculations. For visual comparison purposes, the stresses were normalized to 100 percent maximum stress for each board. The results of the normalized data are shown in Figures 4, 5, 6, and 7. Of the total five specimens from each composite type, four specimens were held for two hours, and the 5th specimen was held for 3 hours. The test data for each of the 3-hour stress relaxation tests are shown in table 2. After the tests, the specimens retained a curved shape due to creep and stress relaxation within the boards. Continuous calculation of the relaxation coefficients, m, for all the boards were also plotted vs. time in Figures 4, 5, 6, and 7.

Table 2—Maximum stress vs. time based on the measured load for a 20mm displacement

stress relaxation—stress value（MPa）vs. time								
Set	Specimen	0 min	30 min	60 min	90 min	120 min	150 min	180 min
1	PB 5-5	14.02	12.51	12.25	12.059	11.90	11.75	11.70
2	HDF 4.6-5	19.94	17.46	17.16	16.96	16.85	16.74	16.59
3	MDF 3.7-5	15.65	14.17	13.91	13.74	13.55	13.45	13.36
4	WFP 2-5	7.26	6.10	5.84	5.80	5.65	5.65	5.65

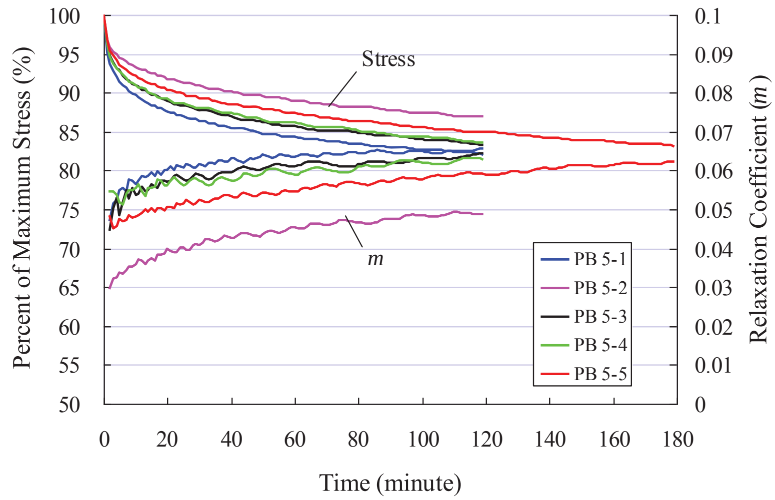


Figure 4—Percent stress relaxation for Particleboard (PB) set with corresponding coefficient *m*.

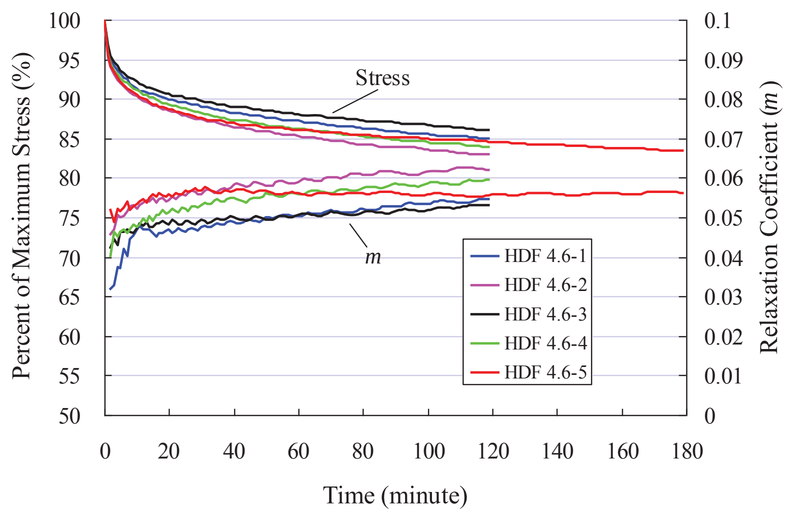


Figure 5—Percent stress relaxation for High Density Fiberboard (HDF) set with corresponding relaxation coefficient *m*.

