The Use of Closed-Cell Spray Polyurethane Foam (ccSPF) to Enhance the Structural Properties of Wall and Roof Assemblies

By Mason Knowles

This article discusses field observations and research that document the ability of closed-cell spray polyurethane foam (ccSPF)[1] to add structural strength to roof and wall assemblies.

It has been known for many years that an SPF roofing system can enhance the wind uplift resistance of a roof covering. Field observations of SPF performance after Hurricanes Hugo and Andrew led to the Spray Polyurethane Foam Alliance (SPFA) sponsoring wind uplift testing of SPF roofing systems by Underwriters Laboratories (UL) and Factory Mutual Global (FM Global). According to UL, SPF's resistance exceeded the capacity of the equipment to measure wind uplift pressures. UL observed that SPF roofs applied over BUR and metal increased the wind resistance of those existing roof coverings. FM Global measured ccSPF's adhesion to concrete at over 990 psf of uplift pressure; and over metal deck assemblies, at over 220 psf of resistance. (Note: The mode of failure was fastener back-out, not the foam.) But little mention has been made of ccSPF's ability to prevent structural damage to roof and wall assemblies.

ROOF DECK STRUCTURAL ENHANCEMENT

First, let's look at some recently conducted laboratory research. In 2008, Honeywell Corporation, Huntsman Corporation, and NCFI Polyurethanes sponsored research on the wind uplift enhancement capability of ccSPF installed to the underside of wood deck assemblies. This was prompted by field research conducted by groups such as the Roofing Industry Committee on Weather Issues' (RICOWI) hurricane team investigators and veteran SPF industry professionals. The investiga-

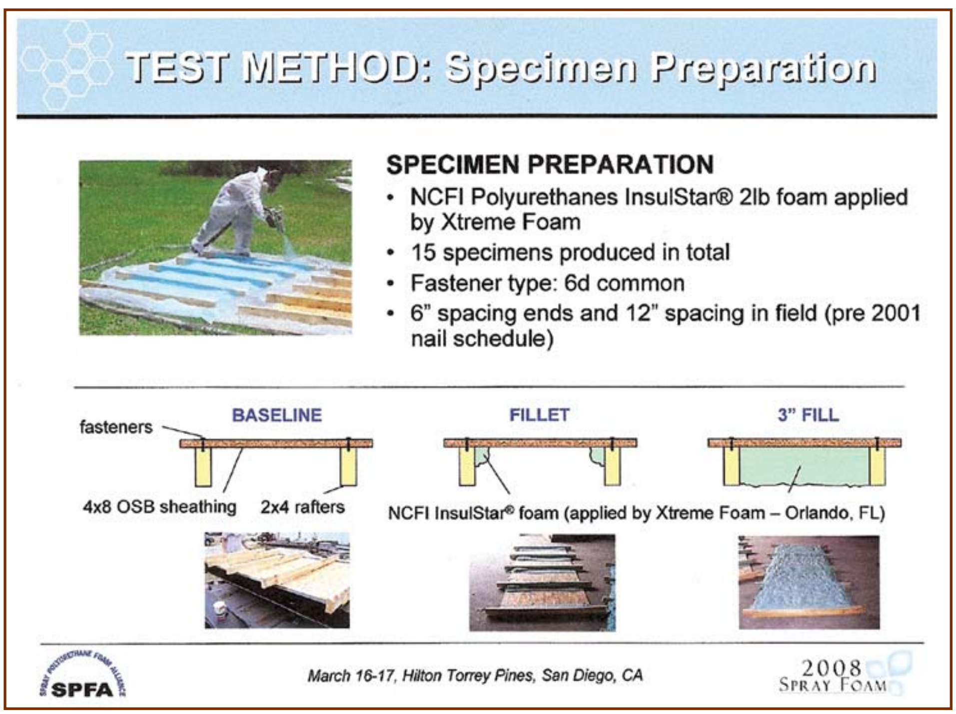

Figure 1 – Wind uplift resistance testing conducted at the Hurricane Research Center, University of Florida, in 2008 and presented by Richard Duncan, PhD, PE, at Sprayfoam 2008.

Maximum Wind Uplift Load PSF (pounds per square foot)									
SPF	**Avg.**	**Max.**	**Min.**	**1**	**2**	**3**	**4**	**5**	**Std. Dev.**
None	75	105	47	75	105	71	76	47	**21**
Fillet	175	195	146	195	178	178	146	178	**17**
3-in Fill	250	283	200	283	246	200	254	269	**31**

Table 1

tors observed examples of ccSPF installed to the interior structure of a building that appeared to minimize or eliminate structural damage caused by high wind events, while other sections of the building without ccSPF were destroyed by pressurization.

