Opportunities to Improve Manufactured Housing Through the Use of Advanced Adhesives and Sealants

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TABLE OF CONTENTS

1

EXECUTIVE SUMMARY

Factory-produced housing provides many opportunities for adhesive-based automation and assembly line methods to significantly reduce labor and increase building performance and durability. Newer adhesives are also available that reduce worker exposure to dangerous chemicals, reduce air pollution and minimize waste disposal concerns that are becoming more common with older solvent-based products.

A team from government and industry was assembled to investigate these opportunities, including representatives from home manufacturers; adhesives manufacturers and distributors; engineering, testing and certification firms; and the U.S. Department of Housing and Urban Development.

Adhesive and sealant opportunities that offer the greatest potential benefit to manufactured housing construction were identified and evaluated. First, an overview of adhesive and sealant use in manufactured home production was developed. This overview was then used in conducting a survey of 21 manufactured housing plants. The survey was designed to evaluate satisfaction levels of current adhesives and sealants in use, as well as identify and characterize other manufacturing, performance and service issues related to adhesives and sealants. Next, 10 adhesive manufacturers were interviewed to get a supplier's perspective. Ten application areas identified during the home manufacturing plant surveys were then prioritized by the industry committee for their potential to positively impact manufactured housing production. Home and adhesive manufacturers were also probed for new opportunities for adhesives in manufactured housing production.

Interior wall construction and bottom board repair were identified as the two application areas where improvements to the adhesive systems currently being used can have the greatest impact on manufactured housing quality and affordability. A research program focusing on these two areas of the manufactured housing construction process is proposed.

2

INTRODUCTION

The highly controlled sequencing of events in factory-produced housing provides many opportunities for adhesive-based automation and assembly line methods that significantly reduce construction labor and increase building performance and durability. Factory construction also provides the opportunity to integrate structural properties of adhesives into the design of the home. Adhesives can be used to combine simple building materials into large composite elements with greatly improved structural integrity.

Newer adhesives are available that reduce worker exposure to dangerous chemicals, reduce air pollution and minimize waste disposal concerns that are becoming more common with older solvent-based products. It is becoming increasingly important to avoid unnecessary construction expenses by identifying low-cost adhesive products and strategies that satisfy workplace and environmental concerns, that are simple to use and maintain without waste, and that also minimize disposal concerns.

Many advanced adhesive products and methods are available. Manufactured housing has been slow to adopt new adhesive products and strategies due to a variety of reasons including: new adhesive products and applications have not been tested in the factory environment; individual manufactured housing companies can rarely afford the costs of full scale testing; and, some advanced methods require factory up-fit and a significant capital investment.

A Steering Committee from government and industry was assembled to investigate these opportunities, including representatives from home manufacturers; adhesives manufacturers and distributors; engineering, testing and certification firms; and the U.S. Department of Housing and Urban Development, Office of Policy Development and Research, and Office of Manufactured Housing Programs. The latter is the government regulatory agency overseeing manufactured housing construction.

2.1 PROJECT OBJECTIVES

Adhesives play a part in almost every aspect of the manufactured housing building system. Use of advanced adhesive products and strategies are an essential part of an overall effort to reduce the cost and improve the quality of manufactured housing. They present an opportunity to do the following:

- Speed production and increase quality of manufactured housing by improving adhesive performance. Advanced adhesive products can have better performance characteristics and a longer life than traditional products. They may facilitate the use of steel framing techniques, Structural Insulated Panels (SIPs), or other innovative technologies that can result in building systems that are intrinsically more durable and easier to maintain.
- Provide equal or superior structural integrity than current adhesive and/or fastening systems. Structural systems using adhesives are far stronger than systems relying solely on mechanical fasteners. Sheathing applied with adhesives is better suited to resist damage from high winds; the increased structural integrity will promote occupant safety. Adhesives allow individual building components to be combined to form composite structural elements. Currently used

in some manufactured housing floor systems to create "T" beams from floor joists and sheathing, this strategy can be expanded to other areas of the home to increase structural integrity and reduce costs.

- Increase worker safety and decrease environmental concerns and disposal costs of current adhesives. Advanced adhesive formulas with lower levels of solvents and other strategies that reduce the amount of volatile chemicals used in the plant can significantly reduce costs for the manufacturer to meet environmental and waste disposal regulations. They also reduce the amount of volatile chemicals released into the plant environment that escape to the atmosphere. These same products have less impact in landfills where the spent containers and other adhesive waste products from manufacturing are ultimately disposed.

Many of these opportunities have the potential to result in a net cost savings to the industry by improving product quality and production efficiency, reducing disposal and other environmental-related costs, improving the workplace environment and worker safety, and reducing property damage from natural hazards.

2.2 RESEARCH PROCESS

The project considered various applications of advanced adhesive, sealant and caulking products in manufactured housing production. Those opportunities and needs that presented the greatest potential to significantly benefit manufactured housing construction were identified and evaluated through the following process (see Figure 2-1):

1. An overview of adhesive, sealant and caulk use in manufactured home production was developed with input from adhesive suppliers, manufactured home plants, and third party testing and certification agencies (Table 3-1).
2. This list was used to develop a survey of manufactured home plants (Section 3.1 and Appendix A)
3. Adhesive manufacturers were interviewed (Section 3.2)
4. Industry representatives then prioritized the adhesive needs and opportunities (Section 3.3 and Appendix B).
5. As a result of this process, a well-defined research proposal focusing on two areas of the manufactured housing construction process that can have the maximum impact on manufactured housing quality and affordability was developed (Section 3.4).

