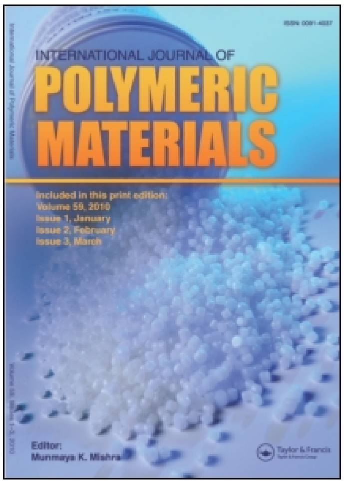

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Improved Viscoelastic Damping for Earthquake-Resistant Wood Structures

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In this work viscoelastic polymeric damping material was studied for its ability to damp out vibrations in wood structures (houses). This is accomplished by placing a thin layer of the material between wood stud and sheathing material. Damping performance of three individual polymers was obtained and compared to two types of blends of the materials. Placing the strips of material next to each other (parallel arrangement for shear) rather than on top of each other (series arrangement for shear), gave improved damping results over a wider temperature range relative to the single polymers. This is attributed to the widening of the damping peak by combining the materials. This is expected to be useful in earthquake-resistant wooden structures, such as housing, by delaying collapse and by absorbing energy, thereby increasing likelihood of saving the lives of the inhabitants.

Keywords: earthquake resistance, viscoelastic damping, wood structures

INTRODUCTION

Viscoelastic (VE) dampers have been used in structures for almost thirty years. Various types of joints have been designed to take advantage of the damping properties of viscoelastic materials, which show both viscous and elastic behavior. The viscous part of the material is what actually performs the damping by dissipating the energy put into

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it. The elastic part of the material ensures that this can be done repeatedly under cyclical loading.

Earthquakes are a major problem for the integrity of structures and are a major threat to life for those caught in such structures in many parts of the world—particularly heavily populated Japan, Turkey, and several Pacific rim countries, including the west coast of the United States. One of the best ways to stabilize structures in earthquake areas is to build into the structure some degree of flexibility and energy absorption capacity. This is now widely practiced in steel structures, and it is now possible to build high-rise buildings in many of these areas. Wood structures offer a different challenge, and the application of viscoelastic materials here has been more restrained.

For wood structures, Shenton et al. [1–2] demonstrated that placing thin "tape" of viscoelastic material between the studs and the sheathing can significantly increase energy absorption without measurably altering construction practices. This is one very attractive and economical solution to this problem, but other designs, for the joints in particular—following what is done for steel structures, are also possible. These add expense and a major change in construction procedures. Dinehart et al. [3–4] have followed Shenton's lead in this research.

One of the major difficulties in using viscoelastic materials for damping is that their damping characteristics depend on frequency, deformation (strain), and temperature. All three variables create challenges for the application of viscoelastic materials. In particular, temperature is critical. A building, such as a house, is in the external environment all the time, and temperature usually varies widely—up to 100°C, for example. It would not do to have a house that is earthquake resistant at 20°C, but not at -20°C. An earthquake in the winter would readily expose the weakness of that situation.

Therefore the major goal of this work is to formulate the viscoelastic damping material in such a way as to give a wider temperature viability with respect to its damping performance. This means combining materials whose damping peaks are at different temperatures in order to get a broader damping peak and, presumably, a wider damping performance as a function of temperature.

MATERIALS AND METHODS

A commercial manufacturer (3 M) produces several viscoelastic "tapes" that have different glass transition temperatures, Tg's [5]. The glass transition temperature is the optimum location, more or less, for the damping characteristics of the material [6–8] to be optimized. The glass transition temperature, Tg, is at a slightly higher value than the damping peak, normally. The peak width varies depending upon many chemical characteristics of the polymer. Typically it can be between 30 and 40°C for a reasonably "broad" peak. This range is insufficient for using viscoelastic materials to dampen wooden structures that are in environments that see a wider swing in temperature. So the problem, simply stated, is to broaden the damping peak to make the application successful at a wider range of temperatures. The materials can be used outside of the maximum damping region, but damping characteristics gradually decrease, and the material is less effective.

