IMPROVING WIND PERFORMANCE OF ASPHALT SHINGLES: LESSONS FROM HURRICANE ANDREW

THOMAS L. SMITH
National Roofing Contractors Association
Rosemont, Ill.

Hurricane Andrew caused very extensive roof covering damage in south Florida. This paper describes asphalt shingle roof covering damage, wind loading, failure modes, life safety and property damage, workmanship, perimeter metal flashings, deck influences, testing, code requirements, and design guides. Finally, it provides conclusions and recommendations for enhanced performance in hurricane-prone and other high-wind regions.

KEYWORDS

Asphalt shingles, blow-off, bond strength, Hurricane Andrew, wind design and wind performance.

INTRODUCTION

Immediately after Hurricane Andrew came ashore in Dade County, Fla., on Aug. 24, 1992, a research team under the direction of the Wind Engineering Research Council began an evaluation of the storm and the damage it had caused. As a member of the team, the National Roofing Contractors Association (NRCA) performed a comprehensive investigation of roof-covering performance.

A previous paper focused on the causes of roof damage and the roof failure modes of various types of roof coverings during Hurricane Andrew.[1] This paper describes asphalt shingle roof covering damage, wind loading, failure modes, life safety and property damage, workmanship, perimeter metal flashings, aging effects, deck influences, testing, code requirements and design guides. It also provides conclusions and recommendations for enhanced performance in hurricane-prone and other high-wind regions.

Hurricane Andrew, which was an extremely strong storm (Category 4 on the Saffir-Simpson Potential Scale), struck a highly populated locality. In the area that received very high winds, it is estimated that more than 95 percent of the low- and steep-slope roof coverings experienced some damage. Although the damage to several of the roofs was minimal, an estimated 70 percent of the roof coverings were significantly damaged.

Unlike most areas of the U.S., only a small percentage of the residences in Dade County had asphalt shingles, although in some subdivisions, asphalt shingles were the predominant or only roof covering used.[2]

General information on wind speeds and the geographical boundaries of the area of south Florida observed was reported in a previous paper.[2] Based on ANSI/ASCE 7,[3] in the area that received the maximum wind speed, the wind was approximately 31 percent above the design wind speed.

OBSERVATIONS

Many asphalt shingle roofs were observed during helicopter and automobile surveys; however, detailed investigations were made on only a few buildings. Photos 1 to 19 give a representation of the observed damage to asphalt shingle roofs (all of which appeared to be of self-sealing, rather than mechanically interlocking, designs). Some of the observed buildings experienced structural damage. In some cases, the structural damage (e.g., loss of plywood roof sheathing) may have initiated progressive failure of the shingles.

In some instances, the estimated wind speed is given. The estimated upper-bound wind speeds for the building locations are based on References 4 and 5, rounded to the nearest 5 mph (2 m/s). The speeds are for a three-second peak gust for Exposure C (flat, open terrain) at 33 feet (10 m). Most of the observed buildings are in Exposure B (urban and suburban areas), but for roof coverings on buildings less than 60 feet (18 m), Exposure C is applicable in accordance with ANSI/ASCE 7.

Two of the roofs investigated were in the area that received the highest winds (peak gust of 170 mph [76 m/s]). Damaged roofs were also observed in areas that received lower winds (125 to 160 mph [56 to 72 m/s]).

Photo 1. The structure from the house on the middle-right of the photo landed near the upper left of the photo (see arrow).

Photo 1 illustrates the great variability in performance. Ten houses are shown, all of which have asphalt shingles. One house experienced significant structural damage (loss of the roof deck and framing). One house exhibited very minor shingle loss. One house lost several shingles over various areas of the roof. Two houses lost most of their shingles, but the underlayment remained. Four houses lost large areas of shingles (one of these lost a small area of underlayment). One house lost a moderate number of shingles in four areas, with loss of underlayment at three of these areas.

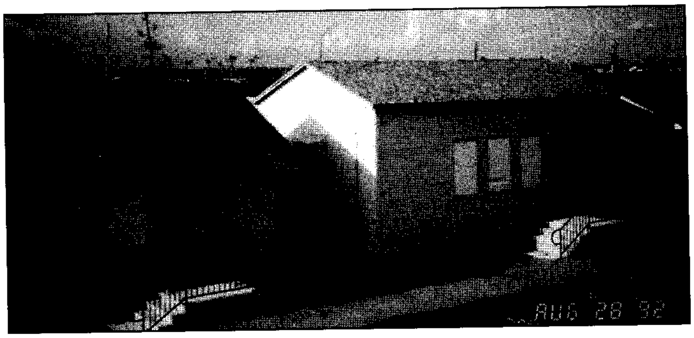

Photo 2.

Photo 2 also illustrates the performance variability. One portable classroom lost only a few ridge shingles while the adjacent classroom was stripped of almost all of its shingles (several pieces of shingles still remained along the rake). Another nearby portable classroom, which is not shown, lost several ridge shingles. Detailed investigation was not performed; hence, the reason(s) for this variability is unknown. The estimated peak gust wind speed was 145 mph (65 m/s).

Photo 3.

At the building shown in Photo 3, essentially all of the underlayment was lost on one side of the roof. The underlayment was fastened with thin metal disks ("tin caps") though it appeared that only a few of these fasteners were used. A few tabs remained along the eave. The perimeter metal flashing (metal drip edge) did not appear to be damaged. The estimated peak gust wind speed was 170 mph (76 m/s).

Photo 4. The tree on the roof was stripped of its leaves, but other nearby vegetation was not stripped. It appeared that some shelter was proviced by nearby buildings; however, the wind was sufficient to break and knock down some trees.

