Effect of Strain Rate on Flexural Properties of Wood Plastic Composite Sheet Pile

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Abstract

Wood plastic composite (WPC) materials are being developed for load-bearing structural applications; therefore, the strain rate-dependent mechanical properties of WPC materials need to be characterized. Extruded WPC Z-section sheet piles composed of 46 percent wood flour, 41 percent polypropylene, and additives were investigated. ASTM D6109 was adopted for assessing flexural properties of plastic lumber in a four-point loading configuration. Coupons were cut from the flanges of the sheet pile section and conditioned for 2 weeks at 21°C and 65 percent relative humidity. The flexural tests were conducted at three different strain rates: 0.55, 1.0, and 5.5 percent per minute. The mode of failure was in tension in the middle third of the bending span. It was found that the mean apparent modulus of elasticity (MOE) increased with the strain rate; e.g., the MOE increased 9.5 percent when the strain rate was increased from 1.0 to 5.5 percent per minute. The variations in mean strain at failure with the strain rate were not statistically significant based on analysis of variance testing. The variation in flexural MOE with the strain rate was compared with the published tensile and compressive MOE values for the same material. The effect of strain rate on the flexural MOE of the polypropylene WPC material was also correlated with the published results for WPC materials with other polymer matrices (high-density polyethylene and polyvinyl chloride). The strain rate effects in the MOE of the WPC material was predicted based on a viscoelastic standard solid model calibrated with the coupon level data.

Wood plastic composites (WPCs), which have been used in nonstructural applications (e.g., residential decks), are now being developed for more demanding structural or load-bearing applications (Wolcott 2001). For structural applications, it is essential that the time-dependent behavior of WPC material be characterized and design methodologies be developed. Sheet piles are vertical retaining structures that support permanent lateral loads; therefore, it is necessary to determine the flexural properties of WPC materials under sustained loads.

To evaluate the mechanical properties of WPC materials, standard test methods for other materials like solid wood or plastic products can be adopted. The American Society for Testing and Materials (ASTM) D07 Committee has developed a suite of testing methods for WPC materials, which are listed in the standard guide ASTM D7031 (ASTM International 2004). This standard guide recommends test methods to obtain various mechanical and physical properties, which are based on plastic and wood testing methods. For assessing flexural properties, ASTM D7031 refers to two standard test methods: D4761 (ASTM International 2005a) and D6109 (ASTM International 2005b). ASTM D4761 was developed for evaluation of the mechanical properties of wood-based structural material such as stress-graded lumber, sawn timber, and reinforced and prestressed timbers. As for the speed of loading, ASTM D4761 recommends that the specimen be loaded in a three-point configuration such that the failure occurs between 10 seconds and 10 minutes, which suggests that the flexural properties are dependent on time to failure. ASTM D6109, on the other hand, was developed for assessing flexural properties of unreinforced and reinforced plastic lumber. Moreover, this standard is applicable to the materials having filler with plastic resin in continuous phase regardless of their weight percentage, such as WPC materials. This standard recommends that the specimen be loaded in a four-point bending configuration at a specific rate of 1.0 percent per minute for determining the flexural properties of the material. A summary of the differences between these test

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methods is reported in Table 1. Speed of loading, load configurations, and specimen dimensions shown in Table 1 only apply to the flexural testing mode; however, it should be noted that these ASTM standards are also applicable for testing in other modes such as compression, tension, and shear.

Between the two test methods discussed, ASTM D6109 seems to be the more appropriate test method for WPC materials; however, these materials have been found to be sensitive to the strain rate or the rate of loading (Brandt and Fridley 2003). The flexural strength or modulus of rupture (MOR) and the modulus of elasticity (MOE) increase with increasing strain rates (Brandt and Fridley 2003). Therefore, quasi-static bending tests were selected in accordance to ASTM D6109 (test method A) with a deviation regarding the strain rate. Three different strain rates were adopted to evaluate the MOE, MOR, and the strain at failure. A series of tests were conducted on specimens cut from the flanges of the WPC sheet piles with an effort to predict full-section properties based on coupon response.

Background

To be able to characterize mechanical properties of viscoelastic materials for structural applications, specific test procedures are needed. Apart from the span to depth ratio and the mode of loading, the rate of loading or the straining rate of the fibers of the specimen plays a vital role in specifying the mechanical properties. It is a well-known phenomenon that for viscoelastic materials, increase in strain rate generally results in increase in the MOE and MOR. Therefore, it is very important to investigate the sensitivity of material properties to changes in strain rate.