Three polymers were used, designated 110, 112, and 130 by the manufacturer. These are unidentified acrylic polymers, that may already comprise blended materials. The tapes were 1.5 inches wide (3.8 cm) and .005 inch thick (0.127 mm) and were obtained in a roll of specified length. Three layers of tape (total thickness in all cases was .015 inches) were placed between the short side of a standard sized wood 2 × 4 stud and a wall or sheathing material on the other side. The sheathing material was OSB, oriented strand board, in common usage for outer walls of housing. The outer wall is commonly nailed to the studs. The nail contributes to the damping and holds the structure together. It is difficult to subtract out the contribution of the nail, so nails were not used in these experiments. The wood pieces were held together by the adhesive quality of the VE material. The joints were made at room temperature and clamped with light pressure overnight, as per manufacturer's directions, to insure a good bond. Bonded samples were then placed in a temperature environment for at least 4 h prior to being placed on the testing machine.

The self-adhesive viscoelastic material was bonded to the stud and sheathing after smoothing the surface with fine-grain sandpaper. A 4-inch (102 mm) long piece of polymer was used in all VE connections. The polymer thickness in all cases was .015 inches (0.38 mm) obtained by layering three pieces of the .005 inch (.127 mm) thick material from the roll supplied by the manufacturer. A schematic of the setup is shown in Figure 1. The manufacturer recommended "layering" in its literature [5], and so this is one of the routes tried. But this did not work well, so a different method was tried that gave improved results.

The testing machine used was a form of an Instron tensile tester. Sine wave cycled tests were performed in a 110 kip (489 kN) capacity MTS (Material Testing System) TestStar Workstation. Tests were conducted at room temperature, 75°F (24°C), hot environment, 120°F (49°C) and cold environment, 15°F (−9°C). The higher temperatures were obtained using an oven, and the cold temperatures using a freezer. Samples were placed in these environments for 4–8 h. They were

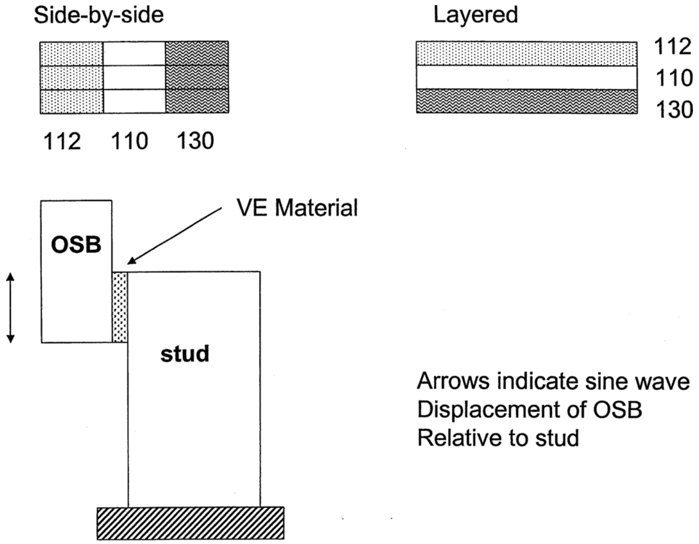

FIGURE 1 Schematic of experimental setup. VE material adhering between the two boards, no nail used. Side-by-side and layered blend configurations shown.

then placed on the tester and run quickly at room temperature. The testing (cycling and setup) took about 4 minutes, and so minimal temperature change in the sample was assured.

All connections were cycled at a constant frequency of 1.0 Hz for 10 fully reversed cycles of constant amplitude (.01 inches). So the maximum shear (.01/.015) was 0.7.

Three independent slave channels in a digital controller recorded time, load, and displacement for the tests. Windows-NT Testware-SX templates were programmed into the PC interface to perform the tests and serve as the data acquisition system. Data were recorded through the TestStar system at a sampling rate of 100 per second.

Upon completion of the tests, the effective stiffness in cycle "i" was calculated by the slope of the maximum and minimum forces corresponding to the maximum and minimum displacements. The energy dissipation was calculated by the area of the hysteresis loop in Force-displacement diagrams, as in Dinehart et al. [3–4]. A typical result is shown in Figure 2. No nail was used in the connection, and consequently did not have to be compensated for.

