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CHARACTERIZING PSAS FOR SEMI-STRUCTURAL APPLICATIONS

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David Dillard is the Adhesive and Sealant Science Professor in the Engineering Science and Mechanics Department at Virginia Tech. He has worked extensively in the field of adhesive bonding, having experience in structural adhesives for aerospace, automotive, and infrastructure applications; adhesives and coatings for microelectronic applications; pressure sensitive adhesives; elastomeric adhesives and sealants; and polymeric membranes. He has coauthored over 160 publications in refereed journals and regularly teaches courses in adhesion science, polymer viscoelasticity, and sustainable energy solutions. His research involves developing test methods and predictive models for understanding and estimating the performance and durability of polymeric materials, adhesives and bonded joints, using the principles of fracture mechanics and viscoelasticity. Over the past several years he has become active in applying these concepts to sustainable energy products including proton exchange membrane fuel cells and solar photovoltaic applications. He is a Patrick Fellow and former President of the Adhesion Society, and the 2010 recipient of their Award for Excellence in Adhesion Science. He is the 2013 recipient of the Wake Memorial Medal.

CHARACTERIZING AND MODELING PSA PERFORMANCE FOR SEMI-STRUCTURAL APPLICATIONS

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Pressure sensitive adhesives (PSAs) are making important inroads into an increasing range of semi-structural applications. A good example of this is for glazing installations, where speed of installation and rapid achievement of strength are sometimes important factors in the assembly and construction process. This presentation will review several of our recent studies characterizing strength and durability properties of acrylic foam tape products for potential semi-structural engineering applications involving residential building construction for shear wall construction (providing enhanced earthquake resistance) and roof sheathing (increasing hurricane uplift resistance). The unique attributes of PSAs may provide improved performance in some applications, though building codes, often written with other joining systems in mind, may still present obstacles to further applications.

Adhesive Applications for Frame House Construction

Approximately 90% of new residential housing in the United States utilize wood-framed construction(1). Adhesives are widely employed in the fabrication of wood products for home construction, including plywood, oriented strand board (OSB), and engineered wood products such as GLULAM (Glue Laminated) beams. Elastomeric construction adhesives (typically much stiffer than PSAs) have been used for floor construction and other purposes, but have not been widely used in framing. Although the strength and stiffness of shear walls fabricated with elastomeric construction adhesives are increased (on the order of 65% and 45%, respectively according to one study(2) that involved typical ASTM E 73 racking as well as simulated seismic loading), the displacement capacities of such walls are significantly reduced, thereby reducing the energy absorption capacities of the structure. Furthermore, observed failure modes tend to be of a brittle nature within the framing members. The use of construction adhesives in residential frame construction, therefore, has been limited (3)[1] because bonds formed with construction adhesives can be too stiff and unforgiving when subjected to certain loading conditions, such as those induced by earthquakes and hurricanes. This ban was instituted in recognition of connection and full-scale wall test results (2, 4-6). The high strength and stiffness, combined with the relatively low deformations to failure that result in thin bondlines of even fairly soft or ductile traditional construction adhesives induces two problems: limited deformations result in minimal energy dissipations, resulting in unforgiving joints, and very high stresses that can damage the bonded lumber.

The nation's demographics suggest that 90% of the population lives in areas that are active seismically or susceptible to hurricanes. As an example, Hurricane Sandy in 2012 reportedly affected 24 states and did $65 billion worth of damage within the U.S, with a significant portion of this

[1] The first edition of the International Building Code effectively banned adhesive use for such applications in high seismic regions.

associated with residential dwellings. If building codes, developed around concerns with traditional construction adhesives in mind, limit adhesive use in such structures, other adhesive options may be inappropriately restricted from consideration. Could acrylic foam PSA tapes with their abilities to seal, damp energy, undergo large deformations, and provide continuous support with limited strength, for example, offer potential advantages in residential construction and avoid problems induced with construction adhesives? And should code development organizations reconsider the possibilities afforded by such joining systems and perhaps allow inroads into this market?