Extensive research studies have been conducted regarding the effect of strain rate on mechanical properties of wood. Tiemann (1908) reported that the strength of wood increased with the rate of loading, with roughly the same increase in compression in parallel as in bending for equal fiber strain rates. James (1968) compared wood bending strength for green wood and air-dried wood at two nominal rates of loading: one at standard static speed and another at about 10,000 times faster than standard static speed. The study showed an increase in bending strength, with an increase of 47 and 32 percent for green wood and air-dried wood, respectively, with the increase in the rate of loading. Keeton (1968) also conducted tests on small clear specimens of structural-grade timber (green and dry wood) in bending, compression, and shear at various rapid loading rates as well as at standard static speed. The study suggested that, in general, ultimate strength increased with loading rate, except for air-dry bending tests. Gerhards and Link (1986) studied the effect of loading rates on the bending strength of Douglas-fir lumber specimens. Results showed that average strength increased nearly linearly with the logarithm of loading rate. The study also showed that the rate of loading affects lumber MOE, increasing with higher loading rates.

Being wood-based, WPC materials are also known to exhibit viscoelastic behavior. Brandt and Fridley (2003) studied the effect of loading rates on WPC full-size box beams consisting of four different formulations at three different loading rates, viz., 4.6, 62.5, and 254 mm/min, which would be approximately equal to a strain rate of 0.07, 1.0, and 4.0 percent per minute, respectively. One of those four formulations used polyvinyl chloride (PVC) as polymer matrix, while others used varying proportions of high-density polyethylene (HDPE) as the polymer matrix. A linear increase in MOR values with the logarithm of loading rate was observed for WPC materials (Brandt and Fridley 2003), which corroborates the findings of Gerhards and Link (1986) regarding the increasing trend in strength values. This study concluded that the strain rate of 1.0 percent per minute recommended by ASTM D790 (ASTM International 2007) and ASTM D6109 provides applicable mechanical properties. Dastoorian and Tajvidi (2008) also conducted bending tests at coupon level in a three-point bending mode at four different strain rates. Although MOR values increased with higher strain rate, statistical analysis did not show any significant differences in these values, whereas MOE values were found to be more sensitive to increasing strain rates and were statistically different.

Experimental Work

Materials

The WPC Z-section hollow cross-section sheet piling (see Fig. 1) was fabricated using a Davis Standard Woodtruder with a gravimetric feeding system at the University of Maine. The WPC material was composed of 46 percent pine wood flour by weight, 41 percent enhanced polypropylene resin by weight, commercial lubricant package, ultraviolet light stabilizer with polyethylene colorant base, and a coupling agent.

Specimen preparation

Test coupons were cut from the Z-section sheet piles and were defined as C-lock and T-lock flange specimens (see Fig. 1). C-lock corresponds to the coupons cut from the

Table 1.—ASTM relevant standard test methods.

ASTM standards	Type of materials	Speed of loading	Load configuration	Specimen dimension
ASTM D6109	Reinforced and unreinforced plastic lumber	At the rate of 1.0% per min in the outer fiber	Four-point loading (equally spaced)	Length = 16 times depth Full size as manufactured No alteration in outside surface
ASTM D4761	Wood-base structural material	Loaded such that failure is achieved in approx. 1 min Acceptable range for failure to occur: 10 s to 10 min	For edgewise specimen, four-point loading (equally spaced) For flatwise specimen, three-point loading or four-point loading (equally spaced)	For four-point loading (edgewise), length = 17–21 times depth For four-point bending (flatwise), length = 32 times depth For three-point loading (flatwise), length = 100 times depth

sheet pile flange having a C-lock type connector, and T-lock corresponds to the coupons cut from the other flange.

The dimensions of test specimen for flatwise bending tests are shown in Figure 1. A margin of 5.0 mm from the edge of the void was maintained at each end for all the sections, which resulted in the width of 165 mm. In accordance with ASTM D6109, which recommends a span to depth ratio of 16, a span of 249 mm was adopted between the supports and an overhang of at least 38 mm was maintained at each end (see Fig. 2).

Tests were conducted in a four-point loading configuration. The distance between the supports was 249 mm and the distance between the intermediate loading heads was 83 mm.

Quasi-static bending test of WPC flange coupons

Flexural testing at coupon level was done to characterize the effect of strain rate on flexural properties of the material. Procedures recommended in ASTM D6109 were followed with a deviation regarding the strain rate. A four-point loading configuration was adopted. To analyze the effect of strain rate on flexural properties of WPC samples, tests were conducted at three different strain rates. One set of test specimens (six test specimens from C-lock and six test specimens from T-lock) were tested with the strain rate of 1.0 percent per minute as recommended by ASTM D6109. While the other two sets of specimens were tested at 0.55 and 5.5 percent per minute, respectively. This resulted in a speed of loading of 4.0, 7.3, and 40 mm/min for the strain rates 0.55, 1, and 5.5 percent per minute, respectively.

