BUILDING AND CONSTRUCTION LOW APPLICATION TEMPERATURE ADHESIVES: EVALUATION AND DEVELOPMENT

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The building and construction industry utilizes a wide array of bonding technology including (but not limited to) fasteners (screws, nails and staples), caulks, liquid adhesives, mastics and tapes. Each technology has its strengths and weaknesses from an application (ease of use of applying) and performance perspective. The specific technology used is also a function of the specific building and construction segment: as one example, the right choice of bonding technology for a building envelope product is not necessarily the same as interior structural components as interior decorative components. Thus, for any work in this market segment, it is necessary to understand and detail the specific application segment and from that identify the appropriate bonding technology/technologies. In order to appropriately evaluate a bonding technology, test methods need to be identified both for screening and for final certification. Final certification test methods are readily available, but screening methods are typically not published and thus not readily available. The goal of this paper is to develop and publish screening methods for a specific sub-segment of the building and construction industry with a focus on methods easily implemented and transferrable to other market sub-segments.

For this paper, we will focus on building envelope, exterior application to base materials without direct exposure to weather conditions. Our focus is on fenestration tapes (flashing tapes) and evaluating performance of pressure sensitive adhesives in these applications. Fenestration tapes need to pass AAMA 711, American Architectural Manufacturers Association test method for “Voluntary Specification for Self Adhering Flashing Used for Installation of Exterior Wall Fenestration Products”. AAMA 711 is a thorough and extensive test method well suited for evaluating fenestration tapes but is also expensive to implement and complicated to implement some aspects of the test. There are testing laboratories available to execute AAMA 711 testing on a tape construction, but the cost of testing a single construction typically exceeds $10K USD and thus is not practical for routine screening purposes.

In addition to the cost of using a testing laboratory for AAMA 711, AAMA 711 tests material under “ideal” conditions: it does not test with dirty materials nor does it consider variations in moisture on the bonding conditions. Some of the more field based tests for AAMA 711 are also quite time consuming: those that involve thermal and humidity cycling. Other tests, such as nail sealability, involve a highly specific testing setup which is not always feasible for those not focused solely on fenestration tapes. While there are undoubtedly AAMA 711 based screening techniques used in the industry, those are not publicly available.

Based on this situation, the goal of this work was to develop easy to implement screening methods for fenestration tape adhesives with a focus on methods that (1) could be quickly and fairly easily implemented in a number of testing labs, and (2) utilizing methods that can also be used for other building and construction applications (methods suitable for usage beyond fenestration tapes).

Lab Screening Test Method Development

For our method development work, the main items identified as key to the method development were:

1. Adhesion to common and readily available building and construction materials that can be used in mechanical testers.
2. Ability to test adhesion over a range of temperatures ranging from low temperatures to high temperatures.
3. Ability to condition the building and construction materials with a standard moisture condition.
4. Ability to model “dirty” building and construction materials with a standardized “dirt” composition and application method.

Building and construction materials

The mechanical tester used for this method development and subsequent evaluation is an Instron 3655 equipped with a variable temperature chamber. The temperature chamber has both heating and cooling capability. The limiting factor on this temperature chamber is the sample grips; materials with thicknesses up to ¼” can be used. A picture of the testing setup is shown in Figure 1.

Figure 1: Picture of Instron 3655 mechanical tester with variable temperature chamber

With these limitations, a ¼" trilaminate plywood was chosen for benchmarking. This material is readily available from home improvement stores. For this work, the plywood was purchased from a local Home Depot. Testing was performed both with and across the wood grain using the definition shown in Figure 2.

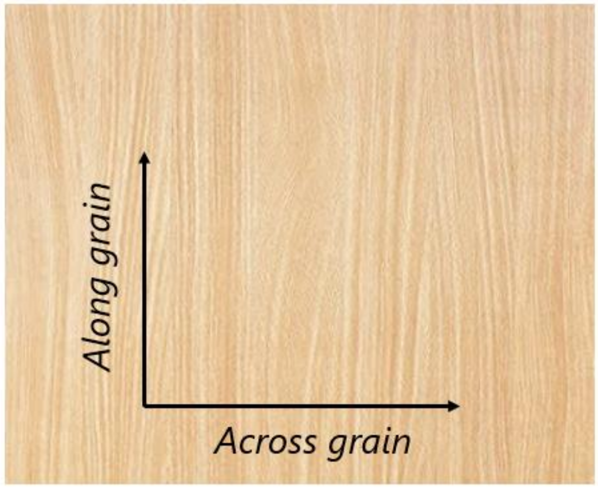


Figure 2: Definition of wood grain direction

Peel adhesion performance under standard conditions (72 °F) were performed on any of the available mechanical testers available in the Henkel Bridgewater Technical Center. All peel testing was performed as 180 degree peels using 1" width strips cut to 6" length. The standard tape construction used in this work was 4 mil/100 gsm adhesive coat weight bonded to 2 mil PET unless otherwise noted.