Result analysis

From the stress relaxation tests, Figures 4, 5, 6, and 7, we can see the reduction in stress for all the board sets for a constant displacement. There were slight differences in the load and hence the stress calculated for each board. The normalized plots show the slight differences in the boards. We believe the variability in the stress curves was due to material properties variation within the board sets. But, it can be seen that the same basic curves are shown for each set. The stress relaxation curves for the HDF and the PB boards are more consistent than MDF and WFP boards. It is possible the thicker boards were more uniform and thus provide similar stress relaxation and as a result produce similar curves. We believe the additional noise for the MDF and WFP boards for the stress relaxation curves may be due in-part to internal stress release inside the panel as well as material property variations. The extent of stress relaxation as a function of time over 180 minutes can be seen in table 3. It can also be seen that the MDF 3.7-5 had the minimum stress relaxation of all the specimens. After 3-hours, the stress value decayed only to 85.4% of the initial stress. From table 2, the MDF specimen had higher stress values than PB specimen, yet the stress relaxation was different. PB 5-5 and HDF 4.6-5 boards each had maximum stress relaxation of 83.5% and 83.2% of initial stress, respectively. The WFP 2-5 board had the lowest stress relaxation effect which might have been expected due to plastic's basic creep properties that are greater than wood. After 180 minutes, the stress value decreased to 77.8% of the initial stress.

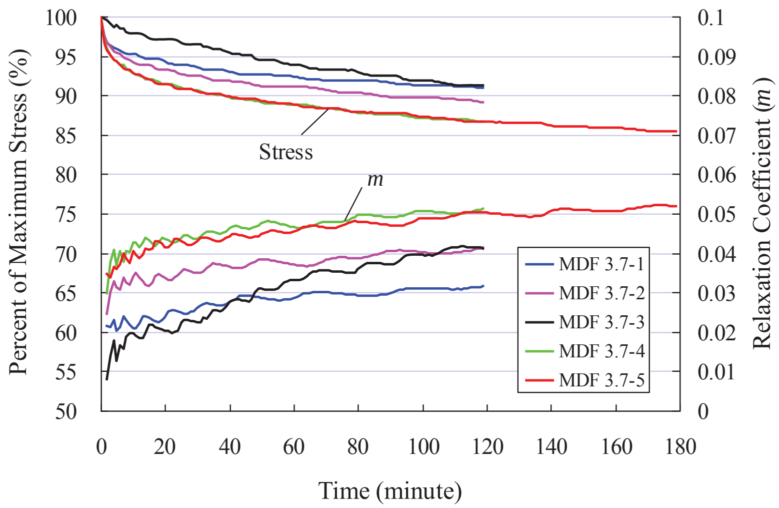


Figure 6—Percent stress relaxation for Medium Density Fiberboard (MDF) set with corresponding relaxation coefficient *m*.

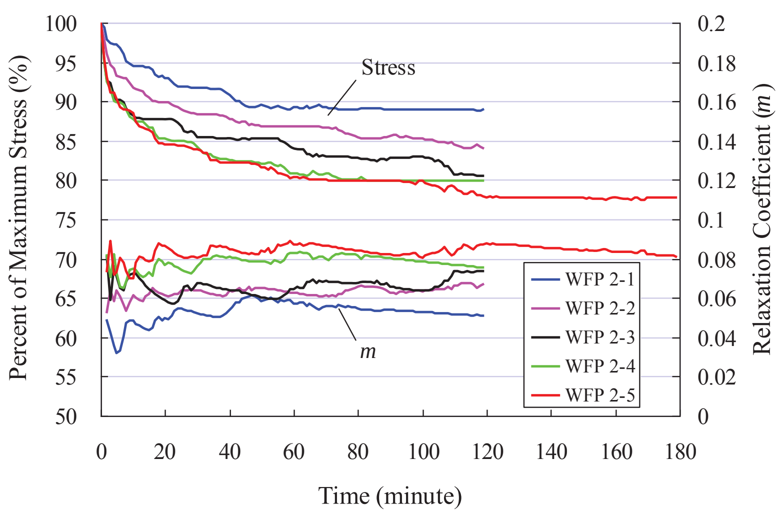


Figure 7—Percent stress relaxation for Wood Fiber Plastic (WFP) set with corresponding relaxation coefficient *m*.