We also attempted to get mechanical characteristics of the material used for damping [6–8], that is, Modulus-Temperature curve and tan δ. This was an essential element of this work, but the authors were not

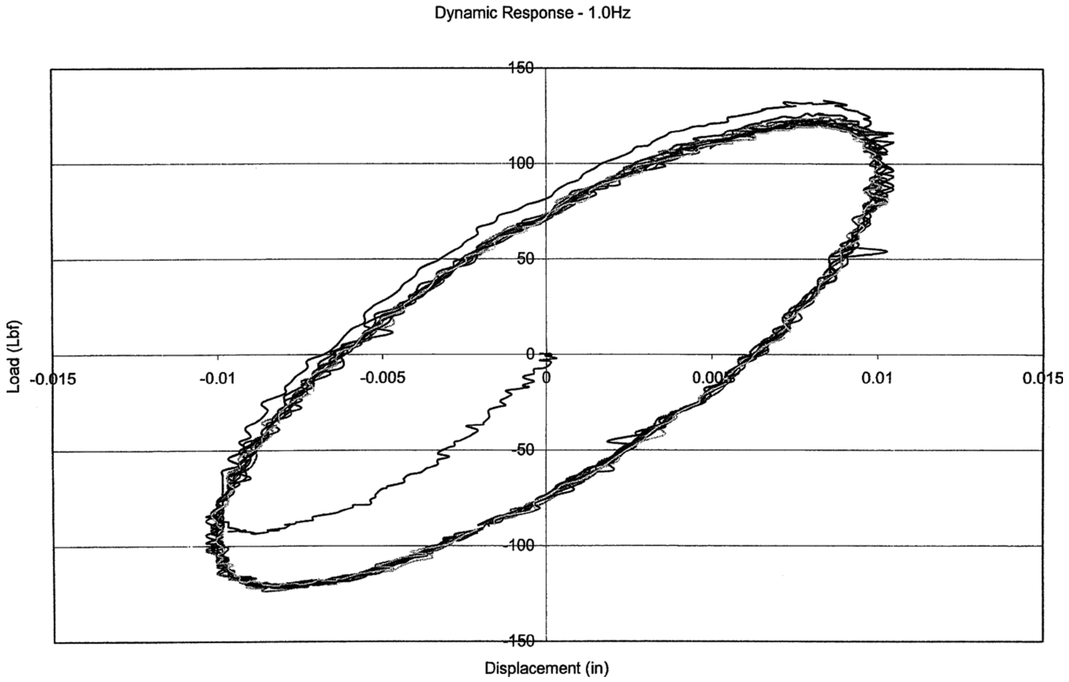

FIGURE 2 Typical dynamic response of wood joint with VE damping layer between stud and OSB board—no nail. Ten cycles, force–displacement curve.

TABLE 1 Energy Dissipation and Stiffness of VE Polymer Samples at 24°C

Sample	Relative damping factor	Avg. energy dissipation, lbf-in	Average stiffness, lbf/in
110	1.0	3.33 ± 17.0%	17.104 ± 12.7%
112	0.6	0.81 ± 15.1%	3.985 ± 15.8%
130	1.0	3.04 ± 12.8%	14.195 ± 11.6%
Layered blend	—	1.34 ± 32.3%	6.667 ± 26.5%
Side-by-side blend	—	2.72 ± 16.4%	11.643 ± 16.1%

able to do it successfully [9] owing to a clamping pressure problem when using a Dynamic Mechanical Spectrometer DMTA IV, from Rheometrics. The arrangement used for clamping thin materials in shear was the first time such a thing was done on this instrument, and the manufacturers had not yet developed a reliable procedure for samples in shear. The samples were too thin to be used in a tensile mode.

RESULTS AND DISCUSSION

The results are shown in Tables 1–3 for the runs at various temperatures. Table 1 is at room temperature; Tables 2 and 3 contain similar data at two different temperatures, one hotter and the other colder than in Table 1.

