Wind Resistance of Asphalt Roof Shingles

Craig R. Dixon [a], Dany Romero [b], Forrest J. Masters [c], David O. Prevatt [d], Kurtis R. Gurley [e]

[a]*University of Florida, Gainesville, FL, USA, craigdixon@ufl.edu*
[b]*University of Florida, Gainesville, FL, USA, dromero22@gmail.com*
[c]*University of Florida, Gainesville, FL, USA, masters@ce.ufl.edu*
[d]*University of Florida, Gainesville, FL, USA, dprev@ce.ufl.edu*
[e]*University of Florida, Gainesville, FL, USA, kgurl@ce.ufl.edu*

1 INTRODUCTION

Roof coverings represent the single most critical line of defense against property damage from high winds and rain. The asphalt glass fiber shingle roof is by far the most common residential roof covering system along the hurricane prone U.S. coast, having had the dominate market share (in 2001) for steep-slope roofing with 44.9% for new construction and 50.4% for re-roofing (Cash, 2000 & 2003). Although the performance of asphalt shingles has been addressed in recent code modifications, the issue of acceptable performance is far from resolved. At present, a substantive, documented correlation between standard shingle testing procedures and actual hurricane conditions does not exist. Therefore, tests applied to asphalt shingles (and most other roofing systems) may not determine the performance of asphalt shingles during hurricanes. A complicating factor is the long-term environmental exposure and aging of shingles, as testing of new shingles does not indicate wind performance several years after installation. This paper presents an overview of a multi-year research initiative that will investigate the performance of asphalt roof shingles exposed to windstorm conditions and natural and artificial aging.

1.1 *Previous Research*

The first model for the asphalt shingle wind uplift mechanism was proposed by Cermak et al. (1983). During a wind event, localized flow separation occurs as wind flow just above the roof surface encounters the leading edge of the asphalt shingle. The result is differential pressure acting on the shingle causing uplift loading on the shingle surface. Work conducted by Peterka et al. (1997) in the mid-1990's validated this model using a combination of model and full-scale tests to assess the behavior of wind on the asphalt shingle roof surface. From this work, ASTM D 7158 – *Standard Test Method for Wind Resistance of Asphalt Shingles (Uplift Force/Uplift Resistance Method)* was developed and currently serves as the wind uplift test standard for asphalt shingles. However, Peterka et al. noted several limitations to their experimental. They include an explanation for significant asphalt shingle uplift pressures recorded during full-scale outdoor tests for wind flow approaching the leeward side of the gable roof and wind flow parallel to the ridgeline. This limitation was attributed to their use of unidirectional wind velocity sensors that did not provide accurate wind flow measurements beyond their installed orientation. Additionally, how aging affects the wind uplift resistance of asphalt shingles has yet to be quantified.

The damaging effect of aging on physical and chemical properties of asphalt shingles was shown by Terrenzio et al. (1997) and Shiao et al. (2003). The results of their natural and accelerated aging tests showed that as asphalt ages, an oxidation reaction occurs in the asphalt resulting in an embrittlement of the entire shingle. Understanding the effect of this embrittlement and other chemical and physical changes in the shingle during aging may explain the results of several post-hurricane damage studies; which noted that older asphalt shingle systems performed worse than newer (FEMA, 2005). The reason for this performance gap may be attributed improved manufacturing and testing standards or it may be attributed to aging effects that adversely affect the shingle's wind uplift resistance. The goal of the project outlined in this paper is to address the critical knowledge gaps that exist in order to better understand the performance of asphalt shingles in wind throughout their intended lifespan.

2 PROJECT OVERVIEW

The project "Residential Roof Covering Investigation of Wind Resistance of Asphalt Shingles" is led by the University of Florida in collaboration with several academic, government, and private institutions. An advisory panel from multiple stakeholder groups was formed to provide oversight and to establish buy-in from all stakeholders that may be affected by this research project. The project is separated into nine tasks over a three year timeframe. The five major experimental tasks are outlined below.