The relaxation coefficient, *m* (equation (3)), whether plotted as actual stress vs. time or with maximum percentage stress vs. time, both provided the same *m* values and resulted in the same *m* plots. The coefficient was low for the initial stress relaxation but as time proceeded, an equilibrium condition began to emerge. *m* for all four board types had similar yet slightly different values. For our tests, equilibrium for the coefficient seemed to occur after about 120 minutes. It was also noted that the coefficient value corresponded to the stress relaxation, where minimal stress relaxation occurred in the specimens then the *m* value was also lower and if the stress relaxation was higher, then the coefficient value was also higher.

This effect needs to be studied to determine how relaxation is related to maximum stress values. We believe the initial high stress relaxation curves from the composite panels are a result of the composite characteristics as compared to the model which was developed for solid wood, equation (2). Composite materials have different stress relaxation mechanisms and may need to have a different model to better determine initial as well as long-term stress relaxation.

Table 3—Percent maximum stress over time over 180 minutes

Set	Samples	0 min	30 min	60 min	90 min	120 min	150 min	180 min
1	PB 5-5	100%	89.3%	87.4%	86.0%	84.9%	83.9%	83.5%
2	HDF 4.6-5	100%	87.6%	86.1%	85.1%	84.5%	84.0%	83.2%
3	MDF 3.7-5	100%	90.6%	88.9%	87.8%	86.6%	86.0%	85.4%
4	WFP 2-5	100%	83.9%	80.4%	79.9%	77.8%	77.8%	77.8%

CONCLUSIONS

(1) The stress relaxation properties of thin wood composites using the cantilever beam principle is potentially feasible. From the tests, we can see stress relaxation properties and the attenuation extent of stress with time.

(2) From the curves of stress relaxation, we can see the attenuation extent of stress is initially greater and slows down. It may be possible that a test time of two hours could provide an initial stress relaxation values. More analysis is needed to see if this is true.

(3) The stress relaxation curves of HDF and PB are more uniform. The stress relaxation curves of MDF are slightly irregular, but more samples are needed to determine average behavior. The stress relaxation curves of the WFP material are worst and needs more investigation as to why.

(4) The relaxation coefficient *m* changes with time until about 120 minutes after testing. The fluctuation of *m* is in accordance with the stress relaxation properties. The coefficient *m* value is related to the stress level. Higher the stress change, the lower the *m* value.

(5) The relaxation coefficient, m, could be used to reflect the stress relaxation properties of wood composites. It has the potential to better identify the stress relaxation properties of different boards. If the value of *m* is higher, the stress relaxation decreases at a faster rate and results in more creep behavior. Conversely, if the value of *m* is smaller, there is less stress relaxation and less creep.

Acknowledgments

The authors would like to thank the forestry industry research special funds for public welfare projects of Chinese State Forestry Administration for funding this research, grant #: 201304512.

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United States Department of Agriculture
Forest Service

Forest Products Laboratory

General Technical Report

FPL–GTR–226

Proceedings

18th International Nondestructive Testing and Evaluation of Wood Symposium

Madison, Wisconsin, USA
2013

Abstract

The 18th International Nondestructive Testing and Evaluation of Wood Symposium was hosted by the USDA Forest Service's Forest Products Laboratory (FPL) in Madison, Wisconsin, on September 24–27, 2013. This Symposium was a forum for those involved in nondestructive testing and evaluation (NDT/NDE) of wood and brought together many NDT/NDE users, suppliers, international researchers, representatives from various government agencies, and other groups to share research results, products, and technology for evaluating a wide range of wood products, including standing trees, logs, lumber, and wood structures. Networking among participants encouraged international collaborative efforts and fostered the implementation of NDT/NDE technologies around the world. The technical content of the 18th Symposium is captured in this proceedings.

Keywords: International Nondestructive Testing and Evaluation of Wood Symposium, nondestructive testing, nondestructive evaluation, wood, wood products

September 2013 (Corrected October 2013, pages 716–722)

Ross, Robert J.; Wang, Xiping, eds. 2013. Proceedings: 18th International Nondestructive Testing and Evaluation of Wood Symposium. General Technical Report FPL-GTR-226. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 808 p.

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