FIELD AND LABORATORY ASSESSMENT OF SPF ROOF SYSTEMS

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This paper summarizes a field and laboratory assessment conducted by the National Roofing Foundation (NRF) on aged spray polyurethane roofs (SPF). Included are physical properties test data of the foam cores, including density, compressive strength and moisture content, taken from SPF roofs ranging from 6 months to 27 years. Aged coating thicknesses are also included for acrylic, silicone and urethane SPF roofs.

KEYWORDS

Coating thickness, compressive strength, core density, insulation, low-slope roofing, moisture content, roofing, spray polyurethane.

INTRODUCTION

The use of spray polyurethane foam (SPF) roof systems is now into its fourth decade, since their inception in the 1960s. From the beginning, all SPF roof systems used a protective cover or coating to shield the polyurethane foam from ultraviolet degradation. In many instances, SPF was chosen for use over decks that could not accommodate a built-up roof.[1] The energy crises of the mid-1970s brought about a huge material demand for thermal insulation to go onto our existing building inventory. At this juncture, the SPF roof system was proposed for use by some as the answer to roofing and thermal insulation needs. Some contractors began to install SPF roof systems without understanding the technology and chemistry behind SPF. When poor application of the SPF was coupled with a lack of knowledge regarding the basic principles of roofing, a non-performing roof resulted. Because of this experience, SPF roofs lost favor to other roof systems. SPF roofs were specified less with the advent of single-ply roofing occurring shortly thereafter.

During the late 1970s and early 1980s, the technology of SPF roofing came into focus. By the mid-1980s, a solid core of technical principles regarding the design, installation and material characteristics of SPF roofs had been promulgated by a number of entities, including manufacturers, trade groups and users. Roof performance is always a concern for the U.S. Government due to the large number of buildings it owns. The Navy has completed a number of research programs on SPF roof systems, including application and maintenance.[2] The Polyurethane Foam Contractors Division (PFCD), now known as the Spray Polyurethane Foam Division (SPFD) of the Society of the Plastics Industry (SPI), has a contractor accreditation program along with numerous publications. In the *1991 International Symposium on Roofing Technology*, Kashiwagi, et. al.[3] published a paper outlining the results of visual surveys on SPF roofs installed in six geographical areas of the United States. According to the National Roofing Contractors Association (NRCA) 1996 roofing industry market survey, SPF roofs account for 3.2 percent of roofing materials used.

OBJECTIVE OF FIELD STUDY

The National Roofing Foundation (NRF) planned a field study of SPF roofs in 1995. The NRF is a nonprofit corporation, separate from the NRCA, that exists to provide funds for educational and research projects substantially benefiting the roofing industry.

The project's goal was to independently assess field performance and work towards the development of performance criteria for SPF roof systems. This includes design, installation and/or material specifications that contribute to performance. The objectives of the study were to:

- Inspect and core sample a minimum of 140 SPF roofs.
- Survey roofs in four different climates of the United States.
- Include acrylic, silicone and urethane coated SPF roofs.
- Include aggregate surfaced SPF roofs.
- Compile independent data with the results to be published.
- Establish and/or verify existing performance attributes for SPF roof systems.

Thermal insulation properties of the SPF material was not part of this study.

The field study was to include SPF roofs of all ages, with older roofs being given priority so the in-service performance could be evaluated. To accomplish this work, the National Roofing Foundation contracted with Structural Research, Inc. to conduct the field and laboratory work, with the final report due in late 1997. Both the NRCA and the SPI/SPFD cooperated with the study.

FIELD STUDY LOCATIONS

A realistic field assessment program must include different climates, various building types, ages of roofs and levels of maintenance. To accomplish this, SPF roofs were sought out in the following climates:

- Hot, humid summers with moderate winters—Texas
- Hot, dry summers with wet cool winters—California
- Moderate to hot summers, with very cold winter temperatures and heavy snow and ice—Illinois and Wisconsin

- Moderate to hot summers, cold and damp winters—New York and New Jersey

Other areas of the United States were viewed as comparable to the climatic regions studied; for instance, Florida has weather similar to south Texas. The Phoenix, Arizona, climate is very dry with summer temperatures well in excess of 38°C (100°F), with low humidity, similar to Palm Springs, California, where a number of SPF roofs were surveyed. Cold winter sites were provided by roofs in upstate New York and northern Wisconsin; these sites are comparable to other cold weather regions in the United States, except Alaska.

FIELD PROCEDURE

At any given geographic location, a number of SPF roofing contractors were contacted and asked to provide a list of SPF roofs to survey. The author would then randomly select the SPF roofs to inspect. Highest priority was given to locating older SPF roofs, regardless of size, condition or building function. An effort was made to balance each geographic location with equal numbers of acrylic, silicone and urethane coated roofs and aggregate surfaced roofs.