The sponsors contracted with the Hurricane Research Center located at the University of Florida to conduct ASTM E330-02 (Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights, and Curtain Walls by Uniform Static Air Pressure Difference) testing of wood roof deck assemblies (*Figure 1*). According to ASTM, "This test method is a standard procedure for determining structural performance under uniform static air pressure difference." This typically is intended to represent wind loads on exterior building elements and is accepted by the state of Florida and Miami Dade County for testing structural elements (including roof deck assemblies) for high wind resistance.

Two types of SPF applications were tested on OSB panels with wood studs installed in accordance with Florida Building Code requirements for high-wind-velocity regions.

The results were eye opening. Even with a roof deck assembly that was constructed to comply with Florida's high wind requirements, the ccSPF increased wind uplift resistance on the 3-in fill from 3 to 3.2 times its original resistance. The fillet-style application increased wind uplift resistance from 1.9 to 2.2 times its original resistance. (See *Table 1*.)

CASE STUDY I

White's Lumber, Port Isabel, TX
Hurricane Dolly Investigation;
Mason Knowles Consulting, LLC

Before Hurricane Allen blew into South Padre Island, TX, in 1980, the author installed a portion of an SPF application to the office section of a lumberyard's post-frame-construction building. The crew completed one corrugated wall and roof section before the storm hit. After the storm, the only metal remaining were the sections insulated with ccSPF.

Figure 2 shows White's Lumber's open-end, post-frame-construction building. New metal was installed to half of the building (right side of the photo) in 2008, and the old metal originally installed in 1980 is on the left. For close to 30 years, there were no significant wind events in the area.

In 2009, Hurricane Dolly—a category 2 storm, packing winds of more than 110 mph—made a direct hit on the towns of Port Isabel and South Padre Island, TX. White

Figure 2 – The author installed the old metal roof on this building in 1980. A new metal roof was installed in 2008 on the right side of the building.

Figures 3 (left) and 4 (below) – Half of the roof blew off of White's Lumber during Hurricane Dolly.

Lumber and Supply lost half of its roof, as shown in *Figures 3* and *4*. But something looks strange, doesn't it? The left side of the building has a new metal skin installed in 2008, while the right side has metal panels that are over 29 years old. As can be seen, the new metal blew off in the storm, while the old metal remained in place. Both are 29-gauge metal[2] with similar fasteners and fastening patterns (in fact, the new metal portion had a closer fastening pattern than the old section, and both are fastened to the same wood framing).

There is a simple explanation. When the metal was replaced in 1980, the owner contracted with the author to install a 2-lb, closed-cell spray foam in a "picture frame" pattern to help secure the metal panels to the wood trusses. Twenty-nine years later, this safety net proved invaluable (*Photo 5*). Unfortunately, when the owner replaced the metal on half of the building in 2008, he could not find an SPF applicator to replace the foam (*Photo 6*). Consequently, high winds blew off major portions of the new metal panels.

Figure 5 – Old metal secured with ccSPF.

Figure 6 – The ccSPF was removed to install new metal.

Figures 7 (right) and 8 (below) – Fasteners pulled through the new metal skin where there was no ccSPF to help secure the panels to the wood trusses.

As shown in *Figures 7* and *8*, the main cause of failure of the new metal skin was pulling of the fasteners through the metal.

INCREASING RACKING STRENGTH OF ASSEMBLIES

Research demonstrates that ccSPF can help increase the racking strength of wall assemblies. Three research studies have been conducted by the Spray Polyurethane Foam Alliance (SPFA) and its predecessor, the Polyurethane Contractor's Division (PFCD) of the Society of the Plastics Industry, on the racking strength of ccSPF. In 1992 and again in 1996, PFCD contracted with the

1992 NAHB Research Center Racking Study

	NonSPF Panels		SPF Panels	
Stud Spacing	**Vinyl Sheathed**	**Plywood Sheathed**	**Vinyl w/ccSPF**	**Plywood w/ccSPF**
16 in	913	2,890	2,800	5,300
24 in	Not tested	2,420	Not tested	6,387
32 in	Not tested	Not tested	2,588	
48 in	Not tested	Not tested	2,298	

Table 2 – 1992 NAHB Research Center racking study (average maximum racking load in pounds).

NAHB Research Center to conduct racking load tests on ccSPF-insulated wall panels. The NAHB Research Center concluded, "During a design racking event such as a hurricane, there would be less permanent deformation of wall elements and possibly less damage to a structure that was braced with SPF-filled walls."

