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

ABSTRACT

Closed Cell Spray Polyurethane Foam has been recognized for years for its ability to remain in place during high wind events. However, its use as a structural enhancement material for roof and wall assemblies has not been fully developed. This paper reviews and discusses field and laboratory research plus case studies relating to the structural use of ccSPF in roof and wall assemblies including; Roofing Industries Committee on Weather Issues (RICOWI) hurricane research (Katrina, Charley, Ivan and Ike), FM and UL tests wind uplift tests, NAHB Research Center racking tests, structural deck assembly testing a the Hurricane Research Center at the University of Florida, observations of ccSPF used in military bases in Iraq and the author's observations after Hurricanes Allen and Dolly.

KEYWORDS: ccSPF, spray polyurethane foam, wind uplift resistance, structural enhancement,

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

It has been known for many years that a SPF (spray polyurethane foam) roofing system can enhance the wind uplift resistance of a roof covering. Field observations of ccSPF performance after Hurricanes Hugo and Andrew led to the Spray Polyurethane Foam Alliance (SPFA) sponsored wind uplift testing of SPF roofing systems by Underwriters Laboratories (UL) and Factory Mutual Global (FM). According to UL, ccSPF's wind uplift 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 uplift resistance of those existing roof coverings. FM Global measured ccSPF's pull resistance on concrete at over 990 lbs of uplift pressure and over metal deck assemblies at over 220 lbs of wind uplift resistance (note: the mode of failure was metal fastener back-out not the foam).

But little mention has been made of its ability to prevent structural damage to roof and wall assemblies of buildings.

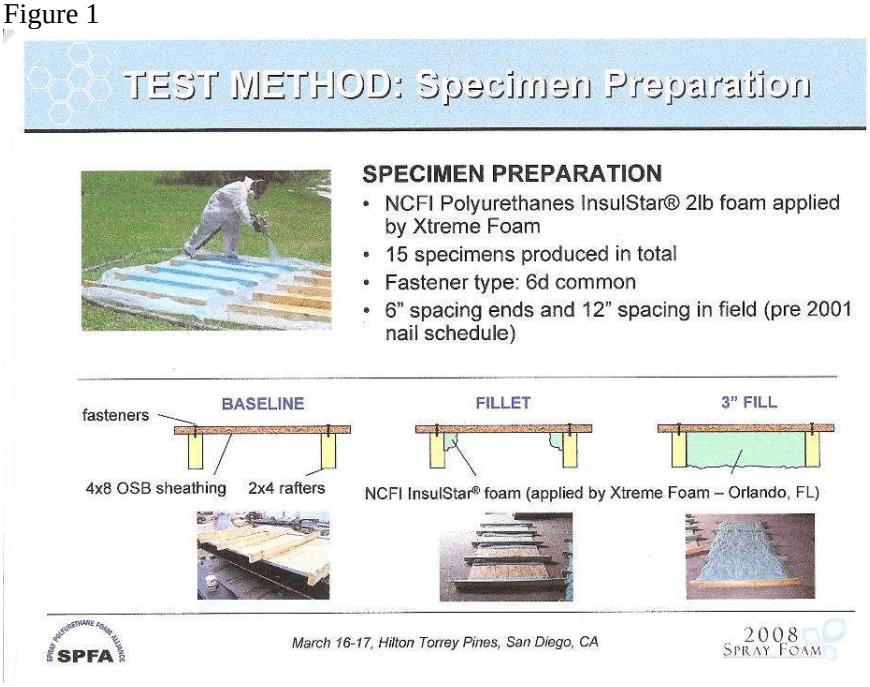
SECTION 1 ROOF DECK WIND UPLIFT ENHANCEMENT:

In 2008 Honeywell Corporation, Huntsman Corporation and NCFI 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 RICOWI hurricane team investigators and veteran SPF industry professionals. The investigators 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 E 330-02 (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. 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 the effects of a wind load on exterior building surface 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 as shown in fig. 1.

Figure 1



The results were eye opening. As shown in table 1, 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" inch fill from 3 to 3.2 times the original uplift resistance. The fillet style application increased wind uplift resistance from 1.9 to 2.2 times the original uplift resistance.