Test specimens were conditioned at a temperature of 21 ± 2°C, and a relative humidity of 65 ± 5 percent for 2 weeks before testing. Tests were performed on a 100-kN Instron servo hydraulic floor model dynamic system with an 8.9-kN load cell in line (Fig. 3). Loads and displacements were monitored and recorded during the tests using LabVIEW and linear variable differential transformers (LVDT). A total of 12 specimens per rate of strain (six each from C-lock and T-lock) were tested in bending up to failure at a constant nominal strain rate as mentioned earlier.

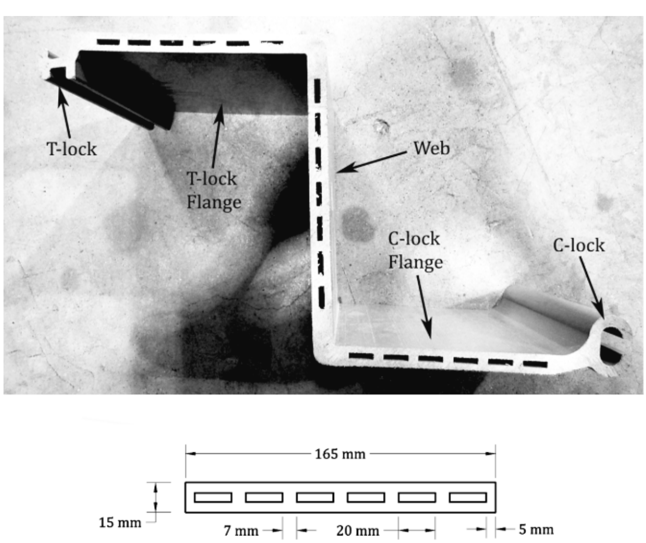

Figure 1.—Components of WPC sheet pile and cross-sectional details of flange.

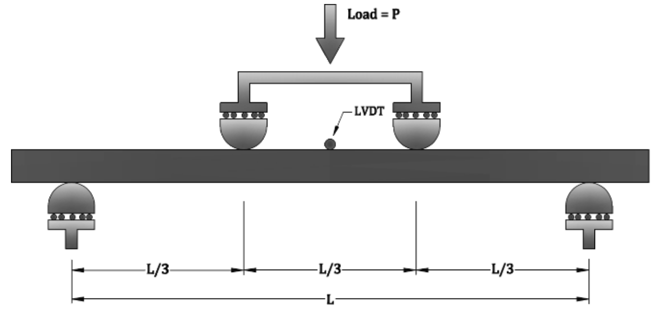

Figure 2.—Test configurations for flexural test of component of WPC sheet pile.

Flexural strength or MOR was calculated corresponding to the maximum load during the testing. Apparent MOE was calculated by linear regression within the linear regions (10% to 40% of ultimate load) of P-Δ curve using the following equation:

$$E = \frac{P/2 \cdot l^3}{28 \cdot \Delta \cdot I} \tag{1}$$

where

E = apparent flexural MOE (GPa),
P = load (kN),
l = beam length (mm),
Δ = beam deflection (mm), and
I = moment of inertia (mm^4).

Maximum strain in the outer fiber, which occurs at the midspan, was calculated using the formula given in ASTM D6109 for a load span of one-third of the support span:

$$r = 4.70 \frac{D \cdot d}{L^2} \tag{2}$$

where

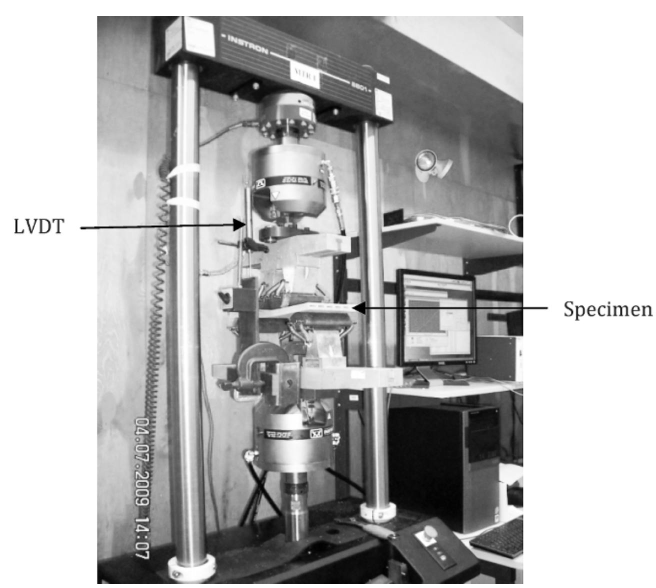

Figure 3.—Flexural test setup (flatwise specimen).

r = strain (mm/mm),
D = midspan deflection (mm),
d = depth of the beam (mm), and
L = support span (mm).