1996 NAHB Research Center Racking Study

Assembly	Maximum Racking Load
OSB w/R19 fiberglass	4,800
OSB w/ccSPF	6,000
Drywall w/R19 fiberglass	2,400
Drywall w/ ccSPF	5,380

Table 3 – 1996 NAHB Research Center racking study (average maximum racking load in pounds).

ATI Racking Study

Assembly	Maximum Racking Load
1½-in, 2-lb density SPF w/polyiso sheathing	2,259
3½-in, 2-lb density SPF w/polyiso sheathing	2,152
Polyiso sheathing	1,109
OSB sheathing	2,908

Table 4 – ATI racking study (average maximum racking load in pounds).

The 1992 research tested ccSPF installed at 3 inches to wall panels constructed of plywood and vinyl cladding, respectively. The panels used 2- x 4-in wood studs with spacing at 16, 24, 32, and 48 inches off center (OC). As indicated in *Table 2*, ccSPF increased the maximum average racking load of a vinyl-clad wall assembly from 913 lbs to over 2,800 lbs at 16-in spacing and more than 2,300 lbs, even at the 48-in stud spacing. It doubled the maximum average racking load of a plywood-clad wall assembly at 16-in spacing and was 2.2 times the racking load at 24-in spacing

The 1996 study measured the racking strength of OSB- and drywall-clad walls, respectively, with metal studs at 16 in OC. As indicated in *Table 3*, the ccSPF-insulated walls at 3 in thick increased the drywall-clad wall from 2,400 lbs of racking load to 5,380 lbs, and the OSB-clad walls from 4,800 lbs of racking load to 6,000 lbs.

In 2007, SPFA tested ccSPF-insulated walls constructed with 2-in x 4-in wood studs, 16 in OC to both polyiso- and OSB-sheathed wall assemblies at Architectural Testing, Inc. (ATI). As indicated in *Table 4*, the ccSPF doubled the racking load of the polyiso-sheathed wall assemblies.

CASE STUDY 2

Pascagoula Shrimp and Ice Company Hurricane Katrina Investigation; RICOWI

As shown in *Photo 9*, internal pressurization destroyed the tongue-and-groove roof deck of this ice plant during Hurricane Katrina. However, the metal building section (depicted in *Photo 10*) that was insulated with ccSPF and connected to the same structure, survived with no damage.

Figure 9 – Internal pressurization during Hurricane Katrina destroyed a tongue-and-groove wood deck at this ice plant.

Figure 10 – The metal building below was connected to the structure shown in Figure 9 and was insulated with ccSPF. It received no damage during Hurricane Katrina.

None of the areas insulated with ccSPF sustained any damage. An interesting observation is that many of the ccSPF-insulated portions of the building were areas that would be considered less structurally sound than other areas (if they were not structurally reinforced with ccSPF). *Figure 11* shows the foam sprayed against metal roof decking and corrugated metal wall panels.

EXTERIOR ccSPF APPLICATIONS TO MINIMIZE WIND AND WATER DAMAGE

Another use of ccSPF is on the exterior of buildings to prevent their damage from high winds and flying debris. There are many cases of ccSPF installed to the exterior of metal buildings, houses, and small commercial buildings where such application has minimized structural damage and water intrusion. The foam acts as a shock absorber for wind-driven debris;[3] a barrier to wind-driven rain; an air barrier to reduce the potential for high wind pressurization of the building; and a glue that holds it together and distributes the load so that if pressurization occurs, the weakest individual components and fastenings are not exposed to the full brunt of the pressure.

Figure 11 – Foam sprayed against metal roof decking and corrugated metal wall panels.

Figure 12 – Port Isabel RV Park, 1979 (before Hurricane Allen).

Figure 14 – Same building after Hurricane Dolly in 2009.

CASE STUDY 3

Port Isabel RV Park Hurricane Dolly Investigation; Mason Knowles Consulting, LLC

Figure 13 – Same building, 2006.

A recent example of this design is the recreation building at the Port Isabel RV Park. Around 1978, a tropical storm caused damage to the exterior wood cladding, allowing water intrusion into the building. After unsuccessful attempts to correct the problem, the author was contracted to install 1.5 in of ccSPF to the outside of the entire structure. The application of ccSPF stopped the leaks into the building.

In 1980, the building was directly in the path of Hurricane Allen, a category 5 storm when it hit Port Isabel. Wind speeds were recorded in Port Mansfield (50 miles north of Port Isabel) at 130 knots.[4] The Port Isabel Press reported two weeks after the storm that the Coast Guard station at Isla Blanca Park on South Padre Island (one mile from the buildings in Port Isabel) recorded wind speeds in excess of 125 mph. The wood structure survived with no damage and no leaks. Many other buildings in the immediate vicinity were seriously damaged from high winds and water intrusion.