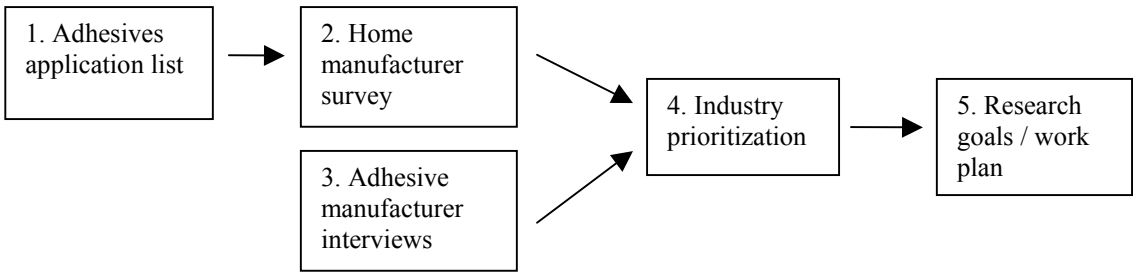

Figure 2-1. Sequence of project tasks

3

IDENTIFYING ADHESIVE AND SEALANT OPPORTUNITIES

3.1 HOME MANUFACTURER SURVEY

A survey of home manufacturers identified several areas of interest to the industry.

3.1.1 Purpose of the survey

The purpose of the survey was to understand the types of adhesives being used in each application and more importantly what the satisfaction level is with each of them. Additionally, the survey aimed to identify and characterize the most serious manufacturing, performance and service issues related to adhesives and sealants.

3.1.2 Development and distribution of the survey

A generic list of the existing adhesive products and methods being used for each application in manufactured housing production was developed through preliminary discussions with housing manufacturers and adhesive providers (Table 3-1).

Table 3-1. Manufactured housing production adhesive and sealant applications

Application	Substrates	Relevant standard(s)
Floors		
▪ Floor deck to floor joists/trusses	Wood-wood	ASTM D3498, HUD UM 60a
Walls		
▪ Interior wall	Gypsum-wood	
▪ Shear wall	Gypsum-wood	ASTM C557, D6464
▪ OSB ext. wall sheathing to wall studs (in conjunction with fasteners)	Wood-wood	ASTM D3498
Ceiling		
▪ Ceiling diaphragm	Gypsum-wood	UL 1296; PEI Std. 89-1
Windows & Doors		
▪ Window/door flanges to sheathing	Aluminum/vinyl-wood	
Wall & Roof Penetrations	Aluminum/vinyl-asphalt shingles	
Flooring		
▪ Linoleum flooring to deck		
▪ Hardwood flooring and tile to deck	Wood/tile-wood	
▪ Carpet and vinyl flooring to deck		

Application	Substrates	Relevant standard(s)
Cabinets, Countertops	Laminate/wood-wood	
Tub surrounds	Plastics(ABS)-vinyl	
Waterproofing		
▪ General waterproofing	Plastics-vinyl/wood	
▪ Asphalt shingle roofs	Asphalt shingles/flashing-wood	ASTM D3019 D4586
▪ Edges and surface areas around cutouts in particle board decking in high humidity and water usage areas	Wood	
▪ Roof-to-gutter interface water seal	Asphalt shingles-aluminum	
Air Infiltration		
▪ Sealing halves of home together	Wood-wood	
▪ Furnace/water heater compartment wiring/piping wall gap filling	Wood-wood/gypsum	HUD code requires flame spread eq. to dim. lumbr. or 5/16" GWB
▪ Furnace room wall corners	Wood-wood/gypsum	
▪ Ext. wall to wall, roof and floor draft blocking	Wood-wood	
Fire Blocking	Gypsum-wood	
Structural Elements		
▪ Construction of ridge beams	Wood-wood	CA 25-4

The survey tool was then distributed for comment to the entire project Steering Committee which suggested additional questions.

Surveys were distributed to nine manufactured housing producers. Each manufacturer was requested to distribute the survey to plant managers or an appropriate person in the corporate office for completion. A total of 21 surveys were received from seven manufacturers. Seventeen of the responses came from individual home manufacturing plants, and four came from corporate engineering or manufacturing offices. In most cases the respondent was a home manufacturing plant manager, or, if at the corporate office, a production or engineering executive.

3.1.3 Description of the Survey

The survey consisted of 13 questions (A complete list of the questions and summary of responses is found in Appendix A.). The first question presented the respondent with a table of 23 adhesive and sealant applications and the most common generic products used for that application as identified by Steering Committee members (Table 3-1). Respondents were asked to identify the adhesive or sealant type or types their plant or company used for the application (or indicate if they used none), and rate their satisfaction as either "very satisfied", "moderately satisfied", or "unsatisfied." There was a space for comments adjacent to each application.

Questions 2 through 4 asked respondents to describe the most significant problems they have with respect to adhesive or sealant use in manufacturing, adhesive and sealant performance, and service issues related to adhesives or sealants respectively.

The remaining questions pertained to new applications, environmental regulations, health and safety, indoor air quality, impressions of the adhesives industry, future trends, and adhesive selection criteria.

3.1.4 Survey Results

Nine key problem areas were identified as follows:

1. Wall panels to studs

It is clear from the surveys that the biggest adhesives issue in manufactured housing plants is the application of wall panels to studs. It is no coincidence that this application is also one of the largest uses of adhesives by volume in the plants (along with 2-part polyurethane foam for the ceilings). Moisture-cured polyurethane (PU) and polyvinyl acetate (PVA) adhesives are the two most commonly used products for this application, with slightly more respondents using PVA. The major performance problem related to wall assembly is loose wallboard panels. While it is acknowledged that PU's are stronger and result in fewer loose panels, they are not immune to this problem and they have other disadvantages, such as difficulty in clean-up. Open time and cure time issues are also evident with both types of adhesives at either hot or cold weather extremes.

The following quote best captures the mood of the respondents:

"*Lots of things have happened for the better in the last 10 years but whoever comes up with an adhesive that solves the problem with loose gypsum in a production atmosphere…will have accomplished something*."

2. Roof trusses to ceilings

A few issues also came to light regarding two-part PU foam used for fastening trusses to ceiling gypsum board. One hundred percent of home manufacturing plants surveyed use this method, however nearly a third of them are only "moderately satisfied", primarily due to application control issues, which impact production costs. Large amounts of adhesive are wasted through over-application due to a "more is better" attitude on the part of workers, even when small amounts of this very strong adhesive are sufficient to do the job.