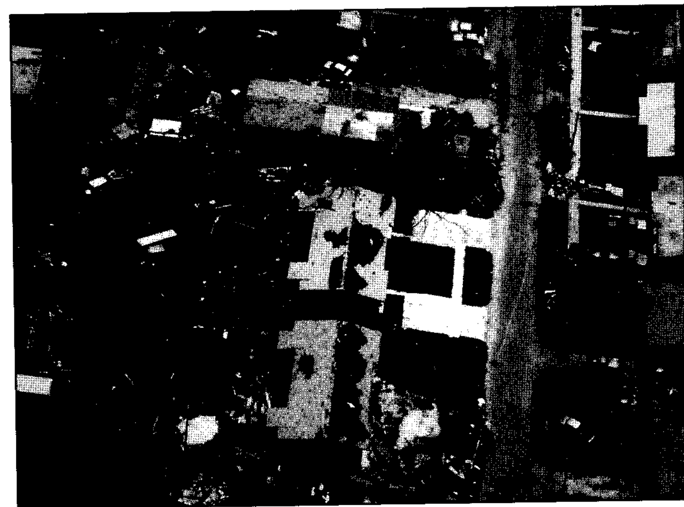

Photo 5. Wind appears to have blown parallel to the street, from the bottom of the photo toward the top.

Photo 4 shows an older roof that lost only a few tabs. Some of the built-in gutter flashing was also lifted up. The estimated peak gust wind speed was 145 mph (65 m/s).

Five houses are shown running up the middle of Photo 5. All lost a large number of shingles, but only the two houses at the top lost large areas of underlayment. The other three houses lost very small areas of underlayment though the house at the bottom had at least five of these small areas. The house at the bottom right side of the photo had some damage near the ridge/rake; however, it may not have had asphalt shingles. The next house lost shingles in two large areas. The next two houses lost the right side of the roof covering, but the underlayment remained. The house at the top lost most of its roof covering and part of the underlayment. These last three houses may not have had asphalt shingles.

Photo 6 shows an apartment or condominium complex. Although most of the roofs lost a large number of shingles, the underlayment remained. The underlayment was fastened with a large number of closely spaced fasteners (which were probably metal disks).

Photo 6.

Photo 7. The wind blew in two primary directions: from the left to the right of the photo and from the top to the bottom. The house on the right has a tile roof.

The asphalt shingle roof on the left in Photo 7 lost a large number of shingles and the underlayment along the rake/ridge/eave. It also lost several shingles over various areas on the side of the roof that is towards the top of the photo. The other house has a mortar-set tile roof. It lost many tiles, but the underlying built-up membrane was not blown off.

Photo 8 shows a house of complex shape in a very high wind area. It lost most of the hip and ridge shingles, as well as shingles near three of the ridges, but the underlayment remained.

Photo 8. The wind appears to have come from three directions: bottom left to upper right of the photo, bottom to top and top to bottom (or top left to bottom right).

Photo 9.

Photo 10. This damage may have been related to increased turbulence associated with the wall shown at the left of the photo.

Photos 9 and 10 show a fast-food restaurant roof that experienced very little damage. Along the hip, most of the shingles were lost. A few tabs along the eave were also lost. At another area, a few shingles were blown off. The shingles were attached with nails, but the number of nails per shingle was not determined. In the area shown in Photo 10, the nails were placed above the self-seal (sealant) strip. The estimated peak gust wind speed was 145 mph (65 m/s).

Photos 11 to 13 show a roof on a building of an apartment or condominium complex. The fiberglass-reinforced shingles were attached with four staples per shingle. The staples were typically installed in the correct location and orientation (i.e., parallel to the sealant strip) except that the end fasteners were about ¼ to ½ of an inch (6 to 13 mm) from the end rather than 1 inch (25 mm). The underlayment was attached with metal disks and staples. The disks were in rows that were approximately 18 inches (460 mm) apart. Along the row, they were placed from about 6 to 12 inches (150 to 300 mm) on center. At one rake (Photo 12), there was a metal edge flashing that had a vertical flange that projected up above the shingle about 1 inch (25 mm). The first fastener of these rake shingles was placed 8 inches (200 mm) from the upturned flange. Asphalt roof (plastic) cement was placed

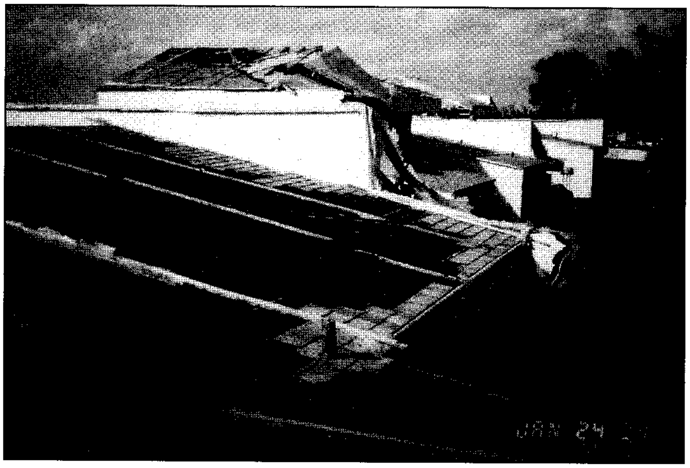

Photo 11. *Some underlayment was lost (bottom center of the photo). The wood strips running up the roof had been placed to hold down polyethylene sheeting, which was no longer in place when this roof was observed in January 1993. On one of the other roof areas of this building, it appeared that wind-blown debris may have initiated the shingle failure.*