In these tables the data are arranged by both polymer type and temperature, so one can see the trends with respect to each of those factors. The frequency was the same in all cases at 1 Hz, and the maximum displacement was the same in all cases, .01 inches. Five different polymer samples were used: three single-sample polymers provided by the manufacturer and the layered blend and the side-by-side blend. Three trials of each sample were done and the results averaged.

TABLE 2 Energy Dissipation and Stiffness of VE Polymer Samples at 49°C

Sample	Relative damping factor	Avg. energy dissipation, lbf-in	Average stiffness, lbf/in
110	0.8	1.00 ± 25.0%	5401 ± 8.3%
112	0.3	0.20 ± 13.8%	2043 ± 7.5%
130	0.7	0.64 ± 26.4%	3835 ± 17.3%
Layered blend	—	0.26 ± 55.9%	2042 ± 48.3%
Side-by-side blend	—	0.51 ± 74.1%	2707 ± 42.5%

TABLE 3 Energy Dissipation and Stiffness of VE Polymer Samples at −9°C

Sample	Relative damping factor	Avg. energy dissipation, lbf-in	Average stiffness, lbf/in
110	0.2 (estd.)	1.95 ± 30.4%	38,698 ± 22.6%
112	0.8	2.70 ± 37.3%	15,310 ± 42.0%
130	0.3 (estd.)	1.34 ± 58.9%	32,670 ± 63.4%
Layered blend	—	NA	NA
Side-by-side blend	—	2.10 ± 2.0%	48,042 ± 4.5%

The +/− entry in the tables represents one standard deviation of the three individual trials.

The three commercially made polymers designated 110, 112, and 130 have Tg's roughly at 30°C, 0°C, and 20°C. The damping factor data provided by the manufacturer shows relatively broad peaks with all polymers. The data were *not* presented as tan δ and modulus versus temperature, but rather as a normalized damping factor ("loss factor") and modulus (G′) with temperature and frequency represented parametrically.

The single-sample results parallel expectations from the manufacturer's literature, the 110 and the 130 polymers behaving very closely and the 112, designed for lower temperatures, being much more flexible and weaker at room temperature. The 110 polymer gives the best performance at room temperature (Table 1) and the 112 the worst. At the cold temperature (Table 3) the results were reversed, the 112 polymer being the best of the three single polymers. The units on the data are typical for the industry, and are so reported here. These can be easily converted using appropriate conversion factors.

The two blends were equal compositions of the three polymers mentioned earlier the layered blend having one polymer layered on top of the other to form a three-layer "sandwich," and the side-by-side blend comprising a triple layer of each polymer set side by side.

In general, the results at all temperatures showed that the layered blend mimicked the weakest polymer—which is not what was wanted at all. This might stand to reason because of the "weakest link" principle. The layered blend acted as a series combination of the three polymers in shear. A stiff polymer would not respond much at all to shear, leaving the most flexible to take up the deformation. This is a little bit like a series combination of springs, where the weakest one will take the largest share of the deformation.

The side-by-side blend showed improved performance in both stiffness and energy dissipation over the layered blend at all temperatures and is almost equivalent to the 130 polymer. The side-by-side blend is more like a "parallel" combination with 3 different polymers (of the same total thickness as all the samples) arranged side-by-side.

Table 2 shows that at 49°C the 110 polymer was the best, and the side-by-side blend gave results close to the 130 polymer, also very good. The layered blend showed results close to the 110 polymer, the worst of the lot.

In Table 3 the data for the layered blend at -9°C were inconsistent and are not reported here. The cold temperature is the most difficult to run, because it is below freezing, and wood contains moisture that could have affected the results of the layered blend. In general, the variation from sample to sample was the largest of the three temperatures, and the authors had the most difficulty running the actual experiment. On some occasions the wood delaminated; on other occasions the VE material would spall and ball up.

The side-by-side blend at the lowest temperature, however, showed a stiffness equal to the highest stiffness of the individual polymers (110–3700 lbf/in) and better damping than the 110 alone, but not quite as high as the 112. This trend is followed at the high temperatures also. The side-by-side blend fell between the weakest and strongest showings of the individual polymers, whereas the layered blend showed performance equivalent to the weakest polymer. Taken as a whole, the side-by-side blend had a wider temperature applicability than the individual polymers or the layered blend, and this constitutes the improved performance.