3. Wall and roof penetrations

There is no consensus on the best product type to use for this application, with asphalt, butyl tape and silicones being the most popular. All solutions received a significant number of "moderately satisfied" responses, with asphalt being the least satisfactory even though it has the most users. Asphalt is messy, has a long cure time, and a short lifespan according to some of the comments.

4. Cabinets and countertops

About two-thirds of respondents use water-based contact adhesives, verses one third using solvent based. Over half of the respondents for both types are either "moderately satisfied" or "unsatisfied" due to poor holding power and durability on laminate countertops and edge banding.

5. Tub surrounds

Solvent-based contacts, followed by double-sided tape are the two most popular products for tub surround installation. Less than half of the respondents are "very satisfied", complaining of failing tape which leads to service problems and bleed-through with contact adhesive.

6. Asphalt shingle roofs

All respondents use roof cement, but less than half are "very satisfied", with two being "unsatisfied". Complaints include "messy" and "drips and seeps on hot days".

7. Air infiltration

Acrylic latex caulk, PU foams and foam tapes are the most common products used for air infiltration, although none provide complete satisfaction. Foam tapes are the most popular but only 36% of respondents are "very satisfied".

8. Bottom board sealing

By far the least satisfaction of any product type in the entire survey is with bottom board tape, with seven of twelve users reporting that they are "unsatisfied" and the remainder only "moderately satisfied". A few home manufacturing plants use spray adhesive (some in combination with tape) but no respondents were "very satisfied" with their solution for this application except the one who does not use anything at all. The tape was reported to not hold well, fall off after a short time in the field, and lack durability.

9. Sealing air duct joint and seam leaks

Solutions for this application were split between mastic and tapes. Mastic enjoys the higher rating, with 73% reporting "very satisfied", although there are some who find that it is messy and has long cure times. Less than half of the tape users were "very satisfied", complaining of poor sealing results and durability.[1]

3.2 ADHESIVE MANUFACTURER INTERVIEWS

Interviews were conducted with 10 adhesive/sealant manufacturers and one adhesive/sealant distributor. The purpose of these conversations was to get initial thoughts on issues and opportunities for adhesives and sealants in the manufactured housing industry from a supplier's perspective. The interviewees who provided input in this round of discussions were all involved as active suppliers to the manufactured housing industry.

In most cases the contact person for these discussions was either a marketing or business manager involved in the manufactured housing industry market segment. In a few cases the contact person was from the adhesives plant or lab. In the case of the distributor, the contact person was a sales manager. Typically, the marketing/business managers were most familiar with the industry's issues and provided the most insightful comments. The interviewees were asked to discuss their top issues with respect to adhesives, sealants and caulks in the manufactured housing industry.

The topics of discussion can be divided into nine categories:

1. **Conservatism**. The manufactured housing industry mindset is not conducive to innovation. It is a challenge to get home manufacturers and adhesive suppliers to look "outside the box".
2. **Cost**. Home manufacturers are fixated on raw "in-the-door" adhesive product price and too often ignore the total cost of their adhesive purchasing decisions which may include: production efficiency effects due to adhesive/sealant performance and product quality effects that may impact warranty costs and customer perception. Adhesive suppliers find it difficult to get manufacturers to pay for what, in the suppliers' opinion, is significant added value. According to one supplier, one way to bypass this hurdle is to get a leading manufacturer to start using a product and thereby set an example for the industry (an example is the adoption of PU foam for ceiling/truss applications).

[1] Mastics have been proven effective in reducing air distribution system leaks and have been promulgated to the industry through MHRA's Improving Air Distribution Systems Performance in Manufactured Homes project. As part of this project, MHRA sent building scientists into 16 housing plants nationwide to train plant staff on various ADS improvement techniques. A report summarizing this work is available from the MHRA website www.mhrahome.org.

3. **Direction**. Adhesive manufacturers find it difficult to get concise research and development direction from home manufacturers.
4. **Certification**. Tests for certification are a significant expense and limit the ability to introduce new adhesive products to the industry. Standardizing the tests for BOCA (modular) and HUD-code construction would be beneficial.
5. **Production line**. The home manufacturers insist on immediately lifting wall sections after gypsum wall board is glued to the studs, imposing high stress loads prematurely and often breaking the adhesive bond. The fast pace of the production line does not permit workers to allow the adhesive to set adequately on wall sections prior to lifting.
6. **Home manufacturer plant environment**. A cleaner, neater work environment would foster a more positive experience with adhesives on the plant floor.
7. **Training**. Clean-up and hygiene is a problem with one-part polyurethane adhesives. Workers are not careful with the adhesive material and it ends up covering hands, tools, clothing, and finished work product. Training is the primary means of addressing this issue, however manufacturer enforcement of rules is lax and plant culture is not conducive to following health and hygiene rules.
8. **Automation.** Home manufacturers are very reluctant to invest in capital equipment. Automation must take into account the production speed requirements of the plant – for example, there are cases where workers, thinking the adhesive dispensing nozzle slows them down, remove it from the hose, and use the adhesive hose like a garden hose. This is also a training issue.
9. **Volatile Organic Compound's (VOC)**. The release of VOC's from adhesive and sealant use in home manufacturing plants presents worker safety and environmental issues. Some suppliers believe that many manufacturers wish to address this issue but do not have the budget to do so. One adhesive manufacturer feels that this is a regional issue, with some regions, particularly the Northeast, caring about it much more than others. At least two adhesive manufacturers believe that the manufactured housing industry needs a strategy to deal with the VOC issue before it becomes a larger problem. Suppliers note that manufacturers do not calculate the cost of the potential fines against the cost of improving environmental performance.