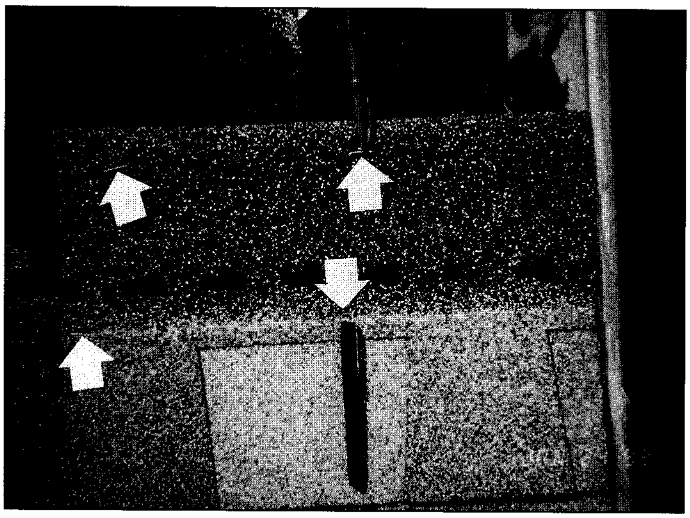

Photo 12. *Close-up of Photo 11. Arrows show the fasteners. This metal edge flashing has an upturned flange.*

Photo 13. *A staple (near the end of the pen) drove all of the way through the shingle.*

between the metal flange and the shingles. Most of these rake shingles remained on the roof. Photo 13 shows a tab that was pulled up during the investigation to evaluate the sealant bond. The bond strength seemed to be very good—the failure occurred within the shingle rather than within the sealant or between the sealant and the shingle. Under this tab, the staple drove all of the way through the shingle. The estimated peak gust wind speed was 170 mph (76 m/s).

DISCUSSION

Roof performance was related to variations in the wind field at a given building site, influences of upwind terrain, building shape and size, and variations in construction (including design, materials, and application). The large number of variations, coupled with the small number of investigated roofs and limited information on them, complicates the analysis of roof system performance.

Very few asphalt shingle roofs in the U.S. are susceptible to winds of the magnitudes experienced by the roofs shown in the photos. However, lessons learned from this hurricane can be used to minimize wind damage to shingle roofs in less windy areas.

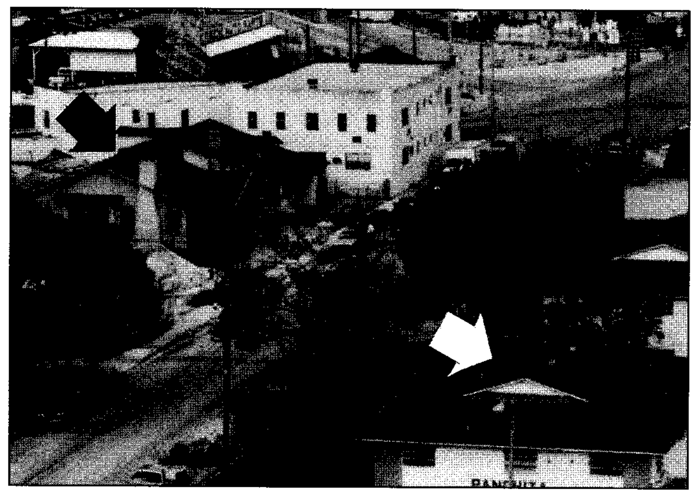

Photo 14. *These two damaged asphalt shingle roofs (see arrows) are located near downtown Miami. The estimated peak gust wind speed was 125 mph (56 m/s).*

Although most of the damaged roofs in Dade County experienced wind speeds that were above the ANSI/ASCE 7 design wind speed for this area (i.e., 130 mph [58 m/s] peak gust), many shingle roofs that experienced winds below the design wind speed were also damaged, as shown in Photo 14.

Based on current knowledge, the keys to successful wind performance of asphalt shingle roof coverings are:

- the bonding of the self-seal strip;
- the number of fasteners used to attach the shingle;
- correct application of the shingle fasteners;
- the mechanical properties of the shingle; and
- prevention of deck blow-off.

The primary issues related to wind performance of asphalt shingle roof coverings are discussed later.

Wind Loading

Roof wind loads derived from ANSI/ASCE 7 represent the pressure differential between the exterior and interior surfaces of the roof envelope. Air-permeable claddings (e.g., shingles) allow partial air pressure equalization between the exterior and interior surfaces of the cladding element. Because of this partial air pressure equalization, the uplift loads derived from ANSI/ASCE 7 can overestimate the load on air-permeable cladding elements.[6]

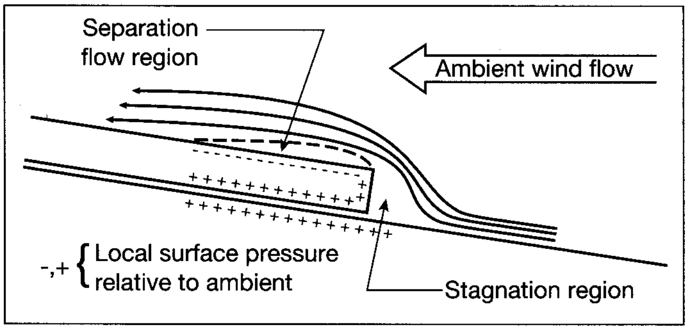

***Figure 1.** Local flow over a shingle (adapted from Reference 7).*

Peterka reported that positive pressure on the underside of asphalt shingles can vent very rapidly, thereby minimizing the uplift load on the shingles.[7] He described the wind flow mechanism that produces the uplift loads on shingles, as shown schematically in Figure 1: "Local flow separation over the top of the shingle causes negative, or uplift, pressures on the top of the shingle. At the same time, a stagnation region forms on the front edge of the shingle, which causes positive pressures (acting toward the shingle surface) in that region. This positive pressure acting toward the shingle surface from below adds to the uplift force on the shingle."

