The Unsealing of Naturally Aged Asphalt Shingles: An In-situ Survey

C. R. Dixon[1], D.O. Prevatt[1], F.J. Masters[1], and K.R. Gurley[1]

[1]Department of Civil and Coastal Engineering, University of Florida, 365 Weil Hall, Gainesville, FL 32611

ABSTRACT

As part of a two-year research project investigating causes of premature roofing failures in windstorms, twenty-seven naturally aged asphalt shingle roof systems on residential houses in Florida were surveyed to investigate the condition of the sealant adhesive strips on the shingles. The thermally activated sealant strip located along the leading edge of an asphalt shingle is the primary load path that resists failure of the shingle due to the wind. The non-destructive survey consisted of applying finger pressure to each shingle edge to determine whether or not the sealant strip was adhered to shingle below. The investigation identified two distinct, nonrandom, patterns of partially unsealed shingles corresponding to the method of shingle installation; vertical patterns with racked installations and diagonal patterns for diagonal installation of shingles. The total percentage of roofs with partially unsealed shingles exhibiting these patterns ranged from less than 1% for a six year old roof to over 79% for a twenty year old roof. Whereas, roofs without the distinct unsealing patterns had less than 1% of the total number of shingle strips unsealed. A statistically significant increase in the total percentage of partially unsealed shingles was observed for older roofs (7-13 and 14-20 years) when compared to newer roofs (0-6 years). Partial and full unsealing also occurred on hip and ridge cap shingles, likely attributed to poor adhesion at the onset of service life. A similar pattern of wind damage was observed in shingles reported in post-hurricane damage assessment reports. This similarity suggests that pre-storm partial unsealing condition is a strong influence in the actual wind resistance of asphalt shingle roofs.

INTRODUCTION

Asphalt shingles are the predominant roof covering material for single-family residential structures throughout the United States. In hurricane prone Florida, asphalt shingles cover the roofs of over 80% of the existing residential building stock (Engineering Team Report, 2009). The study described in this paper was one of seven experiments undertaken under a two year research program at the University of Florida that focused on the wind resistance asphalt shingles. This holistic program quantified the performance of asphalt shingles at the component and system-level in order to define the roles of aging, product design, and wind load mechanics. The ultimate goal of this program is to provide a roadmap for mitigation strategies to improve wind resistance of asphalt shingles.

The asphalt shingle roof system consists of individual strips – up to 4000 for a common residential roof – of asphalt impregnated fiberglass or organic mats nailed to the roof substrate (Figure 1). The rectangular planform of a typical three-tab shingle strip is 305 mm (12 in) high by 914 mm (36 in) wide, while a laminate shingle strip is a slightly larger 330 mm (13 in) high by 965 mm (38 in) wide. Each shingle course (row) is lapped over the preceding course to produce an exposed (visible) surface that is approximately 127 mm (5 in) wide (Figure 1). The shingles are also horizontally offset between courses – three-tab shingles are offset 6 in (i.e., one-half tab width) and laminate shingle offsets range from 102 mm (4 in) up to 178 mm (7 in). Hip and ridge lines are covered with additional cap shingles consisting of either field cut three-tab shingles or pre-manufactured products.

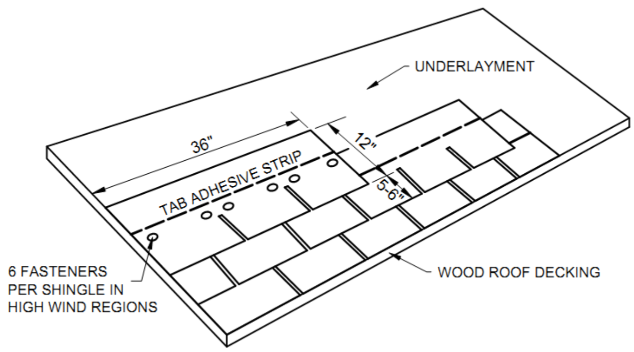

Figure 1. Three-tab field shingle installation (note: laminate shingle follows similar pattern).