Temperature testing methodology

Temperature testing was performed at three temperatures: 0 °F (-18 °C), 72 °F (22.2 °C) and 158 °F (70 °C). These temperatures were chosen to represent the lowest reasonable application temperature for fenestration tape (0 °F), room temperature (72 °F), and a high temperature condition that would be higher than reasonably found in summer in warmer/hot regions (158 °F).

Conditioning of the tapes and laminates were performed for 24 hours prior to lamination. A temperature controlled chamber set to 0 °F was used for the cold temperature testing. Conditioning was performed on either just the tape or both the tape and plywood prior to lamination, and then the bonded laminate was maintained at 0 °F for the desired dwell time. A 4.5 pound hand roller was used for lamination within the temperature chamber in order to keep the material at the desired temperature during bonding.

For room temperature testing, the laminates were kept in CTH (constant temperature and humidity) conditions (50% RH, 72 °F) for 24 hours, laminated, and then maintained at CTH conditions for the desired time. The same 4.5 pound hand roller was used for lamination in CTH conditions.

For high temperature testing, the materials were kept in an oven at 158 °F, taken out of the oven and hand rolled using the 4.5 pound roller, and then put back into the oven for the desired dwell time.

Moisture testing methodology

For testing in humid conditions, a water spray bottle was used to mimic "wet wood". Three (3) puffs from the spray bottle were used and the test strips then applied immediately after the wood had been sprayed.

Dirt testing methodology

For modeling "dirty" wood, a mixture of 90% sand and 10% soil was mixed to uniformity via hand mixing. This mixture was then applied to the plywood via a finger rub and loose material swept away prior to immediately bonding the test strips.

Environmental Testing Conditions Naming

The environmental testing conditions nomenclature is defined in Table I

Table I: Definition of environmental testing conditions

Application condition	Testing condition
Clean Use (Across Grain)	Cold temperature (0 °F)
Clean Use (Across Grain)	Room temperature (72 °F)
Clean Use (Across Grain)	High heat (158 °F)
Dirty Use (Across Grain)	Cold temperature (0 °F)
Dirty Use (Across Grain)	Room temperature (72 °F)
Dirty Use (Across Grain)	High heat (158 °F)
Wet Use (Across Grain)	Room temperature (72 °F)
Clean Use (Along Grain)	Room temperature (72 °F)

Adhesive Selection for Screening/Evalution

Table II illustrates the existing commercial grade adhesives evaluated/screened in this work. These adhesives were chosen to cover a full range of pressure sensitive technologies.

Table II: Commercial adhesives evaluated in this work

Adhesive	Technology	Rationale
Adhesive A	Solvent acrylic	Decent low temperature performance
Adhesive B	Solvent acrylic	Current best in class low temperature PSA
Adhesive C	Tackified solvent acrylic	High peel product
Adhesive D	Acrylic rubber hybrid solvent	Very high peel adhesion
Adhesive E	Rubber hot melt	Low temperature hot melt PSA
Adhesive F	Rubber hot melt	Low temperature hot melt PSA
Adhesive G	Tackified UV acrylic	UV PSA; light side cure
Adhesive H	Tackified UV acrylic	UV PSA; dark side cure (non-UV exposed side)
Adhesive I	Rubber hot melt	Low temperature hot melt PSA

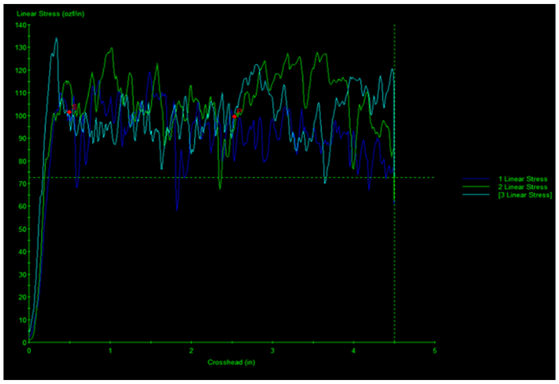
Results

Table III illustrates the results for the various adhesives on plywood at the three different temperatures. These results are with both the tape and panels being pre-conditioned at the measurement temperature prior to bonding. One key finding is that measuring along the wood grain produces a consistently higher peel force than across the grain. For all future testing in this work, unless noted otherwise, across the grain testing was used to measure the more challenging wood direction. It was also noted that across the grain tends to "fiber pick" material from the plywood surface. This was seen both visually and in the peel traces shown in Figure 3. Peel measurements across the grain are inherently noisier due to this "fiber picking" characteristic.