3.3 PRIORITIZATION OF ADHESIVE AND SEALANT APPLICATIONS

Once the problems areas had been identified by the manufacturers and characterized in general terms through the respondents' comments, it was necessary to assess the relative magnitude of the respective problems and potential of the corresponding opportunities. Factors for consideration included:

- Potential impact on the cost of manufacturing the home
- Potential impact on product quality
- Potential to improve the plant environment
- Potential for success
- Magnitude of the research and development effort required

Members of the project Steering Committee rated ten application area opportunities on a scale of 1 (lowest priority) to 5 (highest priority) with respect to the above categories. These ten[2] were identified from the home manufacturer surveys based on the number of manufacturing plants using this application and the prevalence of moderately satisfied or dissatisfied responses and comments. This process resulted in the order of prioritization of problem areas to be addressed through future research shown in Table 3-2 (see Appendix B for complete rating results).

Table 3-2. Prioritization ranking of adhesive and sealant application areas for future research

Application Area	Average Overall Ranking
1. Wall panels to studs	4.1
2. Wall back panels	3.9
3. Bottom board sealing	3.9
4. Two-part PU foam on ceilings	3.0
5. Sealing air duct joint and seam leaks	3.0
6. Asphalt shingle roofs	2.9
7. Air infiltration	2.8
8. Tub surrounds	2.8
9. Cabinets and countertops	2.7
10. Wall and roof penetrations	2.4

The two top priority items, wall panels to studs and wall back panels are essentially the same issue – that of fastening wallboard to studs. As noted in Table 3-2, these two, along with the third item, bottom board sealing, received an overall priority rating of about four out of five. The remaining items all received ratings between two and three out of five. This clear separation between application priorities suggests that the top three areas should be the focus for future investigations.

3.4 CONCLUSIONS

Interior wall panels to studs and bottom board sealing are the two areas identified by the research and the Steering Committee as the highest priority and as having the greatest opportunity to make the biggest improvements in the cost and performance of manufactured homes. Future work will focus on these two areas.

3.4.1 Interior walls

Presently interior walls are typically assembled in the following manner:

1. Studs are placed horizontal on table (the wall may be up to 18 feet long)
2. Adhesive is applied to edge of studs
3. Wallboard is placed down on studs

[2] Nine applications were identified as noted in Section 3.1.4. The wall panels to studs application was split into two: wall panels to studs and wall back panels. Wall Back Panels represents the application of the second sheet of wallboard to the other side of the wall to close it in. This step is performed once the wall is set on the floor deck and electrical, plumbing, and other items have been installed.

4. Varying numbers of mechanical fasteners (typically staples) are installed along the edges and sometimes also in the field of the wallboard.
5. The wall is then lifted up to vertical position and fastened in place on the floor deck.

As revealed in the home manufacturer survey, two types of adhesives are commonly used in this application: moisture-cured polyurethane, used by 36% of respondents and polyvinyl acetate, used by 48% of respondents. Each adhesive presents in own advantages and disadvantages, although problems of loose gypsum board and cure times that vary with seasonal temperatures are prevalent with both types.

- **Moisture-cured polyurethane (PU)**

  Of the nine manufacturing plants responding to the survey that use this adhesive, three were very satisfied, five were moderately satisfied, and one was unsatisfied with its performance. Extremely high strength and fast set and cure time enable walls to be rapidly assembled and lifted into place without fear of failure (high "green" strength). These same attributes make it difficult to clean from tools, hands and work product. Moisture-cured polyurethane has a short set time (as little as a couple of minutes, depending on environmental temperature and relative humidity) and requires solvents to clean it from finished wall surfaces. These solvents often leave a stain on the wall surface that is impossible to clean or cover, as it bleeds through paints and wallcoverings. This stain may require replacement of the wallboard, either in the plant or in the field as a result of customer complaint. To the repair crew, the high strength of the adhesive is a disadvantage. The adhesive bond is stronger than the internal strength of the wallboard, making it exceedingly difficult to remove the wallboard. The repair personnel often resort to chipping the wallboard off in pieces and scraping the residual adhesive off the studs, a laborious and messy process. While the short set-up time is an advantage for most cases in a fast-paced assembly line, longer walls (some up to 18 feet long) may require more than the approximately 3 minute open time of the adhesive, resulting in poor bonds where the adhesive has skinned over prior to assembly of the wallboard onto the studs.

- **Polyvinyl acetate (PVA)**

  Of the 12 manufacturing plants using this adhesive, two were very satisfied, eight were moderately satisfied and two were unsatisfied with its performance. PVA is typically, although not always, water based. It has a slower set-time and cure-time and has a weaker bond strength than urethane adhesives. These properties, especially the water-based formulation, make clean-up easy and replacement of defective or damaged sections of wallboard in the plant or the field much simpler. However, the long set time is less than ideal for the fast pace of the manufactured home plant. The wall must be assembled, lifted, and fastened into place very quickly, often before this type of adhesive has reached adequate holding strength. As a result, additional mechanical fasteners are required to withstand the stress incurred during lifting, fasteners that later require application of additional tape and mud for finishing. At times, even these fasteners do not hold, and the wallboard pops off the studs, requiring repair or replacement. Furthermore, if the home ships from the plant prior to the adhesive fully curing, the vibrations and racking imposed on it during transit may also cause adhesive failure and necessitate costly field repairs.

Industry has not been able to find a happy medium between these two alternatives; the high-strength, fast setting solvent-based adhesive and the low-strength, slow curing water-based adhesive. One possible solution would be an adhesive that can be applied while the wall is in the vertical position, along the corners of the already-assembled stud/wallboard connection (similar to the roof truss to ceiling board connection). Manufacturers have expressed a desire for this type of product; however a

suitable one has not been found. One-component polyurethane foam has too low a density and cohesive strength so it is typically not strong enough for this type of bond. Two-component polyurethane has a high enough density and cohesive strength, making it strong enough for this type of application, however it is too liquid for vertical application.

Research Direction

This problem can be approached in at least two ways, as a strictly adhesives problem, or as a broader manufacturing process issue:

a. A rethinking of the way the interior finish material is applied to the wall structural members, or even a re-thinking of the wall construction itself. This may include concepts such as super-sized wallboard, pre-assembled wall sections or "extruded" walls. This broader view of the interior wall manufacturing process must be tackled by the manufactured housing industry as a whole in partnership with experts in manufacturing processes and materials.

b. A revised adhesive formulation that marries the best attributes of the two adhesives and results in an easy-to-clean, medium strength, faster set-time adhesive. This formulation issue is best left to the adhesives suppliers, working in partnership with their customers, the manufacturers. These partners should work together closely to resolve this product issue.