Each SPF roof was given an identification number, with all pertinent data recorded, including age, type of substrate, type of coating/surfacing, type of blowing agent used (CFC or HCFC), condition of foam, condition of coating, presence of ponded water, blisters, pinholes or other anomalies. Damage due to hail or mechanical action was also noted.

An electrical capacitance moisture meter was used to detect near-surface moisture as well as indicate moisture at blisters, areas of exposed foam, hail strikes or points of mechanical damage. If foam or coating blisters or other anomalies were encountered, they were examined; typical conditions were photographed. Overall roof performance was noted, including the presence of leaks if the information was available. However, in many instances, this information was not available. Perimeter flashings were examined as well as the condition of the flashings at roof penetrations.

A 75-mm- (3-in.-) diameter core was removed from each roof; two additional slit cuts were typically made away from the core area, providing additional points for measuring coating thickness. Samples were bagged and sealed for laboratory analysis. All cores and slit locations were then repaired.

The field survey included SPF roofs ranging in age from new to 27 years in service. The field work for the NRF study began in December 1995 and ended in March 1997. Of the 140 roofs inspected, 11 have 20 years of service or more, using 1996 as the base year. The median age was 10.5 years and the average age was 11 years based on the known year of application. The original date of installation was unknown on 15 of the SPF roofs surveyed. Figure 1 shows the age distribution of the SPF roofs surveyed, without regard to coating/surfacing type or location. A number of these roofs have been recoated. In some instances the top 13 mm. (½in) of foam was removed by mechanical scarification. A new 25-mm (1-in.) layer of foam was then installed, followed by a coating. The vast majority of the recoated roofs received a granule surfacing.

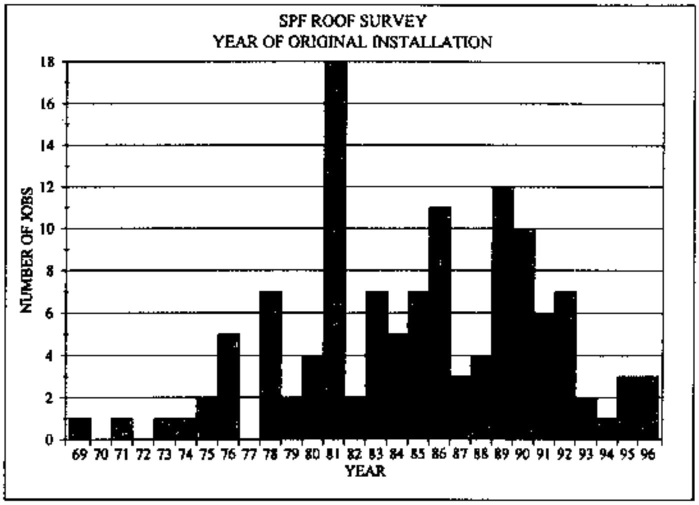


Figure 1. Year of installation for 125 SPF roofs surveyed; 15 roofs are not shown since date of installation is unknown. Age distribution shown is due to selection process used in study.

PHYSICAL CONDITION OF ROOFS

Mechanical Damage

Each roof was audited for signs of mechanical damage including hail. The coating and foam itself can be damaged by abuse, flying debris, bird pecking and large hail. The coating type and the presence of granules or aggregate can improve the resistance to mechanical damage. One unique aspect of SPF roofs with respect to mechanical damage is that they are not in immediate danger of leaking, provided the penetration does not extend all the way through the foam.[4] This is illustrated in Photograph 1. Many of the roofs surveyed in Texas had experienced hail damage and were repaired since damage was localized to the upper surface of the foam.

Flashing Conditions

Flashing conditions were checked at perimeters, curbs and roof penetrations. Very few edge flashing problems were seen with those SPF roofs which were installed over pre-existing metal gravel stops. Splitting of the overlay foam and coating was rarely seen at pre-existing metal flashing joints. A common technique to complete the roof edge detail where SPF meets a metal profile is to grind out a V-notch at the edge of the foam where it meets the metal profile. A bead of elastomeric sealant is then applied to the V-notch as a leveling surface between the edge of the cut foam and the top of the metal edge profile. This detail was observed in numerous SPF roofs and is performing well. It was also noted that metal counterflashings did not exist on many of the SPF roofs audited. Some SPF roofs had a combination of foam and coating being terminated at a pre-existing reglet while other parts of the roof had a metal counterflashing in the reglet protecting the termination line of foam and coating. Both design approaches appear to be performing; however, detailed examination of these two flashing methods was beyond the scope of this work.