The sealant strip located along the leading edge of each shingle is the primary vertical load path that transfers wind uplift forces from the shingle's surface down to the course below (Peterka et al., 1997). The sealant is a thermally-activated bitumen based product that bonds the shingle's leading edge once sealant temperatures exceed the softening point of the material – typically less than 60°C (140°F).

The wind resistance of modern shingle products is classified by test standards ASTM D7158/UL 2390, which evaluate the ability of the sealant strip to resist design level wind uplift loads. These standards are only valid for shingle products that are fully-sealed and the adhesion performance is defined for new products with no regard for changes in the sealant strength that may occur over the life of a roof. Wind uplift forces can increase with the loss of sealant strip adhesion due to wind being forced through gaps in the unsealed sealant strip that increases the underside pressure on the shingle (Peterka et al., 1997). This action increases the vulnerability of the shingle to blow off. Further details on the standard wind test methods for asphalt shingles and evolution of the sealant strip design to resist wind can be found in Dixon et al. (2012).

Post-storm damage assessments have repeatedly reported sealant strip failures of shingles in the field of the roof and along hip and ridge lines, however, their failure mode remains unknown (FEMA, 2005a; FEMA, 2005b; FEMA, 2006; FEMA, 2009). The limited data that exists regarding the long term in-situ sealant strip adhesive performance indicates that partial unsealing can occur on naturally aged shingle roof systems (Marshall et al., 2010). Yet, the extent and specific cause of this partial unsealing issue also remains unknown.

A potential link exists between the observed partial unsealing of field shingles and field shingle cracking issues reported in the early 1990s (Koontz, 1990). This report noted the formation of cracks on the face of three-tab shingles emanating from the end joint of the shingle course below (Koontz, 1990). The cause of the failure was attributed to an internal tensile failure of the reinforcement mat due to long-term thermal cycling of the asphalt shingle strip (Koontz, 1990). As with all other materials, shingles expand when heated and contract when cooled (Cullen, 1963); however, the precise expansion/contraction rate for asphalt shingles remains unpublished. Due to the horizontal offsets placed between shingle courses, each shingle strip is bonded along the sealant strip line to two separate shingle strips on the course below. Heating and cooling of the shingle will impart a differential movement relative to the two adjacent shingle strips, and, as a result, in-plane shear stress is applied through the sealant strip to the upper shingle's surface. For shingle cracking, the tensile strength of the reinforcement was less than the shear capacity of the sealant strip. In response, manufacturers increased the tensile strength of the fiberglass reinforcement mat. However, thermal cycling still exists, however.

The objective of this study was to evaluate the adhesive performance of naturally aged asphalt shingle sealant strips on residential structures throughout Florida. Twenty-seven asphalt shingles roof systems were surveyed in-situ to detect the presence of adhesion along the sealant strip line for shingles in the field of the roof and along the hip and ridge lines. The surveyed residential structures were occupied single-family residential structures that were acquired either through a Florida Department of Emergency Grant or through personal contact with the authors. The roof slopes ranged from 4:12 to 7:12. Roof ages were distributed as follows: one month to six years (six roofs), seven years to thirteen years (nine roofs), fourteen years to twenty years (seven roofs), and unknown age (five roofs). Ten roofs were three-tab style, while seventeen were laminate style. The following sections detail the survey method, results, discussion, and conclusions regarding the long-term adhesion performance of asphalt shingles sealant strips.