Discussion of Experimental Results

Test specimens failed in tension at the middle third region without any warning. The cracks were generally parallel to the breadth of the specimens (see Fig. 4). The load deformation plot for each strain rate tested showed an initial linear relation followed by a nonlinear behavior until failure for all tested specimens (Fig. 5). This validates the calculation of MOE using linear regression between 10 and 40 percent of the ultimate load as per ASTM D6109. Data analyses include calculation of mean apparent MOE, MOR, and strain at failure. Shear deformation was not taken into account while calculating MOE, and it was assumed that the cross section of the specimen remained undeformed throughout loading and that plane sections remained plane.

As the coupons were cut from the C-lock flange and T-lock flange, a k-sample Anderson-Darling's Test, which is a nonparametric statistical procedure, was performed to check whether the populations from which these two groups of data were collected were identical. The test results showed that these two data sets can be pooled and treated as one for all the properties (MOE, MOR, and strain at failure) analyzed (with a 5% risk of being in error). In other words, the positive results from this test establish that the coupons may be treated as one data set rather than being distinguished as T-lock and C-lock flanges. Therefore, the results presented hereafter, for each strain rate, are a combination of data from tests done on C-lock and T-lock coupons.

The mean MOE calculated for all 36 specimens at three different strain rates was 3.8 GPa with a coefficient of variation (COV) of 8 percent (see Table 2). The MOE for the three different strain rates ranged from 3.2 to 4.4 GPa. Similarly, the mean MOR for all 36 specimens was calculated to be 22.9 MPa with a COV of 8 percent and the values ranged from 17.6 to 25.5 MPa. The average value for strain at failure was calculated to be 0.92 percent with a COV of 12 percent. The values ranged from 0.62 to 1.12 percent. Time to failure of the specimens at different strain rates was markedly disparate with the average values ranging from 10 seconds for the highest strain rate to 112 seconds for the lowest strain rate.

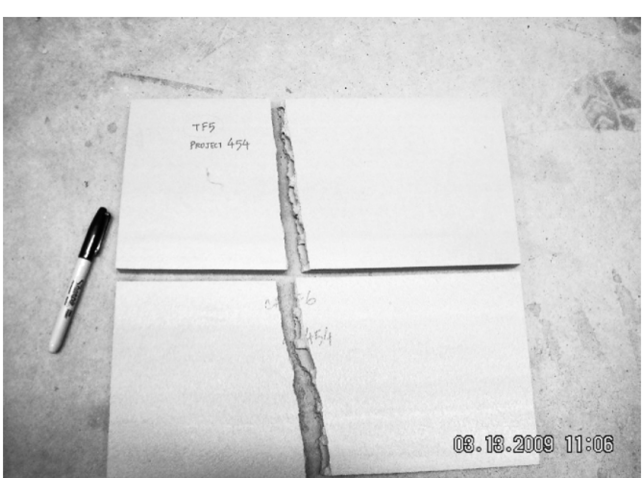

Figure 4.—Typical WPC specimen failure mode.

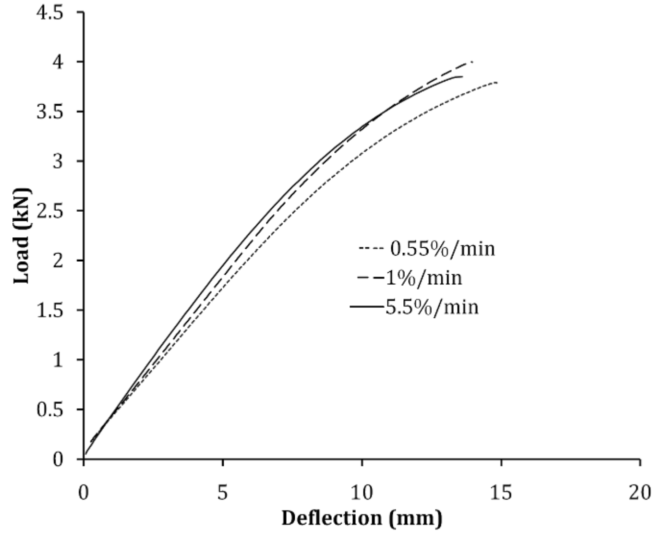

Figure 5.—Typical load-deflection curves.