Surface Texture

The surface texture of the spray foam was also inspected. Typically, the surface of each SPF roof had a variety of texture conditions ranging from smooth to orange peel. The percentage of each texture present would vary from roof to roof. However, the SPF roofs applied with HCFC 141b, the hydrochloroflourocarbon blowing agent introduced in 1992, were seen to have a smoother surface than their predecessors. This is despite the fact that the HCFC blowing agents have a higher boiling point and are more temperature susceptible during application. As a group, the SPF roofs from 1975 through 1984 had more coarse orange peel texture present. The SPF roofs installed from 1985 through 1992 had a smoother surface texture than their predecessors. The SPF roofs installed since 1992 had the smoothest surfaces overall of the SPF roofs audited in this study.

Blisters

Blisters can occur in SPF roof systems, in a manner similar to other roof coverings. There are two types of blisters that were seen to occur—foam blisters and coating blisters. Foam blisters typically occur between lifts (applications) of foam. If a foam blister occurs in the top lift of foam and the blister ruptures, water would more than likely be found in the ruptured blister. However, the SPF roof is typically not vulnerable to leakage for a length of time due to the fact that the closed cell foam is slow to absorb water. Open cell foam, on the other hand, will allow water transmission to proceed rapidly.

The most predominant form of foam blister seen was 75 mm to 150 mm (3 in. to 6 in.) in diameter and would occur in the lower lifts of foam. These localized defects were attributed to installation technique.

A number of coating blisters were observed on urethane roofs installed in the mid-1980s. These roofs more than likely had a base coat with reversion problems.

Exposed Foam

A number of SPF roofs were noted to have localized areas of exposed foam. This was primarily due to lack of sufficient coating which relates to installation error. Since the coating is the primary UV protector and the initial line of defense against water intrusion, foot traffic and mechanical damage to localized areas of the exposed foam was seen to cause repairs to be made. Most of the exposed foam was seen to be cosmetic or easily repairable; it did not require major repair.

AGED PHYSICAL PROPERTIES

Laboratory work was done on core and slit samples to determine coating condition, color and thickness. Foam core properties such as moisture content, apparent core density and compressive strength were determined. Compressive strengths were determined using ASTM D 1621. The average compressive strength for all samples was 404 kPa (58.6 pounds per square inch [psi]). The highest compressive strength was 685 kPa (99.3 psi) and the lowest compressive strength recorded was 199 kPa (28.8 psi). The core sample containing the highest compressive strength was located on a large administration building in upstate New York that was installed in 1975 and coated with silicone. The moisture content of this foam core was 0.79 percent by weight; the apparent core density was 56.4 kg/m³ (3.52 pounds per cubic foot [pcf]). The core sample having the lowest compressive strength was taken from a manufacturing plant roof in New Jersey that was installed in 1983 with aggregate surfacing and no coating on the foam. The moisture content for this foam core was 3.11 percent by weight with an apparent core density of 31.2 kg/m³ (1.95 pcf). The range of compressive strengths is shown graphically in Figure 2. Minimum compressive strength for SPF roofs is currently 276 kPa (40 psi) at yield or 10 percent deformation, whichever comes first per *The NRCA Roofing and Waterproofing Manual*–Fourth Edition.

The apparent core density was determined by ASTM D 1622 with the average apparent core density of 51.6 kg/m³ (3.22 pcf) for all samples. The highest core density was 78.0 kg/m³ (4.87 pcf) and the lowest core density was 30.1 kg/m³ (1.88 pcf). The roof containing the highest apparent core density was a manufacturing plant in northwestern Wisconsin that was installed in 1974. This core sample had a moisture content of 1.07 percent by weight. A compressive strength test could not be run on the sample due to its minimal thickness. The roof having the lowest apparent core density (30.1 kg/m³) [1.88 pcf]) was a shop facility in southern California that had been installed in 1978 and recoated in 1985. The moisture content of this core sample was 1.61 percent by weight. A compressive strength test could not be run on this sample due to minimal thickness. A plot showing the range of apparent core densities can be found in Figure 3. As shown by the plot, the vast majority of the apparent density values occur in the 44.1 kg/m³ to 60.1 kg/m³ (2.75 to 3.75 pcf) range. Recommended minimum foam densities have risen over the years; since 1990, most specification have called for a minimum of 44.9 kg/m³ (2.8 pcf). A plot of the compressive strengths versus core deformation is shown in Figure 4. A large number of foam core specimens yielded prior to 10 percent deformation, generally in the range of 6 percent to 8 percent.