Table III: Testing results for "clean use" peels

Clean Use	Across the grain			Along the grain
Adhesive	**0 °F**	**72 °F**	**158 °F**	**72 °F**
Adhesive A, 20'	20	75	86	177
Adhesive A, 24h	0	130	30	184
Adhesive B, 20'	63	112	52	129
Adhesive B, 24h	53	130	11	135
Adhesive C, 20'	0	173	28	170
Adhesive C, 24h	0	172	30	170
Adhesive D, 20'	0	99	30	150
Adhesive D, 24h	0	140	34	156
Adhesive E, 20'	0	77	0	86
Adhesive E, 24h	0	84	0	100
Adhesive F, 20'	0	109	1	135
Adhesive F, 24h	0	130	0	165
Adhesive G, 20'	0	95	19	108
Adhesive G, 24h	0	107	14	111
Adhesive H, 20'	0	122	19	134
Adhesive H, 24h	0	137	19	140
Adhesive I, 20'	0	76	7	130
Adhesive I, 24h	0	100	12	132

Across the grain peel trace **Along the grain peel trace**



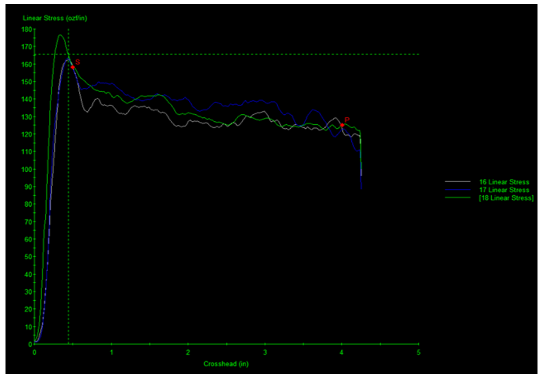


Figure 3: Peel traces across and along the wood grain

Based on these results, the best choice for additional evaluation is Adhesive B as it shows good adhesion at low temperatures, excellent adhesion at room temperature and some resistance to high temperatures (maintains some bond at 158 °F).

Figure 4 shows the comparison of the various adhesives under clean and wet conditions. The lack of differentiation between clean and wet surfaces suggests (1) some moisture on the plywood has limited to no impact on peel adhesion, and (2) further work is needed to evaluate the impact of higher water content on the plywood on bonding strength.

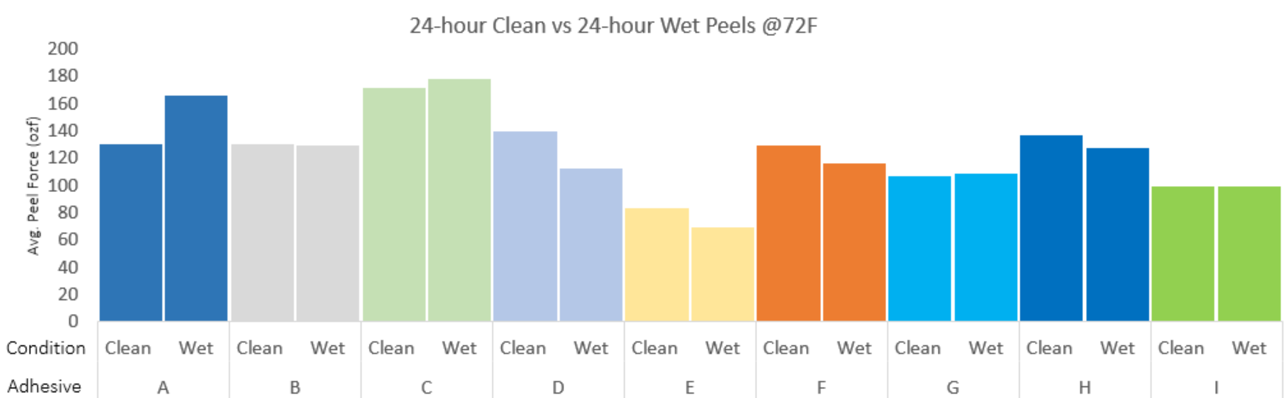


Figure 4: Comparison of peel results from both clean and wet panels for all adhesives

Table IV shows results comparing the impact of conditioning both the plywood panel and tape with conditioning only the plywood panel. This is intended to model tape storage outside in the winter versus applying a warm tape to a cold building. It should be noted that the 72 °F data is the same data set in both cases (obviously the same conditions). Overall keeping the tape warm has a significant impact on the adhesion force. It is interesting to note that conditioning the tape at 158 °F tends to result in higher peel forces versus tape kept at room temperature prior to application. This is likely due to better wet out of the warm tape on the uneven plywood surface.