2.1 *Characterization of Airflow near the Roof Plane*

Shingles fail for a number of reasons, including tear-off and fastener pull-through. These failures are initiated by the localized wind effects on individual shingles in a very complex flow environment. Solutions to solve weaknesses in shingle performance must ultimately come from a clear understanding of the interplay between the wind loads and the shingle's capacity to resist these loads.

Until recently, the technology has not been available to make comprehensive, high-resolution measurements to characterize the temporal and spatial variability of the airflow just above the roof. This will be provided via the Particle Image Velocimetry (PIV) system at the University of Western Ontario (UWO). UWO's new PIV system can take 10,000 simultaneous 3D velocity measurements at 500 Hz without disturbing the flow. This system will capture the correlation structure of the wind field, which will be important in the determination of the expected overall performance of the roof covering.

2.2 *Dynamic Testing of New and Existing Roof Sections*

Using the results of Section 2.1, UF will design and construct a dynamic shingle testing system to evaluate uplift resistance using realistic turbulent load conditions (Figure 1). Tests will be conducted on new, artificially and naturally aged roofing shingles to validate/refine the test procedure outlined in ASTM D7158, and diagnose causes of shingle failure in a controlled wind hazard environment. The hurricane wind load simulation system will thus provide the bridge between realistic wind load conditions, shingle performance, and the current standard of practice for testing shingle products.

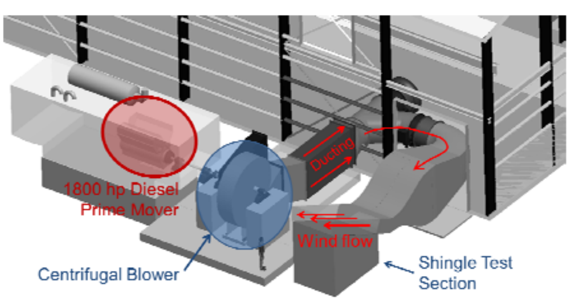

Figure 1. Conceptual rendering of the dynamic testing apparatus.

2.3 *Investigation of the Performance of Naturally and Artificially Aged Roof Shingles*

The objective of this task is to quantify the effects of aging on the wind uplift resistance of lightweight three-tab fiberglass asphalt shingles. The goal is to better understand how weathering affects the performance of shingles in extreme wind events. Shingle samples prepared in conformance with ASTM D 6381 will be continuously heated in a forced air dark oven for up to 12 weeks. Samples will be removed on a set schedule for testing of mechanical uplift resistance (ASTM D 6381) and rigidity (ASTM D 7158). Chemical composition (modified ASTM D 4124 / Gel Permeation Chromatography) and rheological property (ASTM D 7175) tests will be conducted on asphalt samples to quantify fundamental changes that occur in the asphalt during aging. For comparison, asphalt shingle samples will be placed outdoors for natural aging for up to 5 years. Combined heat, UV and water tests, which are other potentially damaging natural weathering effects, are also planned. Also part of this task is the field evaluation of existing shingle roof systems for mechanical wind uplift resistance. The goal of this portion of the task is to characterize the performance of naturally aged roof systems and link these results with the laboratory aged shingle results.

2.4 *Testing of New and Existing Roof Specimens in the IBHS Research Center*

Full-scale shingle roof systems installed on residential structures will be constructed, aged, and tested at the IBHS Research Center. The research center consists of a large open jet wind tunnel. The jet passes through a large test chamber designed to allow air flow to expand around the test object before the flow exits through an outlet. An array of 105 actively controlled, 1.5 m diameter electric fans provide along-wind gusts and lateral flow variation. Full-scale test specimens may be subjected to winds up to 62.6 m/s. Initial tests will revisit Peterka et al.'s work by measuring simultaneous shingle uplift pressures and near surface three component wind velocities, providing a refined asphalt shingle wind uplift model. Testing of common roof features such as roof penetrations and flashing details will also be conducted to quantify the effects of roof details on asphalt shingle behavior.