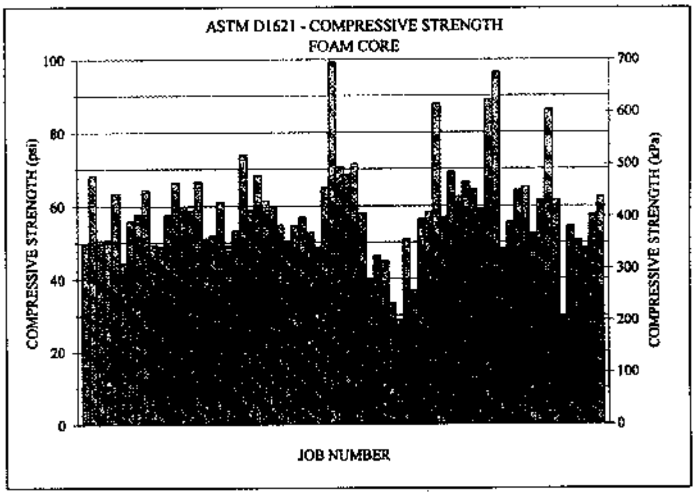


Figure 2. *Foam core compressive strengths for all cores tested.*

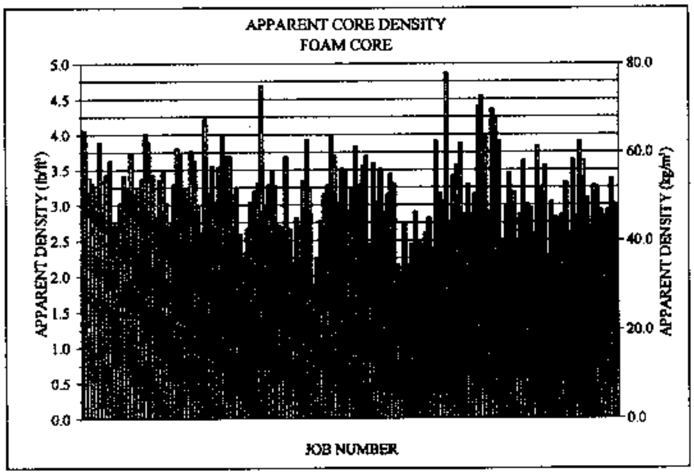
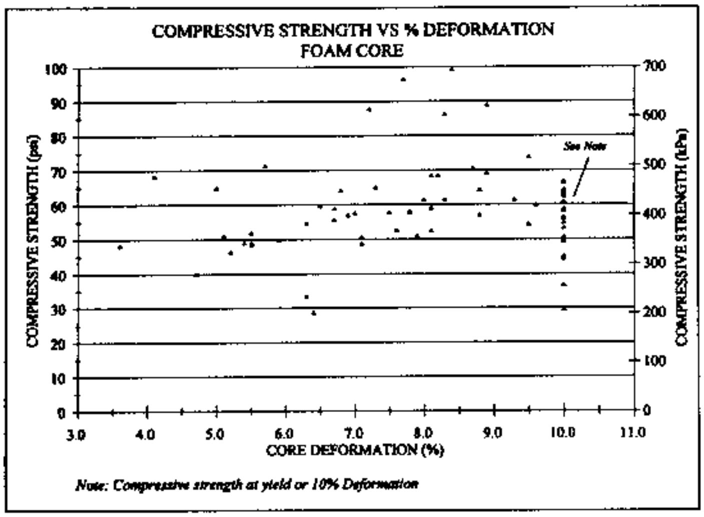


Figure 3. Apparent foam core density for all cores tested.



Note: Compressive strength at yield or 10% Deformation

Figure 4. Compressive strength versus core deformation.

The relationship between compressive strength and apparent core density is shown in Figure 5. The higher density materials have higher compressive strengths as expected. The data scatter can be due to a number of variables, including formulation and field application. The age of these foam core specimens ranges from less than one year to 21 years old. The newest SPF roof had a core density of 64.1 kg/m³ (4.0 pcf) with a compressive strength of 448 kPa (65 psi). The 21 year old roof had a density of 56.4 kg/m³ (3.52 pcf), with a corresponding compressive strength of 685 kPa (99.3 psi) as mentioned.

Moisture content values were determined by oven drying the samples at 50°C (122°F); no further weight change was observed. The average moisture content was 1.02 percent by weight (for 155 specimens with moisture contents less than 10 percent by weight) as shown by the plot in Figure 6. Also shown at the top of the graph are the moisture content results for eight samples that were beyond the maximum scale of the graph (10 percent by weight). These higher moisture contents range from 14.5 percent to 979 percent. It is interesting to note that five of these eight high moisture content values were taken from roofs that were aggregate surfaced. The highest moisture content of 979 percent by weight came from an aggregate surfaced foam roof that had an air conditioned office space immediately below with a suspended ceiling installed below the roof deck. Ponded water was noted to occur near the sample area on this New Jersey SPF roof when it was surveyed in June 1996.