SURVEY METHOD

The purpose of the survey was to develop a boolean sealed or unsealed result, as opposed to a direct measurement of uplift resistance. The non-destructive survey method consisted of personnel using their fingertips to gently apply upward finger pressure along the leading edge of each field, hip, and ridge shingle installed on the roof (Figure 2). Due to the flexibility of asphalt shingles, an unsealed shingle, even partially so, provided nearly zero resistance to uplift and therefore only a small application of uplift force was required. Shingle temperature was recorded throughout each survey; however, no correlation was established between shingle temperature and patterns of unsealed shingles. A partially unsealed shingle was defined as any loss of adhesion on the shingles strip (for laminate) or tab (for three-tab) that was greater than or equal to a continuous 51 mm (2 in) length of sealant. A fully unsealed shingle was defined as the loss adhesion along the entire length of the sealant strip. For each unsealed shingle, the location of the shingle strip on the roof, total length of unsealing, location of unsealing on the strip (i.e., left corner, middle, etc.), and failure mode of the unsealed strip was noted on a roof plan. Each unsealed shingle was also marked on the shingles top surface, where unsealed, using a small strip of colored tape to assist with unsealed pattern recognition and photograph records.

Figure 2. Partially unsealed field shingle discovered during a survey.

RESULTS

Unsealing of Field Shingles

Two distinct, nonrandom, patterns of partially unsealed shingles were observed on 70% of the roofs surveyed and were found on both three-tab and laminate shingle systems. As shown in Figure 3, the patterns (marked with blue painter's tape) corresponded to the method of shingle installation. Vertically installed shingles (i.e., racked) had vertical patterns of partial unsealing, while diagonally installed shingles had diagonal patterns of partial unsealing. Given the random nature of selecting roofs to survey these patterns are likely independent of shingle manufacturer and installer. The newest roof that contained the unsealing patterns was six years old, and the total percentage of shingle strips containing the unsealing patterns – for known roof ages – ranged from less than 1% for a six year old roof to over 79% for a 20 year old roof (Figure 3).

For three-tab shingles, the partial unsealing occurred on the extreme end tab of the strip where the end joint of the shingle course below aligned with the centerline of the tab (Figure 4a). Thus, only one tab of the three within each strip was partially unsealed. In general, the remaining two strips were well sealed along their entire lengths. As shown in Figure 4a, unsealing initiated from the shingle strip's end joint to end joint of the shingle course below – approximately 152 mm (6 in) was unsealed. Laminate shingles exhibited a similar pattern of partial unsealing with the unsealed length running from the end joint of the strip to the end joint of the shingle course below (Figure 4b). The resultant unsealed length for laminate shingles, therefore, was controlled by the horizontal offset that was selected to install the system – typically 102 mm (4 in) to 178 mm (7 in). In general, the unsealing ceased in both three-tab and laminate shingles at the end joint of course below; however, unsealing beyond this end joint was observed on older roof coverings. The failure mode for all field shingles exhibiting the noted unsealing patterns was a cohesive failure in the sealant.

Figure 3. Patterns of partially/fully unsealed three-tab and laminate shingles. (Note: blue tape denotes location of unsealing).

(a) (b)

Figure 4. Location of partial unsealing for (a) three-tab and (b) laminate shingle systems.

To evaluate the role of natural weathering on the observed unsealing, the age of each shingle roof surveyed was determined from publicly available building permit records and information provided by the homeowner. Unsealing statistics from surveys conducted on roofs with unknown ages were not included in this analysis. For each home, the total percentage of unsealed shingle strips – either fully or partially – was calculated by dividing the count of the total number of shingle strips with unsealing by the total number of strips installed on the roof. The total percentage of unsealed shingle strips stratified by roof age is shown in Figure 5. The plot indicates a general increase in the percentage of unsealed shingles as the roof age increases. Recall, unsealing patterns were not observed on roofs less than six years old. The total percentage of unsealing for all roofs with less than six years of aging is less than 1% while roofs with greater than six years of aging had up to 79% of the shingle strips with either full or partial unsealing. The variability of data set appears to increase with roof age as well.