Table IV: Peel results for panel vs. panel and test strip temperature conditioning

Clean Use	**Only Plywood panels**			**Plywood panels and test strips**		
Temperature	*0 °F*	*72 °F*	*158 °F*	*0 °F*	*72 °F*	*158 °F*
Adhesive B						
20 minutes	83	112	24	63	112	52
24 hours	87	130	18	53	130	11
Adhesive A						
20 minutes	39	75	35	20	75	86
24 hours	54	130	7	0	130	30
Adhesive I						
20 minutes	12	76	7	0	76	7
24 hours	79	100	12	0	100	12
Adhesive E						
20 minutes	0	77	0	0	77	0
24 hours	0	84	0	0	84	0

Table V shows the impact of clean versus dirty panels on peel adhesion. The impact is pronounced at higher and lower temperatures, less so at room temperature.

Table V: Peel comparison for clean versus dirty panels

Peel in ozf/inch	**Clean use**			**Dirty**		
Temperature	*0 °F*	*72 °F*	*158 °F*	*0 °F*	*72 °F*	*158 °F*
Adhesive B						
20 minutes	63	112	52	0	138	18
24 hours	53	130	11	10	126	12
Adhesive A						
20 minutes	20	75	86	5	102	34
24 hours	0	130	30	0	165	28

Adhesive Design

The benchmarking results discussed above identified Adhesive B as the best option for a fenestration tape application. Upon customer sampling and testing in the application, the feedback was that Adhesive B, while a reasonable choice within the current product offering, did not fully meet the requirements under all conditions. These deficiencies were identified as insufficient peel and tack at 0 °F in a flashing tape construction (on a polyolefin film) and difficulty/insufficient bonding to adhere to specific hard-to-bond-to materials including OSB (oriented strand board). To address this issue, a product development effort was undertaken utilizing UV hot melt PSA technology.

Key variables identified for this effort included the polymer glass transition temperature (Tg), crosslink density and the polymer molecular weight. Table VI shows the variables used in Adhesive B compared to the relative values for Versions 1, 2 and the final New Adhesive.

Table VI: Adhesive design variables for improved low temperature adhesive

	Adhesive B	Version 1	Version 2	New Adhesive
Base polymer Tg	-25 C	-30 C	-30 C	-30 C
Crosslink density	High	High	Low	Low
Molecular weight	High	Low	Low	High

Test results for these versions is shown in Table VII for adhesion to plywood at 0 °F using a 5 mil adhesive coat weight with a 2 mil PET facestock. These performance results show that the lower crosslinking versions demonstrate significant higher peel at low temperatures.

Table VII: Peel results for developmental versions

Peel in ozf/inch	Peel, 20 minutes	Peel, 24 hours
Adhesive B	64	94
Version 1 high crosslinking	69	91
Version 2 low crosslinking	130	165
New Adhesive low crosslinking	113	150

The results in Table VIII are for an actual fenestration tape construction utilizing a 4 mil thick polyolefin film (previous work was with 2 mil PET film). These results show acceptable adhesion at both 75 and 125 gsm on standard building and construction substrates: plywood, OSB and aluminum. The aluminum panel testing was also conducted in the temperature chamber in the same manner as the plywood testing. The OSB testing was conducted by maintaining the OSB in a cold temperature chamber, using a cooler to keep the material cold and then testing it immediately upon removal from the cooler. The OSB panels are too thick to fit into the temperature test chamber, thus the modified testing conditions.

Table VIII: Application testing in flashing tape construction on B&C materials

Peel in ozf/inch	75 GSM		125 GSM	
	20 minute	**24 hours**	**20 minute**	**24 hours**
Aluminum	37	25	50	26
Plywood	46	53	51	82
OSB	13	10	21	15

Conclusions

1. We have developed an easily implemented screening method for measuring low and high temperature adhesion to building and constructions materials utilizing plywood as a readily available test material.
2. The “dirty material” screening method shows promise for future projects.
3. Additional work is needed for a “wet material” screening method.
4. An improved low temperature bonding fenestration tape adhesive was developed utilizing the low temperature adhesion screening test method developed in this work.

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