The effect of strain rate on MOE, MOR, and strain at failure for the WPC material are illustrated in Figures 6 through 8, respectively. The small dots are the individual data points for each strain rate and large dots are the mean value for that particular strain rate. It appears from visual inspection that MOE and MOR increased with the increase in strain rate, as expected. Table 3 shows that MOE increased by 1.1 percent when strain rate increased from 0.55 to 1.0 percent per minute and it increased by 9.5 percent with the increase in strain rate from 1.0 to 5.5 percent per minute. Similarly, MOR increased by 1.2 percent with the increase in strain rate from 0.55 to 1.0 percent per minute, whereas there was an increase of 7.0 percent in MOR value when strain rate increased from 1.0 to 5.5 percent per minute. These results signify that WPC materials appear to be stiffer and stronger with the increase in strain rate. As for the strain at failure, there was not much difference between strain rates 0.55 to 1.0 percent per minute, while it decreased by 7.1 percent when the strain rate increased from 1.0 to 5.5 percent per minute. This suggests that the increase in strain rate or loading rate hindered the viscous flow of the polymer chain. The polymer chains did not get enough time to reorient their position at higher loading rates, which resulted in specimens failing at smaller deflections. Also, the higher COVs for strain at failure can be attributed to some flaws on the surface of the specimens, which might have helped initiate early cracks, resulting in premature failure.

MOE, MOR, and strain at failure at different strain rates were compared using a one-way analysis of variance (ANOVA) test with the value of $\alpha = 0.05$. Prior to performing ANOVA tests, the data sets were checked for normality and equality of variance. To test for normality of the data sets, the Shapiro-Wilk normality test was conducted. The null hypothesis for this test is that the data set is normally distributed. The test gave a P value of 0.144, which is greater than 0.05. Therefore, the null hypothesis was accepted and it was concluded that the data set was

Table 2.—Effect of rate of strain on mechanical properties of WPC.

Strain rate (%/min)	MOE (GPa)	COV (%)	MOR (MPa)	COV (%)	Strain at failure (%)	COV (%)	Time to failure (s)	COV (%)
0.55	3.6	6	22.2	8	0.94	13	112	8
1	3.7	8	22.5	7	0.95	13	62	6
5.5	4.0	7	24.1	6	0.88	10	10	13
Mean	3.8	8	22.9	8	0.92	12	—	—

normally distributed. Next, Levene's test was performed to check the equality of variance of the data set. The null hypothesis for this test is that variances are equal. The test gave a *P* value of 0.951; therefore, the null hypothesis was accepted and it was concluded that the variances were equal.

Results of ANOVA tests are shown in Table 4. From the one-way ANOVA test, the results for MOE and MOR were found to be statistically different, but the results for strain at failure for different strain rates were found to be statistically similar. ANOVA results for MOE and MOR merely indicated that there was at least one significant difference between two of these three means. To determine which specific means had significant differences, a two-tailed *t* test ($\alpha = 0.05$) was conducted and means were compared between each strain rate for each of these properties.

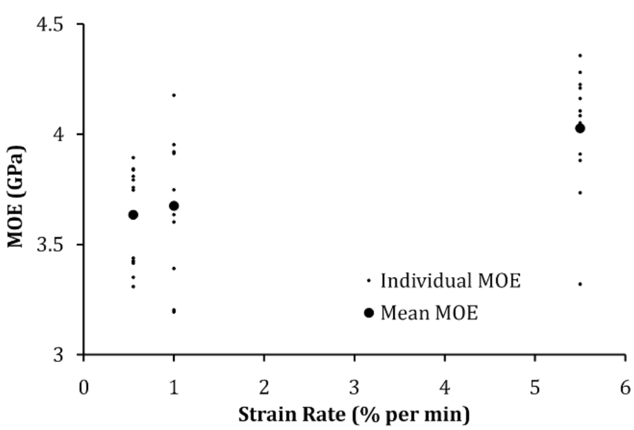

Figure 6.—MOE versus strain rate.