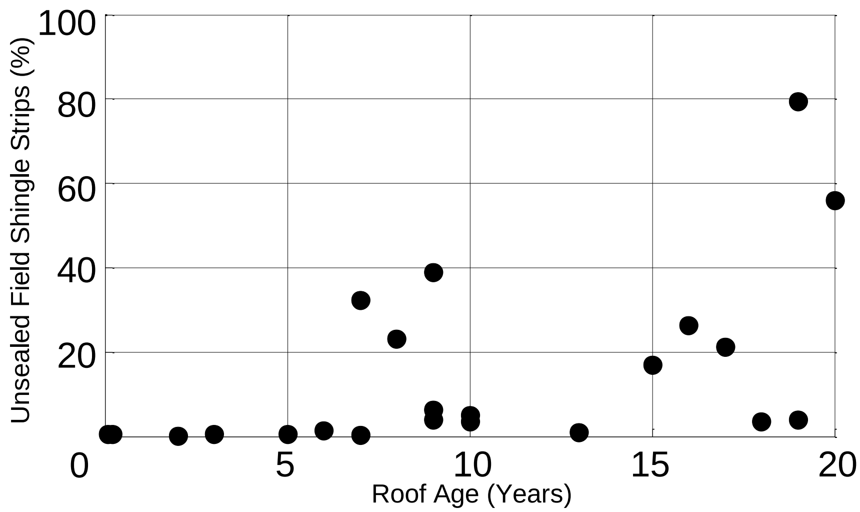

Figure 5. Percent of unsealed shingle strips located in the field of the roof verses roof age. (Note: fully and partially unsealed shingles combined)

Finally, the roofs were grouped into age ranges (0-6 years, 7-13 years, and 14-20 years) to evaluate the statistical significance of the perceived increase in unsealing with increasing roof age. The results of single sided t-test assuming unequal variances ($\alpha = 0.05$) indicates that a statistically significant increase occurred in both the 7-13 and 14-20 year old roofs when compared to the 0-6 year old roofs (Table 1). However, significance was not established between the 7-13 and 14-20 groups.

Table 1. Statistical comparison between grouped roof ages

Roof Age Range (Years) [No. of Roofs]	Mean Amount of Observed Unsealing (%) [σ]	Statistically Significant Increase Between 0-6 Year Old Roofs (P-Value)[a]	Statistically Significant Increase Between 7-13 Year Old Roofs (P-Value)[a]
0-6 [6]	0.7 [0.4]	--	--
7-13 [9]	11.8 [14]	Yes (0.017)	--
14-20 [7]	29.6 [28]	Yes (0.017)	No (0.080)

[a]Statistical significance determined using T-Test single sided test with unequal variance with $\alpha = 0.05$

Unsealing of Hip and Ridge Shingles

Unsealed hip and ridge cap shingles can be classified into two categories: (1) lack of sealant under the leading edge of the shingle cap (Figure 6a), or (2) adhesive failure between the sealant and underside of the cap near the cap's edge (Figure 6b). The lack of sealant can be attributed to the installation method of the shingle system, while the adhesive failures indicate that the cap shingles suffer from a weak bond between the sealant and underside of the cap. The adhesive performance of the sealant located directly on the hip/ridge line was superior to the adhesion towards the edges of the cap.

(a) (b)

Figure 6. Typical unsealed ridge and hip cap shingle conditions: (a) no sealant strip below cap and (b) poor adhesion on edges of cap.