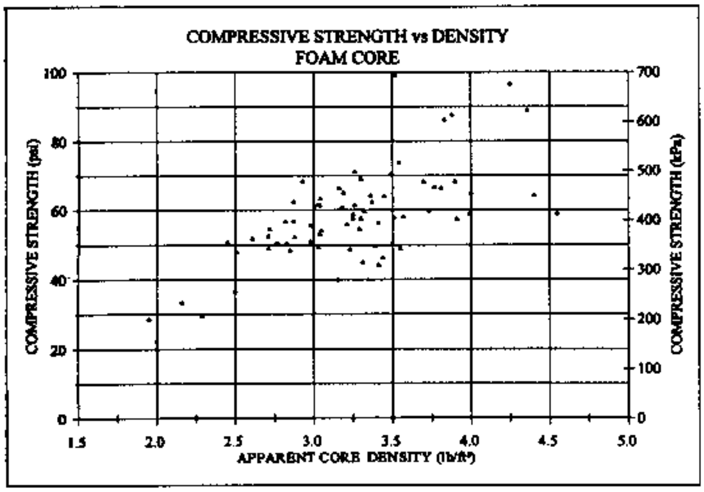
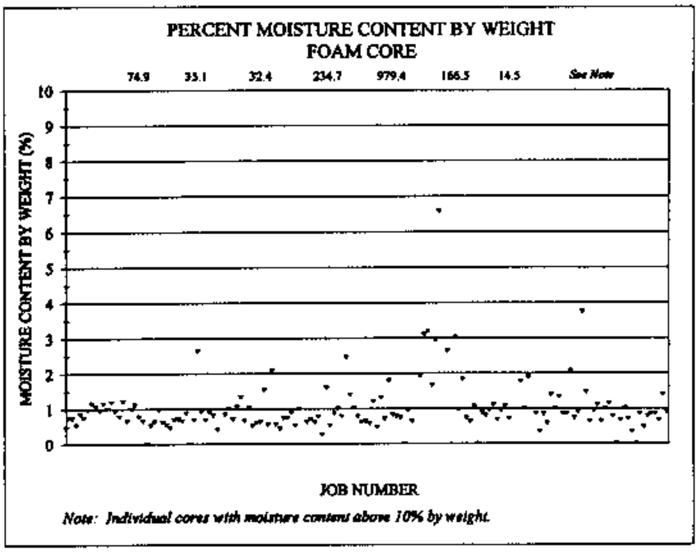


Figure 5. Compressive strength verus apparent foam core density.



Note: Individual cores with moisture contents above 10% by weight.

Figure 6. Foam core moisture content, by weight.

The three other roofs having a high moisture content in the foam core was a SPF roof located in Texas and recoated with silicone in 1993. Another high moisture content (35.1 percent by weight) was found on a church roof in southern California that used an acrylic coating and was installed in 1989. The roof was surveyed in January 1996. A silicone coated restaurant roof was inspected in northwestern Wisconsin in August 1996. This roof was installed in 1978 and recoated in 1992. A deep core sample (87.5 mm [3½ in.] thick) was taken in the kitchen area. The top half of the core sample had a moisture content of 0.72 percent by weight; the bottom half of the core sample had a moisture content of 166.5 percent by weight. Upon further inspection, it was determined that a built-in freezer was immediately below this area and that a moisture vapor drive condition existed due to the presence of the freezer. The silicone coating (while performing adequately) could not resist the passage of water vapor due to the cold conditions at the deck level.

A large manufacturing complex in New Jersey (inspected in June 1996) had nine aggregate surfaced SPF roofs of various ages with moisture contents ranging from 1.67 percent to 6.58 percent by weight in 8 of the 10 core samples taken. The other two core samples from this complex had moisture contents of 234.7 percent and 979.4 percent.

CONDITION OF COATINGS

A wide variety of existing conditions were seen on the coatings. The silicone coated SPF roofs have apparently weathered while still remaining flexible. The acrylic and some of the aliphatic urethane coatings in the weathered state were observed to be surface hard. A number of the multiple component urethane coatings were suffering from reversion of the base coating, which will diminish the coating life.

Reversion is the process of a cured material reverting back to an uncured state, becoming soft and tacky. This is a formulation problem wherein an attempt was made to achieve a thicker film or faster cure from a multiple component urethane that became unstable.

All of the coated roofs retained dirt to some degree and exhibited surface blemishes similar to that seen on white single-ply systems. Most of the discoloration and dirt could be attributed to building location and environmental conditions.

Ponded water was rarely encountered; however, two school roofs in Texas had severe ponding. Many of the roofs have localized "birdbaths" that do retain surface water. The newer SPF roofs were typically found to have good positive drainage with minimal birdbaths being present. The use of granule surfacings has become part of the current specification for many of the coated SPF roofs. The granules increase the surface rate of evaporation and also diminish or inhibit bird peck damage, should it occur. An eight-year-old smooth silicone coated SPF roof in Illinois had recently suffered bird damage; repairs were to be made with a granule coating to be installed.

The total dry mil thicknesses of the coated SPF roofs were determined from core samples and slit samples taken during the survey. The average coating thickness for each acrylic roof is shown in Figure 7. These values include recoated systems as well as original acrylic coatings. The acrylic coating thicknesses ranged from a high of 63.4 mils to a low of 11.7 mils. The SPF roof with 63.4 mils was originally installed in 1981 and recoated in 1995. The SPF roof with 11.7 mils of acrylic coating was installed in 1995.