Table 1
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" Fill	250		283	283	246	200	254	269	31

CASE Study 1: White's Lumber, Port Isabel Texas (Knowles, 2009)

Before Hurricane Allen blew into South Padre Island, Texas, in 1980, the author installed a portion of a SPF application to the office section of a lumber yard'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 was the sections insulated with ccSPF.

Fig 2 shows White's Lumber open end, post frame construction building. New metal was installed to half of the building to the right side of the photo in 2008 and the old metal originally installed in 1980 is on the left

Figure 2

The metal was replaced and 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, Texas. White's Lumber lost half of their roof as shown in figs. 3 & 4. But, something looks strange doesn't it? The left side of the building has a new metal skin installed in 2008 while the left side has old metal panels that are over 29 years old. As you can see, the new metal blew off in the storm while the old metal remained in place. Both are 29 gauge metal 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.

Figures 3 &4

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 sprayfoam in a “picture frame” pattern to help secure the metal panels to the wood trusses (Fig. 4). 29 years later, this safety net proved valuable. Unfortunately, when the owner replaced the metal on ½ of the building in 2008, he could not find a SPF applicator to replace the foam under the new metal (Fig. 5) and consequently, high winds blew off major portions of the new metal panels.

Figure 4

Figure 5

As shown in Figs. 6 & 7, the main cause of failure of the new metal skin were the fasteners being pulled through the metal.

Fugure 6

Figure 7

SECTION 2: INCREASING RACKING STRENGTH OF ASSEMBLIES

Research demonstrates that ccSPF can help increase the racking strength of wall assemblies. 3 research studies have been conducted by the Spray Polyurethane Foam Alliance (SPFA) and its predecessor (Polyurethane Contractors Division of the Society of Plastics Industry (PFCD) on the racking strength of ccSPF. In 1992 and again in 1996, PFCD contracted with the NAHB Research Center to conduct racking load tests on ccSPF insulated wall panels. 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."

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” wood studs with spacing at 16 inch OC, 24 inch OC, 32 inch OC and 48 inch OC. As indicated in table 2, ccSPF increased the maximum racking load of a vinyl clad wall assembly from 913 lbs to over 2800 lbs at 16 inch spacing and more than 2300 lbs even at the 48 inch stud spacing. It doubled the maximum racking load of a plywood clad wall assembly at 16 inch spacing and 2.2 times the racking load at 24 inch spacing

The 1996 study measured the racking strength of OSB and drywall clad walls respectively with metal studs at 16 inch OC. As indicated in table 3, the ccSPF insulated walls at 3 inches thick increased the drywall clad wall from 2400 lbs of racking load to 5380 lbs and the OSB clad walls from 4800 lbs of racking load to 6000 lbs.

In 2007 SPFA tested ccSPF insulated walls constructed with 2” x 4” wood studs, 16” 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.

Table 2

1992 NAHB Research Center Racking Study
Average Maximum Racking Load (pounds)

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

Table 3

1996 NAHB Research Center Racking Study
Average Maximum Racking Load (pounds)

Assembly	***Maximum Racking Load***
OSB w/ R 19 fiberglass	4,800
OSB w/ ccSPF	6,000
Drywall w/ R 19 fiberglass	2,400
Drywall w/ ccSPF	5,380

Table 4

ATI Racking Study
Average Maximum Racking Load (pounds)

Assembly	*Maximum Racking Load*
1-1/2" 2lb density SPF w/Polyiso Sheathing	2,259
3-1/2" 2lb density SPF w/Polyiso Sheathing	2,152
Polyiso Sheathing	1,109
OSB Sheathing	2,908

CASE Study 2: Pascagoula Shrimp and Ice Company (Hurricane Katrina Investigation, RICOWI)

As shown in Fig. 8, internal pressurization destroyed the tongue-and-groove roof deck of this ice plant during Hurricane Katrina. However, the metal building section (depicted in Fig. 9) that was insulated with ccSPF and connected to the same structure survived with no damage.

Figure 8

Figure 9

None of the areas insulated with ccSPF sustained any damage. An interesting observation is that much of the ccSPF insulated portions of the building were areas that would be considered less structural sound than other areas (if they were not structurally reinforced with ccSPF).