If the tabs lift up, the wind loading on the lifted tabs increases very quickly by a substantial amount.

As part of a research project conducted for the Asphalt Roofing Manufacturers Association (ARMA) by Colorado State University (CSU),[8] mean wind speeds were measured in a wind tunnel near the roof surface for three one-story model buildings with different roof slopes.[9] The location of the highest near-roof-surface wind speed varied depending on the direction of the approach flow. The regions with the highest speed were the ridges, corners, and roof edges. These high near-surface flow regions correspond quite well to the Hurricane Andrew damage investigation observations, as well as those observed following Hurricane Hugo.[10] (In some cases, the observed damage pattern was probably influenced by the wind approaching from more than one primary direction as the hurricane passed over the area.) In the most extreme case, near-surface flow was substantially greater than the reference mean wind speed (i.e., the flow near the roof surface was much greater than the approach flow of the wind, measured at the eave height).

This pioneering research is a critical aspect of determining shingle uplift loads. Coupled with pressure coefficient data for the top and bottom sides of the shingle, which was also developed in the CSU research program, it is now possible to calculate the net uplift pressure on shingles with respect to design wind speed, building height, and roof zone (e.g., ridge, field of roof). When ARMA releases these important research results, designers (and contractors functioning in a design role) will be able to perform these calculations.

Failure Modes

- Tab uplift: Uplift of the tabs appears to be the predominate failure mode. If the tab lifts, the shingle is very vulnerable to damage via the tab breaking off (Photo 15) or the shingle pulling over the fasteners and blowing off of the roof (Photo 16). As the shingles progressively fail, several shingles may remain sealed together and blow off in unison.

  As discussed in the previous section, the pressure differential across the tab creates a small uplift force. Because of the light weight of the shingle, this force can be sufficient, even in moderate winds, to cause tab uplift if the tab is not sealed.[7] Therefore, it is critical that the tabs be sealed down or mechanically interlocked. The poor performance of unsealed tabs (free tabs) has long been recognized.[11]

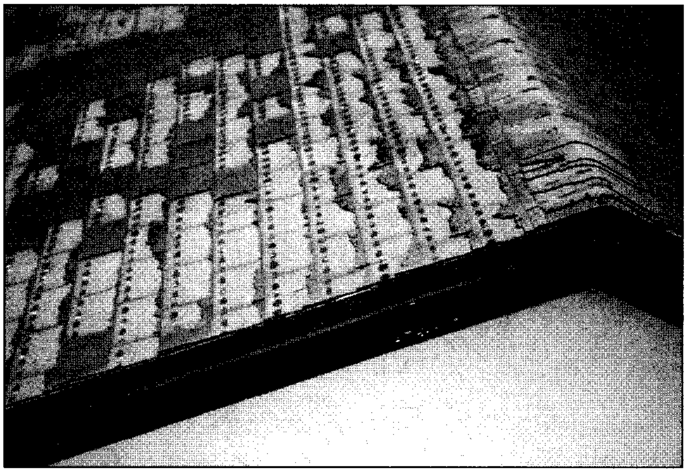

***Photo 15.** These shingles were each attached with four nails, which were located in the self-seal strip. In this corner area, many of the tabs were lifted and broken off. On the right side of the roof, several tabs were lost along the eave, a few were lost along the rakes, and several were lost in the field of the roof, starting about 5 feet (1,500 mm) up from the eave. The estimated peak gust wind speed was 160 mph (72 m/s).*

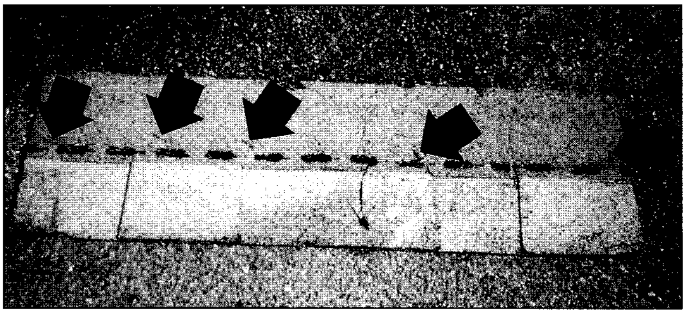

***Photo 16.** Progressive misorientation of staples (see arrows). Also, the staples are located above the self-seal strip rather than below it. The estimated peak gust wind speed was 145 mph (65 m/s).*

- Fastener pullover: After the tabs lift, the shingle may pull over the fasteners. This failure mode is primarily a function of the number of fasteners used to attach the shingle, the shingle's mechanical properties, and wind loading. If staples are used, the orientation of the staple is also important (e.g., if the staple is perpendicular to the sealant strip [Photo 16], the shingle is more vulnerable to tearing). The fastener's location may also be important (e.g., if the fastener is too close to the end of the shingle, pullover resistance may be reduced, or if the fasteners are located above the self-seal strip, additional load may be exerted on them because of the larger tributary area of the lifted tabs).