3.4.2 Bottom board

There are a number of manufacturers of bottom board, and a variety of products used for this application, including polyethylene, asphalt-impregnated fiberboard, asphalt-impregnated fiberglass cloth, and heavy tar paper. Bottom board manufacturers recommend adhesives that are tested for use with their products. These are used in the manufacturing plant to close the bottom board in the event it is accidentally damaged or is cut to access the floor cavity for repair reasons. In addition to these adhesives, tapes are often used to patch and repair openings in the bottom board, both in the plant and in the field. These tapes may or may not be thoroughly tested for compatibility with the bottom board material in use. Often, these tapes fail after a relatively short period of time, according to survey respondents. Other recommended repair techniques involve the installation of rigid frames or boards to serve as a backer for mechanically fastened patches. Openings in the bottom board have been associated with a number of problems, including vermin infestation, moisture intrusion, and air leakage. Intact bottom boards are also important to re-direct duct air leakage back into the home.

The bottom board takes a lot of abuse, during transport and installation, and over the life of the home. Once the home is installed, the crawlspace is often subject to conditions of high humidity, which can adversely affect materials used for bottom board patching and repair. Installers of many services such as television cable and telephone lines, and repair and service crews frequently puncture the bottom board to gain access to the home. A simple, durable and long-lasting bottom board repair method that works with all or most bottom board materials is not available.

Research Direction

Once again, there are at least two ways to approach this problem: reformulating a tape or other method of repairing holes in bottom boards, or re-thinking the design of the floor closure:

a. A rethinking of the purpose and function of the materials used to enclose the floor system. This might include how and where it is applied to the home, the materials employed, and the methods used to gain access. This research may result in a wholesale revision of the bottom board, thereby improving the quality and durability of the home overall, or a complete redesign of the floor system.

b. Reformulating the tape or devising another method of bottom board repair must address the issue of the variety of bottom board materials in use and the associated compatibility

problems. This is most likely a significant effort involving proprietary adhesive chemistries, most appropriately tackled by suppliers of the tape products or the bottom board manufacturers themselves. The development a single or at most a few, simple and inexpensive repair methods for the wide range of bottom board materials in use is in the best interests of these companies.

A

HOME MANUFACTURING PLANT SURVEYS

Answers to survey questions

Question 1: Please fill out the following table by circling the appropriate product type in column B and checking the appropriate space in column C. If you checked "unsatisfied" in column C, please explain in the space provided. Please add any adhesive applications you use that are not listed here in the rows labeled "Other" at the bottom of the table or on a separate page.

Responses to Question 1 are summarized in Table A-1 below.

Table A-1. Home manufacturing plant satisfaction levels with adhesives and sealants

Application	Product Type	Respondents Using Product[3]	Very Satisfied	Moderately Satisfied	Unsatisfied	Respondents' Comments
Floor deck to floor joists/trusses	moisture-cured PU	13	69%	31%		
	solvent-based mastic					
	water-based mastic (latex)	1		100%		
	PVA	10	30%	70%		occasional loose decking issues; manufacturers prefer for ease of application and cleanup, but PU stronger
Interior wall cladding to studs	moisture-cured PU	9	33%	56%	11%	difficult to remove excess from panel faces; clean up a problem; no in-field stapling required
	solvent-based mastic	1		100%		
	water-based mastic (latex)	3	33%	33%	33%	too watery, non-adhering
	PVA	12	17%	66%	17%	occasional loose panel problem; too watery, non-adhering; long coalescing time a problem; manufacturers prefer for ease of application and cleanup, but PU stronger
Shear wall cladding to studs	moisture-cured PU	9	44%	44%	12%	clean up a problem; stronger and performs better - less loose panels; higher shear values
	solvent-based mastic	1	100%			
	water-based mastic (latex)	4		75%	25%	mastic used on back paneling works well; too watery, non-adhering
	PVA	13	23%	62%	15%	too watery, non-adhering; long coalescing time a problem; manufacturers prefer for ease of application and cleanup, but PU stronger

[3] Some respondents use more than one type of adhesive for a given application.

Application	Product Type	Respondents Using Product[3]	Very Satisfied	Moderately Satisfied	Unsatisfied	Respondents' Comments
Exterior wall sheathing to studs	moisture-cured PU	1		100%		
	solvent-based mastic					
	water-based mastic (latex)	2	100%			
	PVA	2	50%	50%		
	none	15	100%	0%		we only glue the sheathing that is sometimes in the axle area
Ceiling diaphragm – ceiling board to trusses	2-component moisture-cured PU expanding foams	21	66%	29%	5%	cost & control of application equipment a problem; ceiling not used as diaphragm
	none					
Window/door flanges to sheathing	silicone sealant	8	88%	12%		
	butyl tape	11	64%	36%		
	synthetic rubber	1	100%			
	PVC foam tape	2		100%		
	expanding foam	1		100%		
	latex adhesives	1	100%			
Wall & Roof Penetrations	butyl: tape or caulk	8	63%	38%		
	silicone: tape or caulk	6	67%	33%		
	asphalt on asphalt shingle roof	9	44%	56%		"black jack" is messy and has long cure time
	synthetic rubber	2	50%	50%		
	expanding foam	2		100%		used for E-star & Super Good Cents
	none					
Flooring: Linoleum flooring to deck	latex linoleum adhesive	7	43%	57%		
	none	12				
Flooring: Hardwood flooring and tile to deck	solvent-based mastic	1			100%	
	water-based mastic	4		75%	25%	
	latex & caulk	1	100%			
	none	15	100%			
Flooring: Carpet and vinyl flooring to deck	tack strip	1		100%		
	tile paste	1		100%		
	latex exterior adhesive	1	100%			
	none	17				
Cabinets and Countertops	solvent-based contact	6	33%	50%	17%	
	water-based contact	14	43%	50%	7%	laminate edge banding with water based contact adhesive does not hold; not as strong as solvent-based adhesives; Counter top edge band peels too easily when bumped at corners.
	none					
Tub Surrounds	double-sided tape	4	50%	50%		tape often fails; does not hold well - service problems are huge
	solvent-based contact	9	44%	56%		some problems with bleed-through