The average coating thickness for each silicone SPF roof surveyed is shown in Figure 8. The silicone coating thicknesses ranged from a high of 78.3 mils to a low of 5.4 mils. The SPF roof with 78.3 mils of silicone was installed in 1978 and recoated in 1990. The SPF roof with 5.4 mils of silicone was installed in 1969 and has never been recoated.

The average coating thickness for each urethane SPF roof is shown in Figure 9. The urethane coating thicknesses ranged from a high of 177.5 mils to a low of 10.8 mils. The SPF roof with 177.5 mils of urethane was installed in 1976 and recoated in 1995 after a severe hailstorm with baseball size hail damaged the roof. The SPF roof with 10.8 mils of urethane was recoated in 1984.

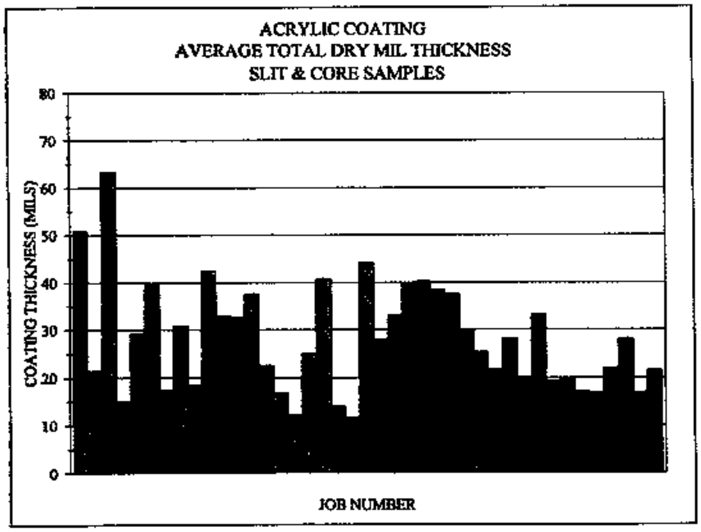


Figure 7. Average total dry mil thickness for acrylic coatings.

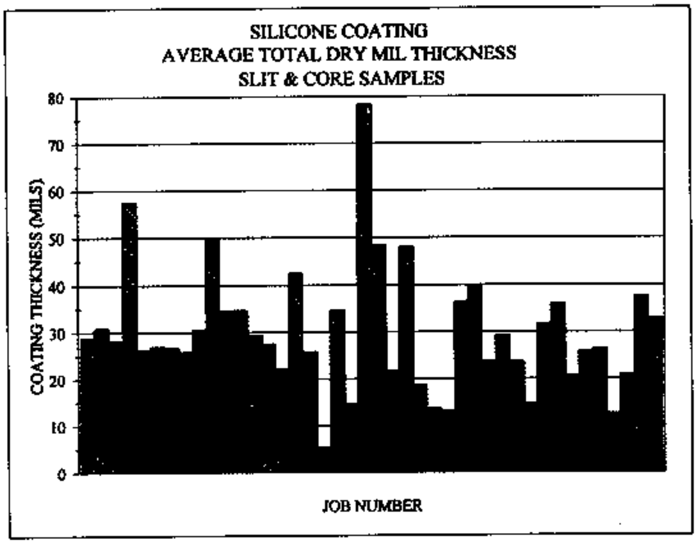


Figure 8. Average total dry mil thickness for silicone coatings.

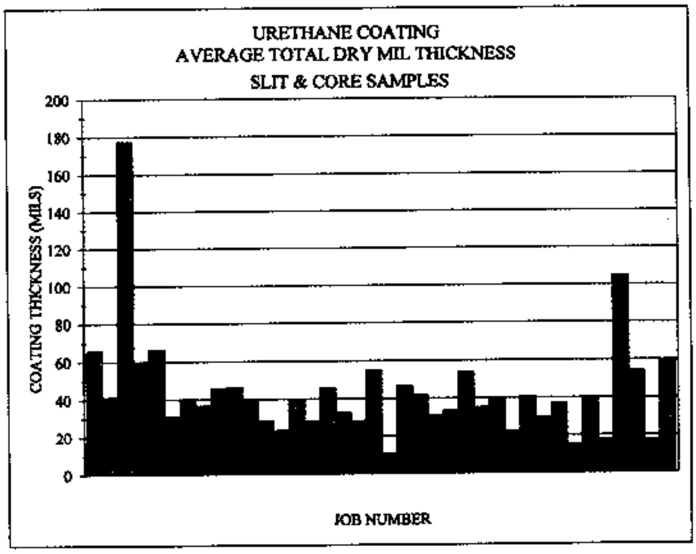


Figure 9. Average total dry mil thickness for urethane coatings.