In 2009, the building was in the direct path of Hurricane Dolly, with up to 110 mph winds. Again, the building survived with no damage except for a small crack (see *Photo 15*) and no water intrusion.

Figure 15 – Only damage after two hurricanes and 30 years of service.

CASE STUDY 4

Military Tent and Plywood Buildings Reinforcement; Department of Defense Presentation at Sprayfoam 2010

The Department of Defense (DOD) has an ongoing program to insulate tents and other nonair-conditioned structures in selected bases in Iraq and Afghanistan with 2-lb density ccSPF (*Photos 16* and *17*). The main goal is to protect against high temperatures in the areas. According to John Siller of the Power Surety Task Force of the DOD, "The foam is providing outstanding performance in this goal." [Editor's Note: See "How Insulation Saves Lives and $$ in Iraq and Afghanistan" on page 42 for more about this project and the activities of an RCI member

Photo 16 – Example before application of ccSPF.

Photo 17 – Example after ccSPF.

Figure 18 – This metal building was approximately 50 yards from the mortar shell's impact.

working in the Middle East.]

But a recent incident may be prompting the military to look seriously at using ccSPF to protect structures against damage from mortars or improvised explosive devices (IEDs). On October 17, 2008, Mearl "Skip" Kline was working with a crew from West Roofing that was insulating tents with ccSPF at a military base just outside the city of Baqubah, Iraq. According to Kline, "The base was attacked by what Army personnel assumed to be 107mm rockets. We hit the ground when we heard the shells coming into the camp. The shells impacted approximately 40 yards from us and 80 to 100 yards away from the ccSPF tents. We were told this type of ordnance has a kill radius of approximately 30 yards. The tents [that were insulated with ccSPF] absorbed shrapnel from the shells without [the shrapnel] penetrating the structures. After the attack, Army personnel were impressed by the foam's ability to absorb the shock of the shrapnel hits. Many expressed a desire to use the foam to increase the impact resistance from enemy shells." (See *Photos 18* and *19*.)

Figure 19 – Shell fragments still capable of severely wounding personnel were embedded in the foam of the structures, 80 to 100 yards away from impact.

THE FUTURE OF ccSPF AS A STRUCTURAL MATERIAL

It is clear from the research and case studies cited that ccSPF can be an important tool for designers to enhance the high-wind resistance of buildings. However, some important steps are required to use the materials as a structural enhancement.

ADDITIONAL RESEARCH AND TESTING

- Engineering studies to quantify the specific strength added when ccSPF is installed to walls and ceilings
- Whole-building tests of ccSPF applications for structural strength
- Effects of aging on the foam's adhesive and physical properties
- Fire testing
- Testing of a wider variety of roof and wall assemblies
- Testing of assemblies for seismic structural enhancement and impact absorption

SPECIFICATIONS AND GUIDELINES

- Industry peer-reviewed guidelines
- Flashing details
- Substrate preparation
- Thickness and density required for each application to achieve desired result
- Building code approvals

QUALITY ASSURANCE

- Inspection procedures (sampling, visual inspection, etc.)
- Training and certification of applicators and inspectors
- Warranties and exclusions

CONCLUSIONS AND COMMENTS

Based on research and field observations, it appears that the installation of ccSPF to either the exterior or interior of a building can result in significant structural benefits and reduced building damage from impact and high winds. Additional information needs to be developed by the SPF industry, building research, and design community to provide the tools necessary to offer this product as a primary structural enhancement material.

FOOTNOTES

1. While not a new product, the term "ccSPF" is the most current designation that refers to a typical closed-cell spray polyurethane foam ranging in density from 1.5 to 3.5 lbs per cu ft used for insulation and roof coverings. The newer designation differentiates the product from a low-density, nonstructural, open-cell spray polyurethane foam that has become popular in interior applications as an insulation and air barrier material.
2. Since 29 gauge is a low-strength metal sheathing material, it is much more likely that fasteners will pull out of such metal, causing damage in a high-wind event. A thicker sheathing might have survived the storm without damage.
3. Wind-driven debris will typically cause dents, cracks, and gouges to exterior applications of ccSPF. A sealant compatible with the coating can repair small (less than 4 in) mechanical damage. Larger areas of damage can be repaired by removing the damaged foam and replacing it with new foam using high-density foam kits or standard SPF proportioning equipment. Recoating may be required if the damage covers large areas of the structure.
4. Joseph E. Minor, PE, William L. Beason, and Timothy P. Marshall, "Effects of Hurricane Allen on Buildings and Construction," *Proceedings of the Fourth National Conference on Wind Engineering Research*, Seattle, WA, 1981.

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