Application	Product Type	Respondents Using Product[3]	Very Satisfied	Moderately Satisfied	Unsatisfied	Respondents' Comments
	none	6				
Water-proofing, interior	silicone: caulk / sealants	5	80%	20%		
	siliconized latex: caulks / sealants	12	50%	50%		
	none	2				
Water-proofing, exterior	silicone: caulk / sealants	11	55%			
	siliconized latex: caulks / sealants	7	57%	43%		
	polymer	2	100%			
	none	2				
Asphalt shingle roofs	roof cement	20	45%	45%	10%	
	none					
Roof-to-gutter interface water seal	polybutylene putty tape	1	100%			
	silicone sealant	1		100%		
	none	17				
Air Infiltration	acrylic latex caulk	6	50%	50%		still pretty leaky
	PU foams	9	56%	44%		still pretty leaky
	foam tapes	11	36%	64%		still pretty leaky
	butyl tape	1	100%			
	none	2				
Sealing halves of home together	foam tape	5	60%	40%		
	compressed insulation	3	33%	33%	33%	
	sealing gasket	10	60%	40%		
	caulk	1		100%		
	foam with non-adhesive back	1			100%	changing to better/thicker gasket, applied both halves
	none					
Furnace/WH compartment wiring/piping wall gap filling and wall corner sealing	expandable foams	18	56%	44%		
	latex caulks	3	67%	33%		
	caulk	2	50%	50%		
	none					
Exterior wall-to-wall, wall-to-roof and wall-to-floor draft blocking	sealant	1	100%			
	latex caulk	5	60%	40%		
	foam tape	8	50%	50%		
	overlapping sheathing	1		100%		
	none	6				foam board installed
Ridge beam construction	PVA	8	100%			
	laminated veneer lumber (LVL)	2	100%			
	structural PU	2	100%			
	none	11				

Application	Product Type	Respondents Using Product[3]	Very Satisfied	Moderately Satisfied	Unsatisfied	Respondents' Comments
Bottom board sealing	spray contact	3		100%		
	tape	12		42%	58%	tape turns loose after a while in field; tape does not provide durable seal
	none	1	100%			
Sealing air duct joint & seam leaks	mastic	11	73%	18%	9%	mastic messy & long open times
	tape	9	45%	45%	11%	changing to mastic plus tape in humid climates
	silicone	1	100%			
	none	1				
Water & drain lines	plumber's glue	1			100%	need better, faster glue

Question 2/3: What are your most significant manufacturing/performance problems?

Twenty-four problems were identified by twelve respondents.

Bottom board

- Bottom board tape does not hold well (3 respondents).

Ducts

- Foil tape does not hold well on heat ducts.
- Mastic applied with brush or caulk tube used to seal ducts has a long open time.

Countertops

- Water-based contact adhesive for countertop laminate has too long a dry time (2 respondents).
- Water-based laminate adhesives do not hold.

Ceilings

- Over usage is a problem with PU foam used on ceiling to rafter connection (2 respondents).
- It is very expensive to rebuild application equipment.
- Two-component PU used to apply ceiling board occasionally has inconsistent mixture.

Walls and floors

- Loose gypsum wallboard (GWB) panels on studs with PU foam adhesive (3 respondents).
- Foam “rolls-up” when applied.
- Don’t like having to staple panels in addition to using adhesive.
- PU adhesive can’t be cleaned from hands or clothes.
- Difficulty maintaining proper bead size with PVA adhesive applied to wall studs.
- PVA adhesive used to apply panels to wall studs is received in varying quantities and consistencies.
- PVA/water-based mastic adhesive used to apply panels to wall studs has too long a cure time.
- Dry time for PU floor deck adhesive is too long when temperature reaches 80 degrees F.
- Expanding foam on floors and walls takes too long to cure when temperature is less than 45 degrees F.
- PU adhesive is difficult to remove from wallboard.

- Excess moisture causes extra expansion in butt joints when using one component PU adhesive on floor decks.

Vapor barrier

- Ceiling spray-on 4 mil vapor barrier has a long cure time and a slow application rate.

Roof

- Roof cement used to apply shingle underlayment paper to roof deck is messy. It gets on house siding, tools, hoses and employees.
- Roof cement drips and seeps on hot days.
- Asphalt-based application of asphalt shingles is messy, has high levels of volatile organic compounds (VOC) and short service life.
- Shingle tabbing is insufficient. Shingles blow off homes during transit.

Caulking

- Caulking and sealing dries, cracks and shrinks.

Flooring

- Solvent-free linoleum adhesive applied with a trowel leaves ridges that dry in clumps.

Marriage line joint

- The thin, porous foam used to seal the marriage line does not create a good air seal.

Question 4: What are your most significant field complaints related to adhesives?

There were twelve problems identified by ten respondents to this question.

- Bottom board tape comes off in field after a time (2 respondents).
- Short life (1-2 years) of asphalt-based shingle adhesive.
- Loose gypsum panels (4 respondents) particularly after long transits.
- PU adhesive bleeds through at panel joints.
- Butyl tape leaves black streaks on home.
- Tub wrap “turns loose”.
- Edgebanding separates.
- Discoloration and shrinkage of caulking and sealants.
- Short life and separation from material with siliconized latex caulks in wet areas of home.
- Duct system leakage due to tape failure.

Question 5: Are there adhesive, caulking or sealant applications that you would use but lack required testing and or product performance certification?

- Ten respondents responded negatively to this question.
- Another respondent mentioned a PU foam sealant for vents and receptacles that they cannot use because of a high VOC content.

Question 6: Where are you currently using mechanical connections for which you would like to substitute an adhesive?