FOAM CORE PHYSICAL PROPERTIES VERSUS COATING TYPE

A further analysis of the database was undertaken to see what range of foam core compressive strengths and densities were present with each coating type as well as aggregate surfaced SPF roofs. Figure 10 is a summary table showing the compressive strength, core density and moisture contents of the foam core samples by coating type and aggregate surfacings. The average moisture contents for urethane coated SPF roofs was 1.1 percent with the silicone coated SPF roofs having 6.4 percent by weight. The acrylics had an average of 1.7 percent by weight moisture content. The average moisture content of all coated SPF roofs was 3.0 percent by weight.

DISCUSSION

Based on the variety and age of SPF roofs audited, it was seen that design, material and installation limitations can affect SPF roofs similar to other roof systems.

	[illegible]		[illegible]		[illegible]
Category	Average Compressive Strength (psi)	(kPa)	Apparent Core Density (lb/ft³)	(kg/m³)	Average Moisture Content* (%)
All Jobs	58.6	410	3.22	51.90	1.02
All Coatings	59.8	418	3.25	52.55	0.87
Acrylic	54.5	378	3.06	48.54	0.77
Silicone	66.2	463	3.43	54.95	0.82
Urethane	55.1	380	3.20	51.26	1.05
Aggregate	53.5	369	3.08	49.34	1.90

** Values reflect data after discounting moisture content values above 10%, by weight.*

Figure 10. Summary table of compressive strength, core density, and moisutre content as a function of surfacing.

The design limitations primarily concern the proper diagnosis of the existing substrate. Poor attachment of an existing roof, along with poor drainage, blisters and pre-existing moisture are design challenges that must be overcome if an SPF roof is to be used to re-cover an existing roof. The predominant design shortcoming of the SPF roofs audited in this study was poor drainage, especially those installed in the early to mid-1980s. Adhesion to the existing substrates was in most cases very good, as it was difficult to break the core samples loose.

Material limitations of the SPF roofs were primarily seen to be formulation problems with some of the older polyurethane coatings as previously discussed. There are a number of performance attributes of materials that need further study and will be discussed later.

Installation procedures were seen to be the most critical item to the success of an SPF roof. Dry bulb and wet bulb temperatures should differ by at least 2.8°C (5°F); wind can cause overspray to occur. Proper foam component ratios (usually 1:1) must be maintained during application. Two roofs of the 140 SPF roofs audited had localized areas of off-ratio foam that resulted in a soft, unstable material. Foam blisters (usually small) were the predominant problem seen that related to installation; however, the roofs were performing.

The moisture content was seen to vary in the foam samples and it was suspected that the higher moisture contents could be attributed to ponding water or vapor drive from the building's interior. Based on the SPF roof's location, coating and existing substrate, the author is of the opinion that the moisture content of the foam core will vary from summer to winter. Since the moisture content data represents a value at one point in time, the author cannot state with certainty how large a variation to expect to see in the moisture content at any given site. The moisture content data for the Texas and southern California roofs came from core samples taken in December 1995 and January 1996. The moisture content data for New Jersey, New York, Connecticut and Wisconsin came from samples taken during the summer months of 1996. Jobs 119 through 140 were sampled in March 1997 in central Illinois. Thus, samples were taken during winter and summer time conditions for a variety of roofs.

CONCLUSIONS

Based on the findings of the field survey, it is apparent that the physical properties of the spray polyurethane foam roofs evaluated, regardless of age, is quite good. High compressive strengths and core densities were seen in older systems as well as in newer SPF roofs. The moisture content was typically found to be very low for coated roofs; the aggregate surfaced roofs had a wide range of moisture contents. The compressive strengths found in this study were substantially higher than that recommended in the current design guidelines as mentioned previously; similarly, the core densities were 15 percent higher than current industry design minimums. In the author's opinion, these properties (compressive strength and core density) are desirable and point to the apparent longevity of the SPF serving as a suitable substrate. The range of the moisture contents was generally within the 0 to 2 percent by weight category as shown in Figure 6. This comports with moisture contents seen in other generic insulation systems such as perlite, isocyanurate, and expanded or extruded polystyrene. Wood fiberboard, on the other hand, is generally found to have a 6 to 8 percent moisture content by weight in performing roofs. Thus, the moisture content found in the SPF roofs was similar to that seen in other generic roof insulations.

The specific design guidelines that need to be established to enhance the performance of SPF roofs are:

1. Establish guidelines for obtaining thicker cross sections of SPF roofs that are required to achieve positive drainage. Today's design guides call for a minimum 6 mm (¼in.) per foot slope, which results in 100-mm to 150-mm lifts (4-in. to 6-in. lifts). There is no defined and accepted procedure on how to accomplish this with SPF roofs.
2. Resolve the different design philosophies regarding the use of metal counterflashing.