As a general observation of the data with respect to temperature, one can see that both stiffness and energy dissipation are markedly reduced at the high temperature. This is the highest temperature one would expect in the field and is well above the Tg of any of the three individual polymers. Relative damping factors for the individual polymers is also given in Tables 1–3. These come from manufacturer's literature [5], and damping factor is relative to that at Tg. Where estimated values are listed in the tables (estd.), these refer to values obtained by extrapolation of data and isotherm. The relative damping factor follows the trends in energy dissipation for all three temperatures, as clearly seen in the tables, and the two are therefore integrally connected.

At the low temperature, stiffness is higher, as might be expected, in all cases. Energy dissipation is sometimes higher, sometimes lower, depending on the Tg of the material. This is the point of the whole study. For example, the 112 polymer shows the highest energy dissipation at the low temperature, because this temperature is close to the Tg of that polymer. The 130 and the 110 polymers show the largest energy dissipation at the middle temperature, for the same reason.

These results, although improved over the individual polymers, still fall short of what is really desired—a clear broadening of the damping peak and a demonstrably and significantly increased damping factor over a wide range of temperature. Ideally, one is looking for a "box" distribution curve for tan δ, where tan δ remains at a high value for a wide range of temperature—as opposed to the more normal, Gaussian-like curve that has a clear maximum at one temperature. This is not the first time such an outcome has been desired in polymer science applications.

This improvement is just a stepping stone to the better results that are needed. However, to get there means more sophisticated approaches will have to be employed. It is quite possible that these tapes have been formulated with the idea of a broad tan δ peak in mind and are, already, some kind of blended polymer. For example, the individual polymers 110, 112, and 130 might have been made by blending various molecular weights, concentration or type of side groups, or molecular weight distributions. Such information was not available from the manufacturer.

Further peak broadening of the damping curve is clearly desired. Methods to achieve this could include interpenetrating polymer networks (iPNs), multiphase blending with gyroid structures, or single phase mixtures. The iPN solution is likely to be too expensive, the gyroid structures difficult to attain, and the mixtures most easily carried out. These approaches should be investigated in the future.

CONCLUSIONS

The layered blend does not improve the damping characteristics. It only mimics the weakest polymer.

The side-by-side blend combination improves performance with respect to variations in temperature, over any of the single polymers by themselves or the layered blend.

Further improvements in damping performance will come by using more sophisticated techniques to obtain a viscoelastic material with a very broad tan δ curve and, at the same time, a high tan δ value.

REFERENCES

[1] Shenton III, H. W., Dinehart, D. W., and Elliot, T. E., *Can. J. Civil Engineering* **25** (3), 412 (1998).

[2] Dinehart, D. W. and Shenton III, H. W., *Earthquake Spectra* **15** (1), 67 (1998).

[3] Dinehart, D. W., Joye, D. D., and Gonzalez de Mendoza, E., Viscoelastic Polymers Improve Cyclic Performance of Wood Connections, *Proc. 8th World Conf. on Timber Engineering*, Lahti, Finland, June (2004), vol. 3.

[4] Blasetti, A. and Foley, D., Evaluation of Energy Dissipation Capacity and Stiffness of Wood Connections with Viscoelastic Polymers at Various Temperatures, technical report to D. W. Dinehart and D. D. Joye, Dept. of Civil Engineering, Villanova University, July (2004).

[5] 3M Viscoelastic Damping Polymers 110, 112, 130, Technical Data, February (1999).

[6] Fried, J. R. (2003). *Polymer Science and Technology*, Second Edition, Prentice-Hall, Upper Saddle River, NJ.

[7] Rosen, S. L. (1993). *Fundamental Principles of Polymeric Materials*, Second Edition, Wiley Interscience, New York.

[8] Jones, D. I. G. (2001). *Handbook of Viscoelastic Damping*, Wiley & Sons, New York, pp. 6, 7, 44, 45, 262.

[9] McGrath, L. M., Testing of Viscoelastic Material by Dynamic Mechanical Thermal Analysis to Determine Damping Properties, Senior Project, Department of Chemical Engineering, Villanova University, May (2003).