- Three respondents indicated a desire to do away with all mechanical fasteners that they currently use to supplement adhesives on wall and floor assembly.
- One respondent requested an improved adhesive to hold cement-foam interior and exterior decorative elements to wallboard.
- One respondent would like an improved cabinet adhesive for style and rail construction.

Question 7: Have you in the past done, or are you currently doing, any research into new adhesive sealant or caulk applications to replace existing adhesive, sealant or caulk applications, or substitute for mechanical fasteners?

- Few manufacturers are doing this type of research, although a few are now, or have, experimented with different adhesive alternatives.
- One respondent said that they are experimenting with the use of two-part PU for exterior walls (without any mechanical fasteners). It was noted that others in the industry are already doing this.

Question 8: How significant are environmental regulations in the selection of your adhesives and sealants?

- Sixteen respondents indicated this is a "very important" issue. Disposal was often cited as a major concern.

Question 9: How significant are manufacturing health and safety concerns in the selection of your adhesives and sealants?

- Sixteen respondents indicated this is a "very important" issue in the selection process.

Question 10: How is the trend toward "improving" indoor air quality (IAQ) currently affecting your business? How will it affect your business in five years?

- There was a general recognition that manufactured homes have improved in this regard over the years and there is a continuing trend towards improving IAQ. The respondents recognized that this does impact the cost of the home; however the public is increasingly educated on this issue.

Question 11: Do you believe that the adhesive and sealant industry has done a good job in keeping pace with changes in building materials and manufacturing processes over the past ten years?

- Two respondents felt the adhesives industry has lacked innovation.
- Thirteen feel that the industry has done well in this area.

Question 12: What are the trends in construction materials and practices that will have the greatest impact on the manufactured housing industry over the next ten years?

A range of responses were received, some relating specifically to adhesives and sealants, and some considering a bigger picture.

- Moisture and mold concerns will have biggest impact due to media and legal exposure – in far less than five years.
- Reduced reliance on mechanical fasteners.
- Use of plastics and recycled products.
- The use of structural insulated panels will grow.
- Indoor air quality issues will be the next big issue. Products with low outgassing will be more important. Heating, ventilating, and air conditioning (HVAC) and associated systems "will finally be pulled out of the 1960s."
- Ceiling gypsum board already prepared with vapor barrier from supplier so textured ceilings can be sprayed without spraying a vapor barrier.

- Growth of PU adhesive for floor frame to deck adhesion. It is superior and reduces floor squeaks.
- The use of PU foam for air infiltration where plumbing lines pass through floors will increase.
- Efforts to streamline the industry will activate a sense of urgency on all others to keep up. This will drive a trend towards better, safer and faster production.
- Increased automation will lower tolerances and increase product quality.
- Recycling of building materials, including drywall and gypsum. Availability of lumber.
- HUD's involvement with modular housing.
- The use of metal studs.

Question 13: Please rank the following six criteria (1 being the most important and 6 being the least) in the selection of adhesive and sealant products for your organization:

Averaging the scores leads to the following consensus ranking:

1. product performance
2. quality
3. price
4. application characteristics
5. service (delivery)
6. technical support

B

PRIORITIZATION

In the course of the survey of manufactured home plants, nine adhesive and sealant application areas were identified as having the greatest opportunity for improvement (Section 3.1.5). These nine were expanded to a total of ten application areas (Section 3.3). The next step of this research effort was to rank and prioritize these opportunities. The purpose of prioritizing the opportunities was to identify those which have the greatest potential for benefit with the least effort.

Members of the industry Steering Committee were asked to complete a rating form. Each opportunity was rated on a scale of 1 to 5 with respect to the categories described below.

- **Cost.** Potential impact on the cost of manufacturing the home. Savings may stem from increasing application reliability, minimizing re-work, reducing in-plant failures, and reducing clean-up and disposal costs.

  1 = negligible impact on product cost. 5 = dramatic impact on product cost.

- **Quality.** Potential impact on product quality. Improvements may stem from increasing durability, improving overall performance, and minimizing service problems.

  1 = negligible impact on product quality. 5 = dramatic impact on product quality.

- **Home manufacturing plant environment.** Potential to improve the plant environment, including worker health and safety.

  1 = negligible impact on plant environment. 5 = dramatic impact on plant environment.

- **Potential for success.** Potential for success in developing new or modified adhesive or sealant product or system that meets the above goals, and having it widely adopted by the manufactured housing industry.

  - In the short term (1-2 years)
  - In the long term (3-5 years)

  1 = little potential for success. 5 = high likelihood of success.

- **Effort required.** Magnitude of the research and development effort required to develop the new or modified product or system and the effort required to bring it to market (i.e. testing, marketing, etc.). How attractive would this opportunity be to adhesive and sealant suppliers?

  1 = minimal R&D effort required. 5 = major R&D undertaking required.

- **Uniqueness to manufactured housing.** The uniqueness of this application to the manufactured housing industry. The degree to which improvements to the application will be dependent on the efforts of the manufactured housing industry itself.

  1 = application is no different from other industries. 5 = application is unique to the manufactured housing industry.

- **Overall assessment.** Your overall assessment of whether improvements in the longevity and performance of adhesives and sealants in this application should be pursued.

  1 = Do not pursue. 5 = Pursue aggressively.

  Table B-1 summarizes the prioritization responses. They represent and average of nine responses, including four from home manufacturers, three from adhesive suppliers, one from a DAPIA and one HUD GTR.