The performance attributes on SPF materials that need further development are as follows:

1. Develop a systemized approach to evaluate the resistance to impact damage on SPF roofs. Static impact and dynamic impact tests should be used in a systematic approach to evaluate the impact resistance for new and aged SPF roof systems. Hail impact testing has started on new coated SPF roof systems; further development is needed. Aged SPF roofs need to be evaluated in a manner that allows for all coating/surfacing systems to be evaluated.
2. Water vapor transmission rates need to be established on aged uncoated foam as well as new and aged coated foam roofs. There is no current industry recommendation on water vapor transmission rates for SPF roofs.

One issue relating to installation that needs further work is the foam blister mechanism(s) and how it may be avoided.

This field and laboratory assessment program has shown design, installation and material improvements have taken place with SPF roofs. Finished appearance has improved significantly. The use of granule/aggregate surfacing has also improved mechanical protection for the SPF roofs.

ACKNOWLEDGMENT

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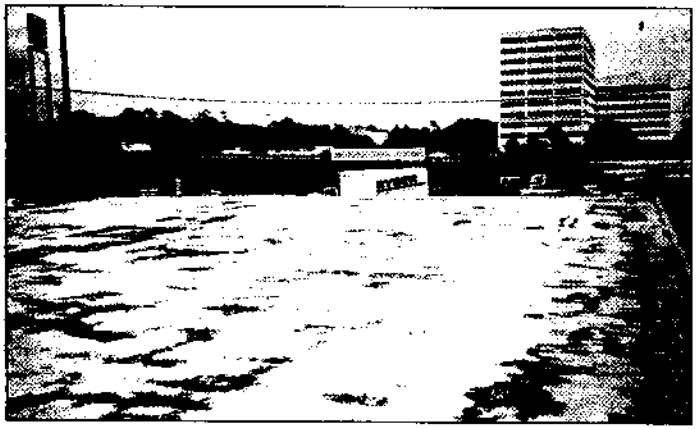

Photo 1. *The blotchy appearance of this light-colored roof is caused by dirt accumulation at birth baths.*

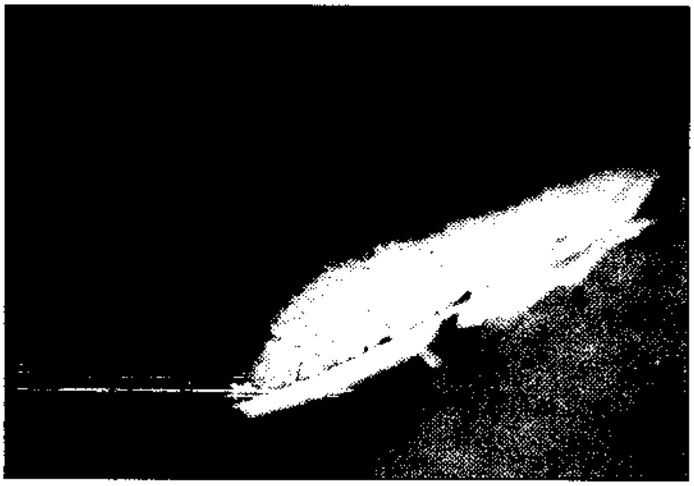

Photo 2. *This roof had a deep gouge into the foam. Water is laying in the bottom of the gouge. The exposed foam is quite dark, due to dirt pick up. A slit sample was cut at the edge of the gouge, above the water line. Water had only penetrated about 1.5mm (1/16 in.) into the exposed foam. (An end of an ink pad shows the scale of the photo.)*

Photo 3. *These two blisters have ruptured and are in need of repair. However, this is a minor repair item. The foam at the bottom of the blistered area will provide water resistance for a substantial length of time.*

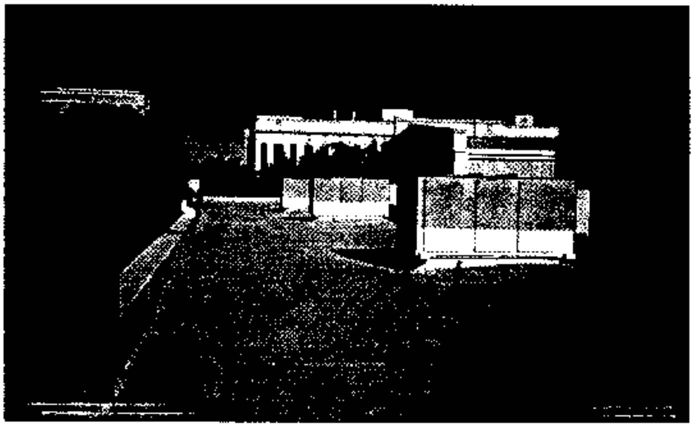

Photo 4. *This SPF roof is surfaced with light brown granules, which present a relatively attractive appearance.*