When fasteners are properly located, each fastener actually engages two shingles (i.e., one row of fasteners is near the self-seal strip, and another row, which attaches the overlying shingle, is near the head of the shingle). Hence, if a shingle is attached with six fasteners, it actually has 12 fasteners penetrating it. However, if the tabs lift up, almost all of the blow-off resistance is provided by the first row of six fasteners. If the shingle pulls over this first row, the shingle lifts up farther, and it lifts the tabs on the course above. This exerts load on the second row of fasteners.

If the tabs lift and the shingle is attached with six fasteners rather than four, the shingle is less susceptible to blow-off though the amount of reduced susceptibility has not been quantified in the literature. Depending on wind speed and direction and the shingle's material properties, the two additional fasteners may or may not be sufficient to prevent progressive failure.

- Deck failure: Good performance of an asphalt shingle roof system also depends on the deck remaining attached. There were several instances of deck blow-off (Photo 17).

Photo 17. This section of plywood decking blew off. The shingles were each attached with four nails, which were located in the self-seal strip (see arrows).

- Fastener pullout: Pullout of the shingle fasteners from the deck was not observed. However, this failure mode was observed in Hurricane Hugo.[10] Fastener pullout appears to occur primarily when fasteners are too short.
- Hip/ridge shingles: In some instances, the primary damage was loss of hip or ridge shingles (Photos 2, 8 and 9). Although not documented, these failures were probably related to the use of fasteners that are too short or the use of unsealed premanufactured hip/ridge shingles.

Life Safety and Property Damage

Asphalt shingles typically do not travel great distances when blown off of a roof; hence, unlike many other low- and steep-slope roof coverings, they represent a very low threat to life safety or damage to neighboring buildings or other property. However, as with any type of roof covering, when the covering/underlayment is seriously damaged in hurricanes or many other types of wind storms, extensive water damage commonly occurs to the building interior and contents.

As shown by the photos, the underlayment was not blown off of many of the buildings that lost all or a large number of their shingles. Normally, in these instances, the amount of interior water damage is greatly mitigated. The excellent performance of many of the underlayments was probably related to the underlayment attachment. In south Florida, the use of metal disks to attach underlayment is quite common, whereas in many other parts of the U.S., roofing nails or staples are commonly used. The underlayment is less likely to pull over the large head of the metal disks than over the smaller surface area provided by roofing nails and staples. Also, in south Florida, the underlayment fasteners typically appear to be placed much closer together than is commonly the practice in other parts of the U.S. where the underlayment is tacked down rather than secured.

Although underlayments do provide a secondary means of protection against water infiltration if the shingles blow off, the underlayment is typically a watershedding, rather than a waterproofing, element. Therefore, during the hurricane and subsequent storms, some infiltration could have occurred. A two-ply underlayment with offset side laps can minimize wind-driven water infiltration.

Workmanship

A large number of workmanship deficiencies were observed. These were primarily related to the incorrect location of fasteners, and in the case of staples, incorrect orientation. The fasteners in Photos 10, 15, 16 and 17 were incorrectly located. All of these fasteners are too high—they are located in or above the self-seal strip rather than below it. The end staples in Photo 12 are located too close to the end. With staples, not only is the correct location important, but the staple should also be correctly oriented (i.e., parallel with the sealant strip). Photo 16 shows the progressive misorientation of staples. The first staple is close to the correct orientation, but the last staple was turned 90 degrees. This was caused by the natural tendency of the mechanic to rotate the staple gun as staples were driven along the shingle.

The influence of fastener location/orientation problems has not been quantified in the literature. Some of these types of workmanship problems may have very little influence on wind resistance while others may have great influence. An example of a significant problem may be a fastener in the sealant strip that is not set against the shingle. The fastener reduces the sealant contact area, but more importantly, it may prevent a portion of the tab from being sealed.

Soon after the hurricane, a local newspaper reported that representatives from the Dade County building department stated that contractors had failed to remove the plastic release tape from asphalt shingles (Photo 18) and that this kept the shingles from bonding. They were incorrect, the tape does not need to be removed. The release tape keeps the shingles from bonding while they are packaged, but when installed, the sealant is offset from the release tape on the overlying shingle.

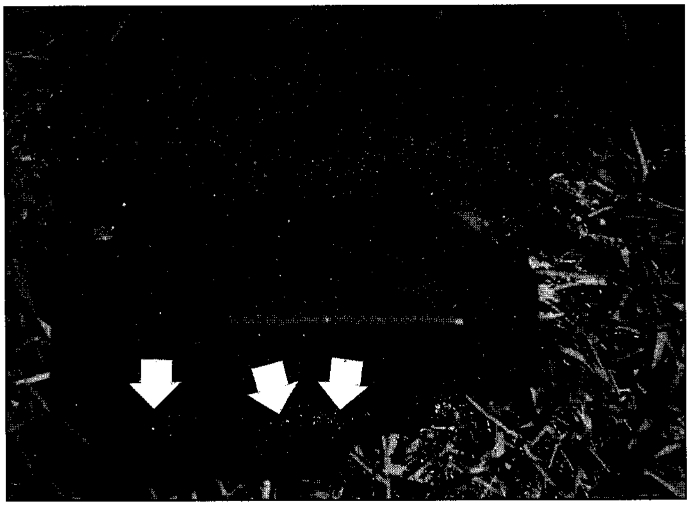

Photo 18. Underside of a shingle that blew off; note the lack of bonding between this shingle and the sealant (see arrows).