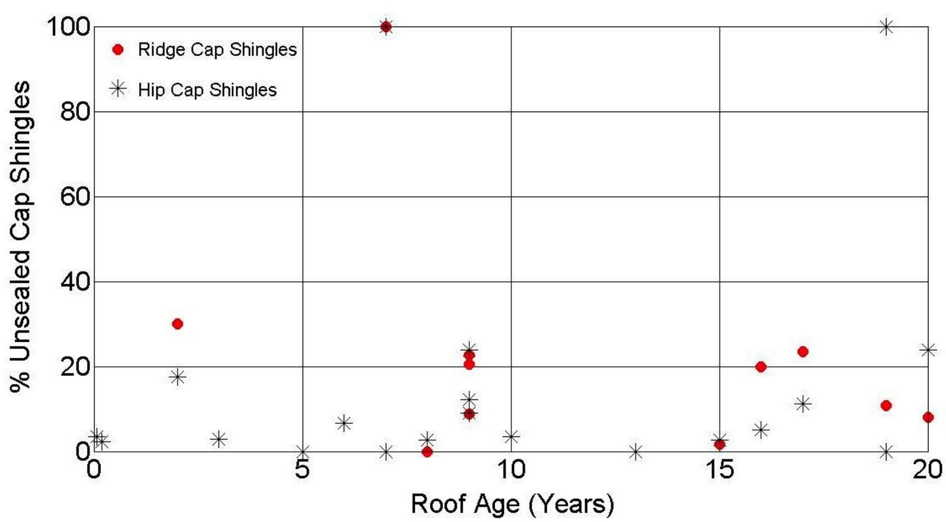

Figure 7. Percent of fully/partially unsealed cap shingles (hip and ridge) verses roof age.

Similar to the field shingles analysis, the total percentage of unsealed hip and ridge cap shingles was calculated for each surveyed roof. Placing this percentage in the context of shingle age it is apparent that no correlation exists between roof age and the percentage of unsealed caps (Figure 7). As expected, hip and ridge cap shingles are equally as likely to be unsealed. Aside from the cap shingles that did not have sealant below their leading edge, the total percentage of unsealing for caps ranged from 0 – 30%.

DISCUSSION

The results detailed above indicate potential issues in the long-term adhesive performance of the shingles sealant strip. This unsealing is likely a result of a systemic failure of the sealant, rather than a random loss of adhesion. Two questions arise: (1) what are the mechanisms that drive the partial unsealing observed in the field and hip/ridge shingles and (2) what is the wind damage vulnerability potential for asphalt shingle roofs containing this unsealing.

First, the mechanisms that drive the partial unsealing in the field shingles and hip/ridge shingles are likely different mechanisms. For field shingles, a statistically significant increase in the total percentage of unsealed shingles was established on older roofs when compared to newer. For hip and ridge cap shingles, no statistical significance between the newer and older roofs was established. Furthermore, the failure mode of partially unsealed field shingles – cohesive failure in the sealant – did not match the failure mode of the hip/ridge cap shingles – adhesive failure in the sealant. It is postulated that the partial unsealing of field shingles reported in this paper and in Marshall et al. (2010) is a result of long-term cyclical thermal movement of the shingle system causing an internal shear failure of the sealant strip material. For hip and ridge cap shingles, poor adhesion at the onset of service life is the most likely cause of their partial unsealing. Field-cut and pre-manufactured cap shingles are originally flat strips that are folded over the hip/ridge line to match the roof slope. Quick bond of the sealant strip is required once the cap has been installed to prevent the cap from reverting back to its original, flat, state. The adhesive failure between the sealant and bottom cap surface indicates that current shingle cap design may not adequately provide this early tack, leaving the edges of the cap vulnerable to unsealing.

Second, the impact of unsealed asphalt shingles on the wind performance of shingle roofs has not been addressed in previous literature. Post-storm damage assessment reports provide the most relevant information; however, their conclusions contain uncertainty as the condition of the damage roof prior to the storm is unknown. Reports by FEMA (2005a, 2005b, 2006, 2009) have consistently noted asphalt shingle wind damage patterns that have striking similarity to the partially unsealed shingle patterns observed in this study (Figure 8). These failures are most often attributed to a lack of fasteners on the end joint of the shingle due the racked installation method. However, as the sealant strip is the primary load path, unsealing of the sealant strip is required before nail placement becomes an issue. Hip and ridge cap failures are the most frequently reported asphalt shingle-related failures in post-storm reports (FEMA, 2005a). The failures are attributed to poor adhesion between the cap and the sealant strip (FEMA, 2005a) – echoing the findings of this study.