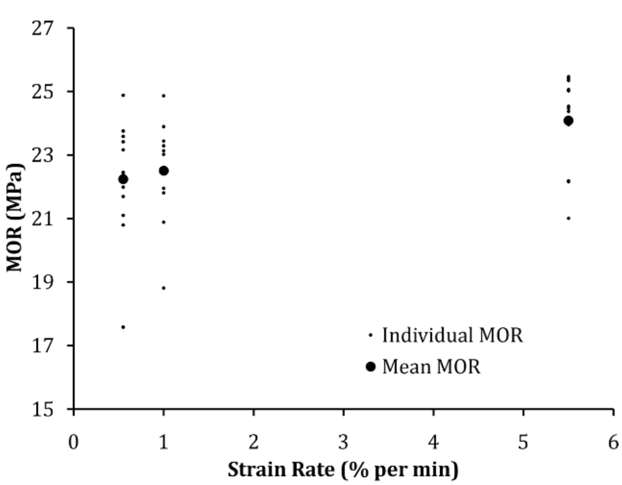

Figure 7.—MOR versus strain rate.

Mean values for MOE and MOR were found to be statistically different (Table 5) for all the strain rate comparisons except for the case between strain rates of 0.55 and 1.0 percent per minute. MOE was found to be more sensitive than MOR. This could be due to the fact that MOR is governed by the failure of the specimen, which is highly dependent on crack initiation and crack propagation. Therefore, even a small flaw at a critical location might initiate a crack causing the specimen to fail prematurely.

It was found that the time to failure at different strain rates were within the range specified by ASTM D4761. However, the differences in responses (MOE and MOR) were statistically significant, which suggests that WPC material should be tested at a specific strain rate as recommended by ASTM D6109 to determine its flexural properties.

In this study, specimens were obtained from the flanges only. It should be noted that the mechanical properties of the specimens obtained from the other locations of the cross section (for example, webs) might be different due to the nonhomogenous nature of the WPC formulations. Moreover, inconsistencies in mechanical properties might arise depending on the location along the length of the sheet pile.

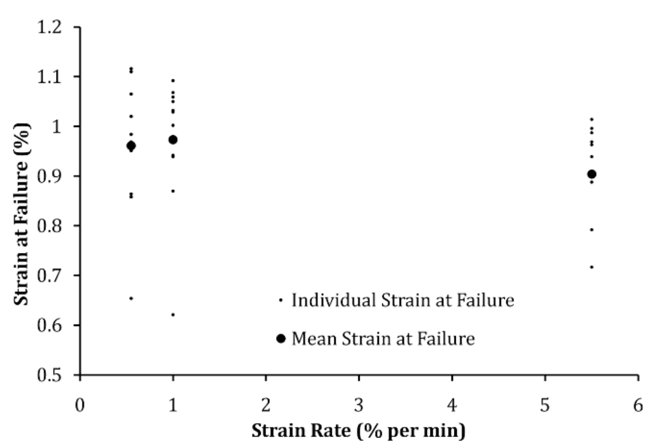

Figure 8.—Strain at failure versus strain rate.

Table 3.—Variation in mechanical properties with strain rate.

Mechanical properties	Variation (%) in mechanical properties with strain rate[a]	
	0.55%–1%/min	1%–5.5%/min
MOE	+1.1	+9.5
MOR	+1.2	+7.0
Strain at failure	+1.3	−7.1

[a] Positive values indicate increment.

Table 4.—One-way ANOVA for comparison of mechanical properties.[a]

Mechanical properties	Source of variation	SS	df	MS	$MS_{\text{Between Groups}}/MS_{\text{Within Groups}}$ (F ratio)	P value	F critical
MOE	Between groups	1.115	2	0.557	7.537	0.002	3.285
	Within groups	2.441	33	0.074			
Total		3.556	35				
MOR	Between groups	23.816	2	11.908	4.376	0.021	3.285
	Within groups	89.802	33	2.721			
Total		113.618	35				
Strain at failure	Between groups	0.033	2	0.017	1.205	0.313	3.285
	Within groups	0.454	33	0.014			
Total		0.487	35				

[a] SS = sum of squares; df = degrees of freedom; MS = mean square.

Table 5.—t Test result for MOE and MOR for different strain rates.

Properties	Strain rate (%/min)	t statistic	t critical	P value	Statistically different?
MOE	0.55–1	0.372	2.086	0.714	No
	1–5.5	2.940	2.074	0.008	Yes
	0.55–5.5	3.742	2.080	0.001	Yes
MOR	0.55–1	0.383	2.080	0.705	No
	1–5.5	2.534	2.074	0.019	Yes
	0.55–5.5	2.668	2.080	0.014	Yes

Table 6.—Comparison of modulus of elasticity.