Perimeter Metal Flashing

Recent research by Texas Tech University (TTU) shows that the pressure coefficient on perimeter metal flashing (metal drip edges) of the size commonly used on asphalt shingle roofs is quite high in comparison with the larger metal edge flashings found on membrane roofs.[12] Many metal edge flashing problems on membrane roofs were observed, but only one asphalt shingle roof was documented as having a problem with the metal drip edge (Photo 19). This may be explained by TTU's finite element analysis, which indicates that the load on drip edges is quite small though the pressure coefficient is high. The low load is related to the small dimension of the vertical face of commonly used drip edges. Also, the TTU research building did not have a gutter or roof overhang whereas most of the shingle roofs did. Perhaps gutters and overhangs influence airflow such that the resulting pressure coefficient (and, hence, load) on the drip edge is reduced. Further investigation on this issue is needed.

Photo 19. The perimeter metal flashing blew off of the rake in two areas (see arrows). It also blew off along most of the eave though this damage may have been initiated by the deck failure. The shingles blew off, but most of the underlayment remained. The estimated peak gust wind speed was 140 mph (63 m/s).

Aging Effects

The observed roofs ranged in age from about 1½ years (or less) to perhaps 15+ years. The influence of aging on wind performance was not determined though aging probably does play some role in the performance of older roofs. Further investigation on this issue is needed.

Deck Influences

On the roofs where detailed observations were made, it was found that the shingle fastener (i.e., nails or staples) typically remained in the deck. Keith reported that there was substantial evidence from damages that fastener withdrawal resistance is adequate with plywood and OSB roof sheathing thicknesses of 7/16 of an inch (11 mm) or greater.[13] Siple reported that plywood seemed to have the advantage over OSB with respect to withdrawal resistance of roofing nails, but he did not provide information to support his position.[14]

Lab Testing

Wind resistance of asphalt shingles is currently evaluated by one of two test methods that are virtually identical—ASTM D 3161 and UL 997. These test methods are inadequate for assessing wind performance.[8, 15] Part of the inadequacy of the methods is the low test speed (60 mph [27 m/s]). The 60 mph (27 m/s) criteria was based on the capacity of the equipment at the time these tests were developed about 35 years ago.[11] Also, the flow structure is not adequately simulated in these tests.

Recognizing the limitations of the current test methods, ARMA developed a new test method.[16] This method assesses the bond strength of the self-seal sealant. With this load resistance data and the load calculation procedure developed by CSU, it will be possible to specify shingles for the wind environment in which they will be located.

After ARMA completed initial development of the bond-strength test procedure, work began within the American Society for Testing and Materials (ASTM) to develop the method into an ASTM standard. This standard is still under development.

Code Requirements

The 1988 *South Florida Building Code (SFBC)* was the building code in effect in Dade County at the time of the hurricane. It required asphalt shingles to be attached with a minimum of four nails or staples per shingle though most manufacturers recommend six fasteners in high-wind areas. The code also required an underlayment consisting of one No. 15 felt (two layers on slopes less than 4-in-12 [33 percent]).

The 1994 *SFBC* requires six "approved nails or approved fastening devices." It also clarified requirements for setting shingles in asphalt roof cement at "intersections," eaves, rakes, and valleys though the required application has a high potential for causing blisters. Also, there were some modifications to the underlayment requirements, and new requirements for underlayment attachment were added (these requirements are unclear).

The 1994 *Standard Building Code (SBC)* has prescriptive wind requirements for asphalt shingles. Depending on conditions as specified in the code, four or six fasteners are required. According to the 1994 *SBC*, shingles in south Florida would have been required to be fastened with six fasteners.

Although ASCE 7-95 will recognize reduced loads on air-permeable claddings, it will specify that the loads derived from its calculation procedure be used unless approved test data or recognized literature demonstrates lower loads. As the building codes adopt the ASCE 7-95 wind provisions, to comply with the requirements, it appears that a large number of fasteners will be needed unless the results of the CSU research are available and implemented. For example, a two-story house with a gable roof in the Miami area would require 16 fasteners per shingle in the zones around the eaves, rakes, and ridge. Ten fasteners would be required in the field of the roof. (This example is based on the minimum fastener pull-through resistance specified in ASTM D 3462 for fiberglass-reinforced shingles, with a safety factor of two.) The same house in the majority of the U.S. would require five fasteners per shingle in the perimeter zones. These examples illustrate the importance of the CSU research and the necessity for its results to be available to the industry.

Design Guides

The *NRCA Steep Roofing Manual* (1989) provides no guidance on the use of asphalt shingles in high wind areas except for two minor recommendations. It recommends that the nailing of the perimeter metal flashing be at 4 inches (100 mm) rather than at 8 to 10 inches (200 to 250 mm) on center, and it recommends the use of perimeter wood strips when reroofing over wood shingles in high wind areas.

ARMA's *Residential Asphalt Roofing Manual* (1993) recommends the use of six fasteners in high-wind areas, and it provides information on their correct location and orientation. ARMA defers the determination of what a high-wind area is to the local building code authority.

Designers (and contractors functioning in a design role) are, therefore, primarily dependent on manufacturers for high-wind design recommendations. Most manufacturers recommend six fasteners in high wind areas but typically do not define a high-wind area. Their other high wind recommendations (e.g., hip and ridge shingle attachment enhancement) are generally limited or nonexistent.