Figure 8. Potential link between (top) post-hurricane Katrina damage observed by FEMA (2012) and (bottom) observations of pre-existing unsealing during roof surveys.

CONCLUSIONS

In this study, 27 naturally aged asphalt shingle roofs located on single family buildings in Florida were surveyed in-situ to evaluate the presence of sealing along the asphalt shingles sealant strips. The age of the shingle roof coverings ranged from one month to over twenty-five years.

The study found significant, nonrandom, patterns of partial unsealing in both field and hip/ridge cap shingles. Partial unsealing for field shingles occurred near the end joint of each strip on both laminate and three-tab shingles. The failure mode of the unsealing was a cohesive failure in the sealant, indicating that the shingle was, at one time, fully sealed. The total percentage of partially unsealed shingles on a given roof statistically significantly increased with roof age. Damage patterns from post-storm assessments are similar to the patterns of partial unsealing discovered in this study, suggesting that partial unsealing may be the root cause of observed wind damage of field shingles.

The partial unsealing of hip and ridge cap shingles occurred on roofs of all ages with no correlation established between roof age and the amount of unsealed cap shingles. Partial unsealing occurred on the edges of the caps with good adhesion found on the portion of the cap directly over the ridge line. Failure of hip and ridge caps frequently occurs in below-design level wind storms and adhesion at the beginning of the caps in-service life may define the long-term wind performance.

The results gathered from this study are a critical step towards better defining the cause of asphalt shingle failures in below design-level wind storms. Future work by UF will focus on quantification of thermal movement in asphalt shingles and the expansion of roof surveys to other regions of the United States.

ACKNOWLEDGEMENTS

This research was funded by the Southeast Region Research Initiative (SERRI), which is managed by Oak Ridge National Laboratory for the U.S. Department of Homeland Security, the Florida Building Commission, and the Florida Department of Emergency Management. The authors would like to thank the Jeff Streitmatter II family for their assistance on the procurement of several homes for survey.

Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the sponsors, partners and contributors.

REFERENCES

Engineering Team Report (2009). "Survey of Single Family Residential Buildings in Florida," Submitted in support of the Florida Public Hurricane Loss Model. International Hurricane Research Center (IHRC), Florida International University.

Cullen, W.C. (1963). "Solar heating, radiative cooling, and thermal movement – their effects on built-up roofing." National Bureau of Standards Technical Note 231.

Dixon, C.R., Masters, F.J., Prevatt, D.O., Gurley, K.R. (2010). "An historical perspective on the wind resistance of asphalt shingles." *RCI Interface.* RCI, Inc., pp. 4-14.

FEMA (2005a). "Hurricane Charley in Florida." *FEMA 488*, Federal Emergency Management Agency.

FEMA (2005b). "Summary report on building performance: 2004 Hurricane Season." *FEMA 490*, Federal Emergency Management Agency.

FEMA (2006). "Hurricane Katrina in the Gulf Coast." *FEMA 549*, Federal Emergency Management Agency.

FEMA (2009). "Hurricane Ike in Texas and Louisiana." *FEMA 757*, Federal Emergency Management Agency.

FEMA (2012). "Home builder's guide to coastal construction." *FEMA P-499*. Federal Emergency Management Agency.

Koontz, J.D. (1990) "Shingle splitting problem." *Western Roofing Magazine.*

Marshall, T.P., Morrison, S.J., Herzog, R.F., Green, J.R. (2010). "Wind effects on asphalt shingles." *29th Conference on Hurricanes and Tropical Meteorology.* American Meteorological Society.

Peterka, J.A., Cermak, J.E., Cochran, L.S., Cochran, B.C., Hosoya, N., Derickson, R.G., Jones, J., Metz, B. (1997). "Wind uplift model for asphalt shingles." *Journal of Architectural Engineering*, pp. 147-155.