Section 3: Exterior ccSPF Applications to Minimize Wind and Water Damage:

ccSPF is also used on the exterior of building to prevent high wind and flying debris damage to buildings. There are many cases of ccSPF installed to the exterior of metal buildings, houses, and small commercial buildings that minimized structural damage and water intrusion. The foam acts as a shock absorber for high impact wind driven debris, a barrier to wind driven rain, acts an air barrier to reduce the potential for high wind pressurization of the building, glues it together so that if pressurization occurs, that the weakest individual components and fastening are not exposed to the full brunt of the pressure.

Case Study 3: Port Isabel RV Park: (Hurricane Dolly investigation, Mason Knowles Consulting LLC)

A recent example of this design is the recreation building at the Port Isabel RV Park. After the building was constructed in the late 1970,s a tropical storm caused damage to the exterior wood cladding that allowed water intrusion in to the building. After unsuccessful attempts to correct the problem, the author was contracted to install 1.5 inches of ccSPF to the outside of the entire structure. The application of ccSPF stopped the water leaks into the building. The following year, the building was directly in the path of Hurricane Allen a category 5 storm packing 125 mph winds when it hit Port Isabel. 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 directly in the path of Hurricane Dolly, with up to 110 mph winds. Again, the building survived with no damage (except for a small crack, see photo) and no water intrusion.

Photo 1 Port Isabel RV Park 1979 (before Hurricane Allen)

Photo 2: Same building 2006

Photo 3: Same building after Hurricane Dolly in 2009

Only damage after 2 hurricanes and 30 years of service

Case Study 4: Military Tent ccSPF Insulation Resists Rocket Damage

The Department of Defense (DOD) has an ongoing program to insulate tents and other non air conditioned structures in selected bases in Iraq and Afghanistan with 2 lb density ccSPF. The main goal is to protect against high temperatures in the areas. According to John Siller, OSD of Power Surety Task Force, of the DOD the foam is providing outstanding performance in this goal.

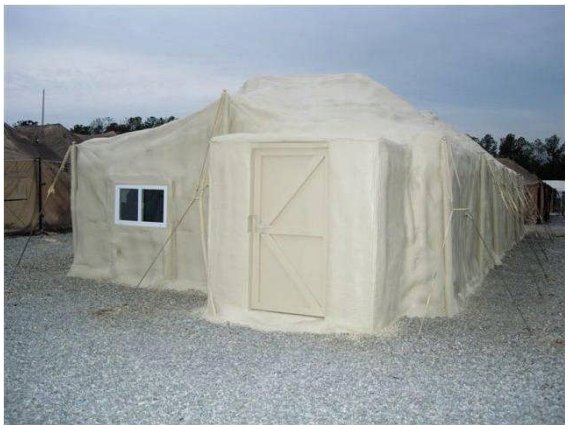
But an incident Oct 17, 2008 may be getting the military to look seriously at using ccSPF to protect structures against damage from mortars or IEDs. Mearl "Skip" Kline, was working with a crew from West Roofing insulating tents with ccSPF at a military base just outside the city of Baqubah, Iraq. According to Kline, "The based was attacked by what was assumed by Army personnel to be 107 mm rockets.* We hit the ground when we heard the shells coming into the camp. The shells impacted approximately 50 yards from us and 80 to 100 yards away from the ccSPF insulated tents. We were told this type of ordinance has a kill radius of approximately 30 meters."

The tents (that were insulated with ccSPF) absorbed shrapnel from the shells without penetrating the structure. 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."

** Note: according to Jane's Ammunition Handbook, Iranian made 107 mm rockets have been used frequently since 2007 against U. S troops in Iraq and that "On detonation, the warhead produces approximately 1,214 fragments spread over a lethal radius of 12.5 m."*

These photos represent examples of the type of structures being insulated with ccSPF in bases in Iraq and Afghanistan



107 mm rockets are commonly used by Iraqi Insurgents

A metal building and the tail gate of this pick up truck were approximately 50 yards from the mortal shells impact. Skip Kline reports that his son was standing next to the truck at the time of the mortar attack.

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

Section 4 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 in order 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 ceiling
    - Whole building tests of ccSPF applications for structural strength
    - Effects of aging on the foams adhesion 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 & 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.

Acknowledgements:

Photos:
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