Guidance is available regarding fastener types though the guidance is not specific to high-wind areas. *The NRCA Steep Roofing Manual* recommends roofing nails; it is silent on staples. ARMA's *Residential Asphalt Roofing Manual* advises that nails are the "preferred fastening system;" however, criteria are also given for staples. Editions of the ARMA manual prior to 1993 did not give a fastener preference. ARMA's preference for nails is also stated in a 1994 bulletin.[17]

Several Hurricane Andrew damage investigation reports stated that stapled shingles did not perform as well as nailed shingles.[13, 18, 19] However, these reports lack documentation to support what may be overly generalized conclusions. With proper deck engagement, either fastener type has sufficient strength to resist the small uplift load on the shingle provided the tabs remain sealed. The blow-off potential develops if the tab becomes unbonded, in which case, the fastener pull-through resistance of the shingle and the number and orientation of fasteners govern performance. If nails are superior to staples, their superiority in preventing blow-off after sealant failure is minimal. However, nails do have the advantage of not having orientation problems. If staples are misoriented, as shown in Photo 16, the reduction in pull-through resistance appears to be significant.

The ARMA and NRCA manuals also give guidance on underlayments though again the guidance is not specific to high-wind areas. The performance of many of the underlayments shown in the photos is quite remarkable considering the size of the underlayment exposed and the extremely high winds that were experienced. The local practice of using metal disk fasteners at close spacings provided exceptional underlayment wind resistance upon shingle loss. Following the hurricane, the Federal Emergency Management Agency (FEMA) recommended a water-resistant membrane underlayment in the absence of "code-rated shingles."[20] As an example, FEMA suggested two felts with a mopping of hot asphalt between them. However, FEMA did not give guidance on underlayment attachment.

CONCLUSIONS

By subjecting roofs to wind speeds of varying magnitude, from very to extremely high, Hurricane Andrew afforded an excellent opportunity to study wind performance of asphalt shingle roof coverings and develop strategies for enhanced wind resistance. Conclusions from the research are:

- The cost of wind-induced roof damage is typically insignificant compared to the costs associated with water damage to the interior of the building and its contents. Particularly in hurricane-prone regions, if more building owners and roof system designers recognized the wind threat and its consequences, it is probable that funds would be allocated for a more conservative (i.e., wind-resistant) asphalt shingle roof covering system and that there would be greater attention paid to the design of the system and selection of the roofing contractor.
- Three-tab and laminated asphalt shingles can offer very good wind resistance in exceptionally high wind events; however, more commonly, their performance is poor. Poor performance was also experienced on roofs in areas that received winds which were below the design wind speed.

  Data are insufficient to quantify to what extent the poor performance was due to materials, design, workmanship, aging, an inadequate wind-resistance test method, or other factors. *However, the important lesson from Hurricane Andrew is that asphalt shingles can perform.* The challenge will be to implement strategies to enhance the wind-resistance reliability of this system.
- Upon loss of shingles, underlayments can minimize water infiltration. When well-attached, underlayments can provide exceptional wind resistance.
- Wind performance of asphalt shingles is overly dependent on performance of the self-seal strip. Redundancy needs to be developed to minimize progressive failure in the event the sealant fails.
- Greater attention is needed to correct application, with emphasis on fastener location and, in the case of staples, correct orientation.
- Enhanced design guides are needed.
- ASTM test method D 3161 is inadequate to differentiate shingles that have good or poor high-wind resistance.

RECOMMENDATIONS

To enhance the performance of asphalt shingle roof coverings, the following are recommended:

1. The bond-strength test method standard that is under development within ASTM should be expedited so that a consensus standard is available for determining the bond strengths of shingles.
2. The ARMA-sponsored CSU research results should be expeditiously made available to the industry via a design guide, which would allow designers to easily determine the required bond strength for shingles on specific projects.
3. "Types" should be added to the material standard for fiberglass-reinforced shingles (ASTM D 3462) to reflect different fastener pull-through resistance values. This will allow specifiers/purchasers to obtain shingles with higher pull-through resistance for those projects where greater resistance is advantageous. It is recommended that fastener pull-through resistance criteria be added to the material standard for organic-reinforced shingles (ASTM D 225).
4. Additional research should be conducted in order to improve shingle performance in the event of sealant bond failure (Photo 18). Presently, the reliability of shingle performance in the event of bond failure is not quantified, but in most cases, it appears to be poor. In 1989, Lamb also reported on damage to shingles that had been sealed but failed in wind speeds that were reported to be less than 60 mph (27 m/s).[21]

   This additional research should provide guidance on the enhancement of both the mechanical properties of shingles and the fastening requirements necessary to minimize shingle blow-off in the event of sealant bond failure. Ideally, if a bond failure is experienced, the worst case scenario would be loss of tabs (Photo 15) rather than blow-off of entire shingles.

   This research should also assess fastener pullout from the deck. It appears that this is not a common problem when fasteners of adequate length are used. However, if enhancements are made to minimize fastener pullover, fastener pullout may then become an issue if it is not sufficiently evaluated.
5. Research should be conducted to develop a suitable method for assessing the effect of aging on wind performance.
6. Research should be conducted to quantify the significance of common fastener workmanship problems. If this sensitivity analysis identifies workmanship issues that are critical to wind performance, this criticality awareness may motivate and inform roofing mechanics of the importance of their work.
7. The ARMA and NRCA manuals should be updated to include information related to wind performance in high-wind areas (i.e., areas with a three-second peak gust greater than 90 mph [40 m/s] at 33 feet [10 m] in Exposure C).
8. Until high-wind design guidance is incorporated into the ARMA or NRCA manuals, the following are interim design recommendations for high-wind areas (as defined in Recommendation 7):
   - Obtain bond-strength data from manufacturers and specify/purchase a minimum strength value that appears reasonable. For example, for projects in the windiest portions of the U.S., shingles with bond strengths in the upper range of available strengths would be preferable. Lamb provides some information on bond-strength requirements.[21]