Evaluating Potential of Utilizing PSA Tapes in Shear Wall Construction

Shear walls are an important means of resisting lateral forces such as wind loads and inertial loads applied by upper floors and roofs in seismic events for buildings of all sizes. In residential construction, shear walls are typically constructed of plates, studs, and sheathing (Figure 1). The strength of these shear walls is largely dependent on the fasteners, typically nails, that are used to join the sheathing to the frame(7). To evaluate the potential of using PSAs, double-sided acrylic foam tapes from several vendors were considered. A series of connection tests was performed in accordance with ASTM D 1761-88 on the PSA tapes as well as using three different construction adhesives for comparison purposes. Test of nail-only as well as nail plus PSA tape bonds were also performed. Nominally 2" x 4" No. 2 Grade, Surface-Dry Spruce-Pine-Fir (SPF) framing lumber was sheathed with plywood or OSB. As-received, sanded, and primed surfaces for framing member and sheathing were all considered. Tests were conducted in a universal load frame at a displacement rate of 1.3 mm/min, with specimens mounted in a jig appropriate for the D 1761 test standard, as illustrated in Figure 2.

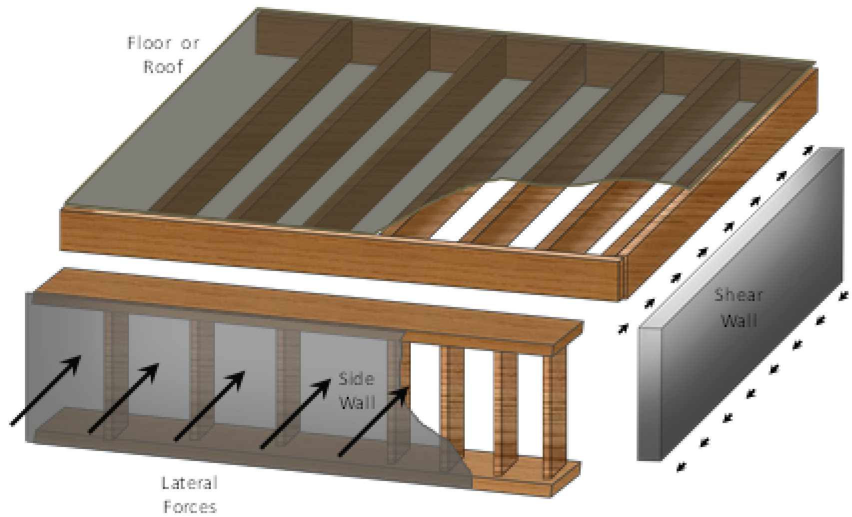
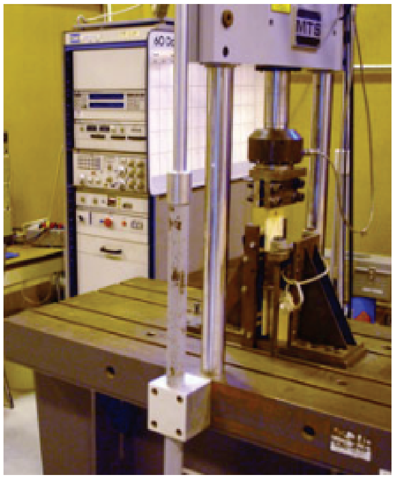


Figure 1. Illustration of a shear wall subjected to shear loading.



Two of the three PSA tapes performed quite well, though one product appeared inferior in our testing. Of those performing well, displacement limits were about eight times the PSA adhesive tape thickness, and 4-5 times the displacement capacities measured with construction adhesives. Surface preparation steps seemed to improve adhesion for OSB, but were not needed on plywood to achieve good performance. Details of these tests, along with results and statistics can be found in (8, 9), which have recommended that allowance for high-performance PSA tapes in shear wall construction be extended to high seismic zones.