Description	Source of data	Testing mode	Sample size	MOE (GPa)	COV (%)
WPC from sheet piling	This study	Flexure	12	3.68	8
WPC	Dura (2005)	Tensile	6	3.49	7
WPC	Dura (2005)	Compressive	6	3.52	12

Comparison with WPC Material Properties from the Literature

MOE values calculated at 1.0 percent per minute strain rate from this research were compared with previously published values. Comparisons include MOE values calculated by Dura (2005) from coupon level tests in tensile and compressive modes (Table 6).

Dura (2005) performed tensile and compression tests at coupon level of WPC specimens with the same formulation as that in the current research and calculated an initial tangent modulus with a linear regression analysis between strain values of 0.05 and 0.20 percent. MOE from the work in the present study when compared with findings by Dura (2005) is 3.2 percent higher when compared with tensile MOE, and 4.5 percent higher when compared with compressive MOE reported by Dura (2005). A possible explanation for the lower MOE could be the removal of the outer skin for preparing the specimens. In general, the MOE calculated from the coupon level tests by Dura (2005) and this study were similar. These comparisons show that MOE calculated from tests in different loading modes (e.g., tension and flexure) generally gives similar results.

Strain Rate Analysis for Different WPC Materials

Previous research work has been done on WPC material to assess the effect of strain rate on material properties. Brandt and Fridley (2003) performed quasi-static bending tests at different strain rates for full-size box beams made of various thermoplastic materials. The first formulation for box beams was composed of 50 percent PVC and 50 percent wood flour, while the other three formulations were composed of HDPE (31%, 32.5%, 30.95%) and wood flour (58%, 67.5%, 67.5%), respectively, named HDPE 8, HDPE 67.5, and HDPE 67.5 with maleated polyethylene (MAPE). Also, the MOE was calculated by performing a linear regression analysis between 0 and 30 percent of the ultimate strength.

Table 7.—MOE versus strain rate for various thermoplastic material.

Material[a]	MOE variation (%) for strain rate increments[b] 0.07%–1%/min	1%–4%/min	Sample size
WPC w/PVC	−7.7	+4.9	5
WPC w/HDPE 8	+30.1	+15.4	5
WPC w/HDPE 67.5	+11.8	+15.6	5
WPC w/HDPE 67.5 w/MAPE	+9.3	+18.2	5

[a] Adapted from Brandt and Fridley (2003). Notations described in ''Strain Rate Analysis for Different WPC Materials.''
[b] Positive values indicate increment.

The variation in MOE of various WPC material formulations tested with varying strain rate is shown in

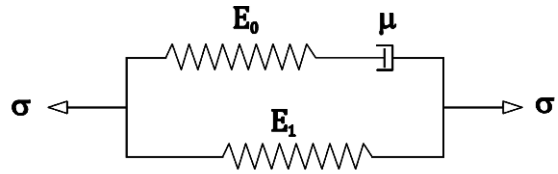

Figure 9.—Viscoelastic linear solid model.

Table 8.—Experimental and predicted MOE.

Strain rate, $\dot{\varepsilon}$ (%/min)	Experimental MOE (GPa)	COV (%)	Model prediction of MOE (GPa)
0.55	3.6	6	3.5
1	3.7	8	3.6
5.5	4.0	7	4.2

Table 7. All the formulations, except for WPC with PVC, show an increasing MOE with increasing strain rate.

Modeling Stress–Strain Response at Different Strain Rates

The viscoelastic stress–strain response was modeled using a standard solid model, as shown in Figure 9. The objective of this model was to predict the apparent MOE at different strain rates. The viscoelastic model consists of a Maxwell element (spring with modulus E_0 and dashpot with viscosity μ in series) and a spring with modulus E_1 placed parallel to each other. The spring element is perfectly elastic and the strain rate has no effect on the stress–strain response. However, the stress–strain response of the Maxwell element is time-dependent due to the presence of the dashpot, simulating a viscoelastic material. Equations 3 and 4 represent the stresses for a spring element and a Maxwell element, respectively. The stress solution of the Maxwell element, as a function of strain and strain rate in Equation 4, was adopted from Brinson and Brinson (2008).

$$\sigma_s = E_1 \cdot \varepsilon \tag{3}$$

$$\sigma_m = \tau \cdot E_0 \cdot \dot{\varepsilon}\left(1 - \exp\left(\frac{-\varepsilon}{\tau \cdot \dot{\varepsilon}}\right)\right) \tag{4}$$

where $\dot{\varepsilon}$ is the strain rate, and τ is the retardation time, i.e., $\tau = \mu/E_0$.