     It is recommended that bond-strength data be based on the latest draft of the test method that is under development within ASTM. Upon approval of the method, the ASTM standard should be used.
   - Specify nail attachment (per *The NRCA Steep Roofing Manual*) with six nails per shingle. (The use of nails eliminates fastener orientation problems.)
   - To minimize water damage in the event of shingle blow-off, specify that low-profile capped-head nails or thin metal disks attached with fasteners be used for underlayment attachment. Also specify the nailing schedule. In areas of the U.S. with the most extreme conditions, fasteners at 6 inches (150 mm) along the laps and at 12 inches (300 mm) along two rows in the field of the sheet are recommended, although this may be somewhat conservative. (Siple[14] and the 1994 *SFBC* also give this nailing schedule.) To minimize water infiltration, also consider specifying two plies of underlayment (with offset side laps). If two plies are specified, one row of fasteners (rather than two) in the field of the sheet are recommended.
   - Hand tabbing the rake and hip shingles is recommended, per Reference 22.
9. A professional roofing contractor experienced with asphalt shingles should perform the application.

10. Future damage investigation research should try to obtain more data on asphalt shingle roofs that perform well. This should be done via destructive observations to determine specific information, including fasteners (type, location, and number), characteristics of the shingles (e.g., their bond strength and fastener pull-through resistance) and deck characteristics (e.g., thickness and panel type). (Because of the difficulties of performing destructive observation shortly after a strong storm, this work would probably need to be performed six months to a year after the storm.) More comprehensive data on damaged roofs also needs to be obtained for research purposes.

ACKNOWLEDGMENTS

The building owners who permitted access to their roofs deserve special thanks. Their cooperation was critical to the research.

REFERENCES

1. Smith, T.L., "Hurricane Andrew provides insights on roof damage," *Professional Roofing*, March 1994, p. 36.
2. Smith, T.L., "Insights on tile performance in hurricane regions," *Professional Roofing*, September 1994, p. R6.
3. ANSI/ASCE 7-93, *Minimum Design Loads for Buildings and Other Structures*, American Society of Civil Engineers, 1993.
4. Powell, M.D., S.H. Houston, and T.A. Reinhold, "Standardizing Wind Measurements for Documentation of Surface Wind Fields in Hurricane Andrew," *Proceedings of the Hurricanes of 1992: Lessons Learned and Implications for the Future*, American Society of Civil Engineers, 1994, p. 52.
5. Reinhold, T.A., personal communication, December 1994.
6. *ASCE 7-95, Public Ballot*, May 15, 1995.

7. Peterka, J.A., G.D. Lamb, and J.E. Cermak, "Wind Resistance of Asphaltic Roofing Shingles," *Proceedings of the Seventh International Conference on Wind Engineering*, Vol. 3, 1987, p. 21.
8. "Asphalt Shingles Endure Rocky Mountain Wind Test," *Up On The Roof*, Residential Edition, Volume 94, No. 2, Asphalt Roofing Manufacturers Association, August 1994.
9. Cermak, J.E., J.A. Peterka, R.G. Derickson, and L.S. Cochran, *Prediction of Wind-Induced Uplift of Asphalt Roofing Shingles on Low-Rise Buildings*, Colorado State University, December 1991.
10. McDonald, J.R. and T.L. Smith, *Performance of Roofing Systems in Hurricane Hugo*, Institute for Disaster Research, Texas Tech University, April 1990.
11. Cullen, W.C., "Wind Resistance of Asphalt Shingle Roofing," *New Building Research*, National Academy of Sciences—National Research Council, 1960, p. 33.
12. Wang, W., J.R. McDonald, and H. Jiang, "Full-Scale Tests for Wind Pressures on Metal Edge Flashings," *Proceedings of the 11th Conference on Roofing Technology*, National Roofing Contractors Association/National Institute of Standards and Technology, p. 60-66
13. Keith, E.L. and J.D. Rose, *Hurricane Andrew Structural Performance of Buildings in South Florida (August 24, 1992)*, APA Report T92-21, September 1992.
14. Siple, D., "Residential Roofing Failures," *Interface*, Roof Consultants Institute, January 1993, p. 3.
15. Nichols, G.G. and S. Gerace, "A Survey of Hurricane Andrew," *Southern Building*, March/April, 1993, p. 12.
16. Shaw, D.E., "ARMA's New Approach For Evaluation of Asphalt Shingle Wind Resistance," *Proceedings of the Third International Symposium on Roofing Technology*, National Roofing Contractors Association, 1991, p. 216.
17. *Technical Bulletin, Nail Application of Asphalt Shingles for New and Re-Cover Roofing*, Asphalt Roofing Manufacturers Association, May 1994.
18. Cook, R.A., *Hurricane Andrew Damage Investigation and Assessment, Summary of Damage to Conventional Residential Structures*, Florida Department of Community Affairs, September 24, 1992, p. 2.
19. Zollo, R.F., *Hurricane Andrew: August 24, 1992, Structural Performance of Buildings in Dade County, Florida, Technical Report No. CEN 93-1*, University of Miami, March 11, 1993, p. 22.
20. *Building Performance: Hurricane Andrew in Florida, Observations, Recommendations, and Technical Guide*, Federal Emergency Management Agency, December 21, 1993, p. 47.
21. Lamb, G.D. and J.S. Noe, "Wind Performance of Asphalt Roofing Shingles," *Structural Design, Analysis and Testing*, Proceedings of Structures Congress '89, American Society of Civil Engineers, May 1989, p. 528.
22. Smith, T.L., "Enhancing wind resistance of asphalt shingle details," *Professional Roofing*, December 1994, p. 54.