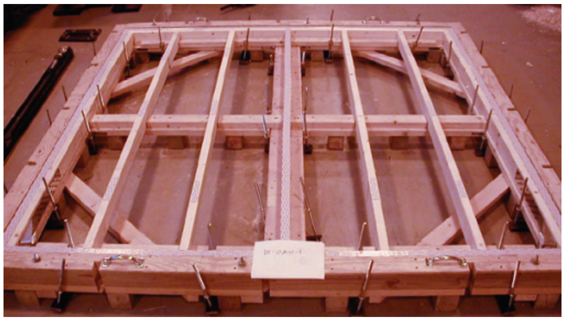


Figure 3. Construction jig used to frame the shear walls.

In addition to the small connection-level tests, racking tests of 23 individual 8' x 8' shear walls were also performed on several of the above cited material combinations. Frames were built by hand in a construction jig, as shown in Figure 3. Applying the appropriate bonding pressure required for sufficient pressure sensitive contact, wetting, and adhesion on these larger scales required a special pressurization device(9). Though this could present challenges in on-site construction, wall panels constructed in a factory could be easily produced. Once appropriately instrumented, these panels were subjected to quasi-static displacement loading as well as cyclic loading of increasing amplitudes using a CUREE seismic protocol (10), as illustrated in Figure 4, while mounted in an outdoor test setup, shown in Figure 5.

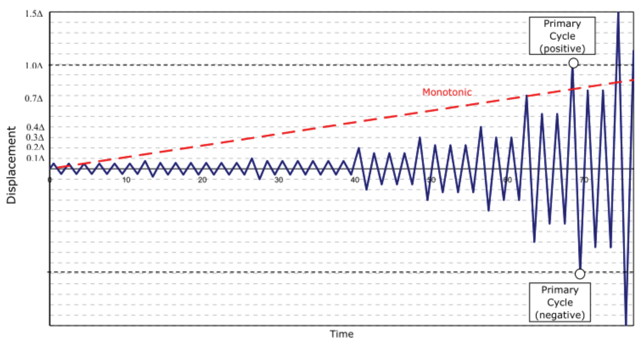


Figure 4. Imposed displacement history based on general CUREE protocol.

Figure 5. Photograph of the seismic racking setup, showing the hydraulic actuator used to control displacement.

The shear wall tests revealed that adding acrylic foam tape in conjunction with a reduced schedule of nails could increase wall racking strength significantly (on the order of 70%). Adhesive only walls had strengths comparable to traditional construction methods, thereby offering no performance advantage. These adhesive only walls performed poorly in the simulated seismic exposure. In contrast, walls constructed with the PSA tapes and a reduced (50%) nail schedule retained stiffness better than nail-only walls during cyclic loading, suggesting a possible reduction in damage to finish materials in homes subjected to such loading scenarios. Details of these tests, analysis, results, and conclusions can be found in (9).

Extending this application further, the benefits of acrylic foam tapes for resisting roof uplift were also examined(11) and a portion of this work has been published(12). In contrast to the shear dominated tests of the connection and shear wall tests described above, a different connection test was used for this study, subjecting the adhesive tapes to nominally tensile loading. Again, possible benefits of the tape plus mechanical fastener were noted, along with the suggestion that adding acrylic foam tapes in high wind areas could be beneficial.

A related wind resistance application involved the use of climatic wind speed data from selected hurricanes to determine the likely effect on acrylic foam tape in structural glazing applications. Studies were conducted in both tension and shear measured the quasi-static and viscoelastic behavior(13), the creep rupture data(14), and used a linear damage accumulation model to assess the impact on durability(15). Additional details on this work can be found in (16-18).

Conclusions

Pressure sensitive adhesive products are finding increasing opportunities in the assembly of a wide range of engineering products, including for semi-structural applications where their flexibility, energy damping properties, strength and toughness, sealing potential, and load distribution capabilities afford specific inroads. Several studies of incorporating acrylic foam tapes into residential construction reveal some of the limitations as well as potential advantages. Specifically, the combination of foam tapes with current or even reduced nail schedules may offer improved strength, stiffness, and resistance to damage for quasi-static, seismic, and wind loading scenarios, at least as measured in laboratory settings. Further work is needed to understand the potential benefits, cost trade-offs, environmental consequences, and limitations. Nonetheless, recognized engineering procedures can be used to characterize and evaluate pressure sensitive adhesives for such semi-structural applications.

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