When a stress (σ) is applied to the model, the strains induced in the Maxwell element and the spring are equal. The total stress in the model is equal to the stress exerted in the Maxwell element (σ_m) plus the stress in the spring element (σ_s). Hence, adding Equations 3 and 4 results in

$$\sigma(\varepsilon, \dot{\varepsilon}) = E_1 \cdot \varepsilon + \tau \cdot E_0 \cdot \dot{\varepsilon}\left(1 - \exp\left(\frac{-\varepsilon}{\tau \cdot \dot{\varepsilon}}\right)\right) \tag{5}$$

The constants E_0, E_1, and τ of the model were determined by performing a surface fit in MATLAB. For surface fitting, only the initial linear portion (0% to 40% of maximum stress) of the experimental stress–strain response at each strain rate was used. From the results of the surface fit, the values of E_0, E_1, and τ were found to be 1.9 GPa, 3.4 GPa, and 0.9 second, respectively. These values were used in Equation 5 to predict the stress–strain response as a function of strain rate. Then, the apparent MOE was calculated with a linear regression analysis on the initial portion (0% to 0.20% strain) of the predicted stress–strain curve. However, the standard solid model does not account for the damage accumulation in the material beyond the linear stress–strain range. Therefore, the full stress–strain response could not be generated and consequently, the MOR could not be predicted as a function of strain rate. The comparison between experimental and predicted MOE is shown in Table 8 and Figure 10. The model prediction fairly matched the MOE calculated from the experimental data.

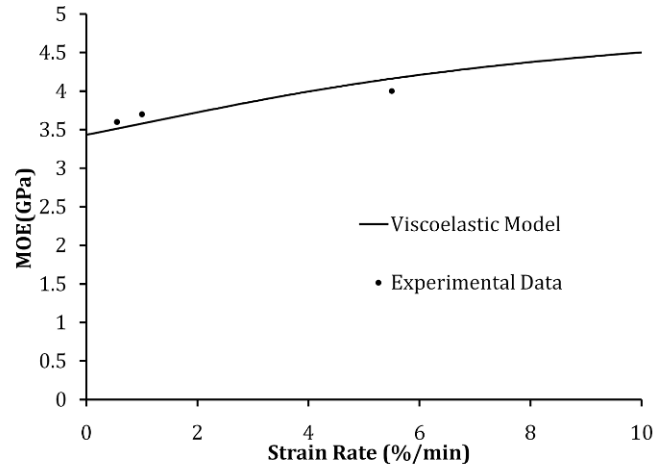

Figure 10.—Variation in MOE as a function of strain rate.

Conclusions

The effect of strain rate in the mechanical properties of WPC material was investigated through quasi-static bending tests on coupons cut from the flanges of WPC sheet piles. It was observed that both MOE and MOR shifted to higher values as the strain rate increased. The apparent MOE increased by 9.5 percent as the strain rate increased from 1.0 to 5.5 percent per minute. Similarly, the MOR values increased by 7.0 percent when the strain rate increased from 1.0 to 5.5 percent per minute. Both MOE and MOR were found to be statistically different when the strain rate increased from 1.0 to 5.5 percent per minute. The strain at failure decreased by 7.1 percent as the strain rate was increased from 1.0 to 5.5 percent per minute. The average time to failure decreased from 112 seconds at 0.55 percent per minute to 10 seconds at 5.5 percent per minute strain rate. The MOE was more responsive to the variations in strain rate compared to the MOR. This could be because MOE is directly related to the relaxation of molecules, whereas MOR is dependent on damage accumulation and fracture mechanism.

Differences between the ASTM test methods, recommended by ASTM D7031 to evaluate WPC material, were discussed. The findings of this research indicated that ASTM D6109 is more suitable than D4761 for evaluating the flexural properties of WPC materials. Because of WPC material's strain rate dependency, flexural tests should be conducted in accordance with a specific standard test method and at a specific strain rate to avoid discrepancies while defining and comparing the mechanical properties of different WPC materials.

A viscoelastic standard solid model consisting of a Maxwell element and a spring in parallel was adopted to predict the apparent MOE at different strain rates. The model prediction fairly matched the experimentally obtained MOE. The effect of strain rates in the MOE of the WPC sheet pile section under design loads can be predicted based on this model.

The experimental MOE correlation with the tensile and compressive elastic moduli from the literature validates the application of the flexure test to WPC coupons cut from a sheet pile section. This justifies the flexure test as a practical approach to characterize WPC materials for load-bearing applications.

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