2.5 *Conduct Post-Hurricane Forensic Surveys of Residential Building Stock*

Working in coordination with FEMA Mitigation Assessment teams, post-hurricane roof cover damage assessments will be conducted on residential structures. The purpose is to ascertain the performance of asphalt shingle roofs. This task additionally provides a framework to address regional difference in shingle performance. This is a critical element of the projects overall goal of improving asphalt shingle performance during wind events. It will provide a source of "ground truth" that will complement the work conducted in the laboratory. Similar studies were conducted by the University of Florida during Hurricanes Gustav and Ike in 2008. Nearly 1000 homes were surveyed within 36 hours of landfall and compared to aerial imagery collected by FEMA. Preliminary data is shown in Figure 2 to illustrate the type of information that can be gathered. Figure 2 contains a bar plot of damage states versus the age of the roof for Hurricane Ike. It is clearly evident that new roofs (< 5 years) performed adequately, yet older roofs experienced damage.

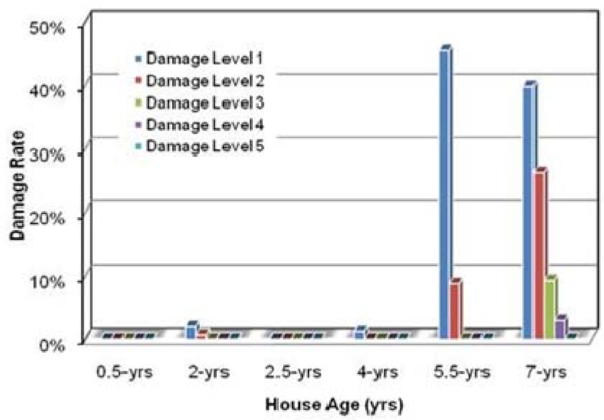

Figure 2. Damage to asphalt shingle roofs as a function of age in Hurricane Ike.

3 CONCLUDING REMARKS

This paper will present an overview of a new research project investigating the wind uplift performance of asphalt shingles. The holistic approach of the project combines investigations of aging effects, refined flow field studies, full-scale testing, and post-storm assessments to advance the knowledge of asphalt shingles. Further project details and preliminary results will be detailed in the full paper.

4 ADKNOWLEDGEMENTS

The authors greatly appreciate the funding for the project provided by the Southeast Region Research Initiative through Oak Ridge National Labs and the Department of Homeland Security and the funding provided by the Florida Building Commission.

5 REFERENCES

Cash, C. G. (2000). "Estimating the Durability of Roofing Systems." *Durability 2000: Accelerated and Outdoor Weathering Testing*(1385).

Cash, C. G. (2003). *Roofing failures*, Spon Press, London ; New York.

Cermak, J. E., Peterka, J. A., and Hosoya, A. (1983). "Wind-tunnel study of wind pressures on roofing shingles." Fluid Mech. and Wind Engrg. Program, Colorado State Univ., Fort Collins, Colo.

FEMA (2005). "Summary Report on Building Performance: 2004 Hurricane Season." *FEMA 490*, Federal Emergency Management Agency, 68.

Peterka, J. A., Cermak, J. E., Cochran, L. S., Cochran, B. C., Hosoya, N., Derickson, R. G., Harper, C., Jones, J., and Metz, B. (1997). "Wind Uplift Model for Asphalt Shingles." *Journal of Architectural Engineering*, 3(4), 9.

Shiao, M. L., Nester, D. A., and Terrenzio, L. A. (2003). "On the Kinetics of Thermal Loads for Accelerated Aging." *Roofing Research and Standards Development*, 1, 17.

Terrenzio, L. A., Harrison, J. W., Nester, D. A., and Shiao, M. L. "Natural vs. Artificial Aging: Use of Diffusion Theory to Model Asphalt and Fiberglass-reinfoced Shingle Performance." *Proc., Fourth International Symposium on Roofing Technology*.