Table B-1. Prioritization of Adhesive and Sealant Applications

Application area	Cost	Quality	Plant Environment	Potential for success		Effort required	Uniqueness to manufactured housing	Overall Assessment
				Short term	Long term			
1. Wall panels to studs	3.4	4.7	2.7	3.7	4.3	2.7	3.1	4.1
2. Bottom board sealing	2.8	3.6	1.6	3.7	3.7	3.2	4.8	3.9
3. Wall back panels	3.1	4.0	2.5	3.8	4.5	2.7	2.9	3.9
4. Sealing air duct joint and seam leaks	2.8	3.6	1.6	2.8	3.7	2.8	2.1	3.0
5. Two-part PU foam on ceilings	3.2	2.7	3.4	2.7	3.3	3.6	4.7	3.0
6. Asphalt shingle roofs	2.4	3.1	2.5	2.7	3.0	3.3	1.9	2.9
7. Air infiltration	2.4	3.7	2.2	2.7	3.3	2.3	1.7	2.8
8. Tub surrounds	2.3	2.9	2.1	3.2	3.5	2.7	3.0	2.8
9. Cabinets and countertops	2.6	3.2	2.8	3.5	3.7	2.9	2.2	2.7
10. Wall and roof penetrations	2.1	2.8	1.9	3.2	3.3	2.8	2.1	2.4

C

TECHNOLOGIES ARTICLE

The Newsletter of the Manufactured Housing Research Alliance Volume 3 Issue 4

MANUFACTURED HOUSING TECHNOLOGIES

Adhesives with Staying Power

The production-focused environment of a manufactured housing plant naturally lends itself to the incorporation of new techniques and methods aimed at significantly reducing construction labor and increasing building performance and durability.

New technologies that employ advanced adhesives may provide a way to streamline production processes, address environmental concerns and improve the quality of manufactured homes.

However, the industry has been slow to adopt these new products and strategies due to a lack of adequate testing and research and the capital investment required for new equipment.

Inside

Visit **TECHNOLOGIES** *online at www.mhrahome.org*

The Sticking Point

MHRA organized an effort to evaluate the current adhesives and strategies used in the factory to determine if there was a need for improvement, and if so, what performance requirements were most requested by manufacturers.

The Advanced Adhesives and Sealants Committee surveyed manufacturers and adhesive suppliers to reveal these needs and identify existing adhesive products to address them. The committee is made up of home manufacturers, adhesives producers, suppliers, representatives from the Department of Housing and Urban Development and testing laboratories.

"It's a win-win situation," says Ornella Atwell, chairwoman of the committee and engineering manager for Fleetwood Enterprises. "We can outline the properties we desire from advanced adhesives to improve quality and efficiency, and producers can create a new market by recommending and developing products that meet those needs."

First, the committee evaluated how manufacturers currently use adhesives. A survey of manufactured home producers was conducted to identify the types of adhesives currently used and the satisfaction level with each method. Additionally, respondents were asked to identify their most serious manufacturing, performance and service issues related to adhesives and sealants.

Among the chief complaints by respondents were concerns that some adhesives were messy and difficult to clean up, had too-long cure times, had poor holding power and that the equipment used to apply them promoted waste and was too expensive. There were also concerns about environmental issues such as worker

Adhesives are commonly used to install and seal duct systems.

Adhesives *continued on page 3*

Adhesives continued from page 1

safety and disposal of unused or spent product.

The survey pinpointed several applications that provided the greatest opportunity and could be rapidly implemented. A few of the adhesive processes the respondents felt could use improvement included the fastening of wall panels to studs and the sheathing under exterior siding to studs, and the sealing of the bottom board and ducts.

Going to the Source

Next, MHRA talked with the adhesive and sealant manufacturers and distributors to find out if they could recommend advanced adhesives and sealants currently used in other industries that could be adapted for use in manufactured homes.

The suppliers of these products felt that the manufactured housing industry is often not responsive to innovation and noted that it was a challenge to think "outside the box." They were also concerned that manufacturers looked only at adhesive product price and often ignored the total costs, such as production efficiency and quality enhancements that could impact customer satisfaction.

Additionally, adhesive suppliers found it difficult to get concise research and development direction from home manufacturers and admitted that the cost of obtaining certification limited the appetite of adhesive producers to introduce new products.

MHRA plans to conduct a second, more in-depth round of discussions with these and other adhesive suppliers to incorporate the performance requirements requested by home producers and identify possible new applications for advanced adhesives, sealants and caulks.

Putting it Together

This fall, MHRA will release a technical document summarizing the research methods and findings of this study. The report will list the range of available adhesive products, identify the most important criteria for selecting new products, and assess their applicability to the manufactured housing production process.

If sufficient funding and interest arise from this report, further testing may be conducted in manufactured home plants to evaluate the most attractive adhesive products and strategies. Those that demonstrate particular promise during in-plant evaluations will be subjected to the additional testing required for approval from HUD and other agencies.

For more information about the adhesives research, contact Jordan Dentz at (212) 496-0900, ext. 13 or jdentz@research-alliance.org.

ON THE RIGHT PATH

Sealing Air Distribution Systems

With the results in hand from the ***Manufactured Housing Duct System: Guide to Best Practices***, MHRA set out to assist 16 plants in evaluating the air distribution systems installed in manufactured homes. This evaluation program, which was funded through PATH, showed that targeted changes at the plant resulted in dramatic improvements.

"The MHRA testing showed us where we could make improvements and we have now achieved duct leakage of less than 5 percent," said Jim Fitzgerald, manager of quality control for Castle Homes in Knox, Penn. "We've even purchased our own equipment to continue testing."

The in-plant testing in the 16 plants evaluated found that leakage in ducts was often caused by inadequate sealing of joints and connectors. Moreover, some duct leakage occurred through riveted metal seams.

One of the most interesting findings was that holes in the bottom board intensified overall leakage of air from the home, while an intact bottom board redirected air leaking from ducts back into the house.

Building scientist installing a calibrated duct fan to measure duct leakage.

Additionally, the durability of duct sealant tape, traditionally used in residential applications, was also a concern. In some usages, the tape didn't maintain the seal under the normal stresses of home building. In these cases, mastic sealant, instead of tape, was recommended to significantly reduce duct leakage.

MHRA's building scientists worked in partnership with manufacturers to cost-effectively mitigate a significant portion of duct leakage by using the methods and materials outlined in ***Manufactured Housing Duct System; Guide to Best Practices***. To order this publication, contact the MHI Bookstore at (703) 558-0400 or order online at www.manufacturedhousing.org.