

Ongoing Research at the University of Florida Directed Toward the Wind Resistance of Asphalt Roof Shingles

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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 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-1990s 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. (1997) noted several limitations to their study. 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 systems (FEMA, 2005, Gurley and Masters, 2011). The reason for this performance

gap may be attributed to improved manufacturing and testing standards or it may be attributed to aging effects that adversely affect the wind uplift resistance. The goal of the project outlined in this paper is to address the critical knowledge gaps that exist 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. The project is separated into two phases over a three year timeframe. The seven major experimental tasks are outlined below.

2.1 Characterization of Airflow near the Roof Plane

Shingles fail in strong winds 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 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 (Figure 1). 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.

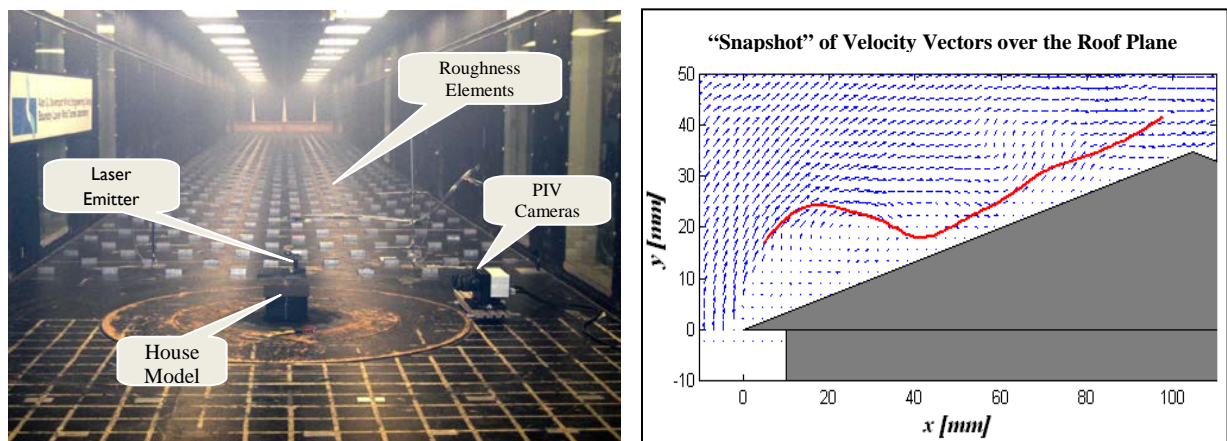


Figure 1. Particle Image Velocimetry Study at the University of Western Ontario

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 2). Tests will be conducted on new and artificially and naturally aged roofing shingles to validate/refine the test procedure outlined in ASTM D7158 (2008) and diagnose causes of shingle failure in a controlled wind environment. The hurricane wind load simulation system will provide the bridge between

realistic wind load conditions, shingle performance, and the current standard of practice for testing shingle products. The two experiments utilizing this apparatus are outlined in Sections 2.2.1 and 2.2.2.

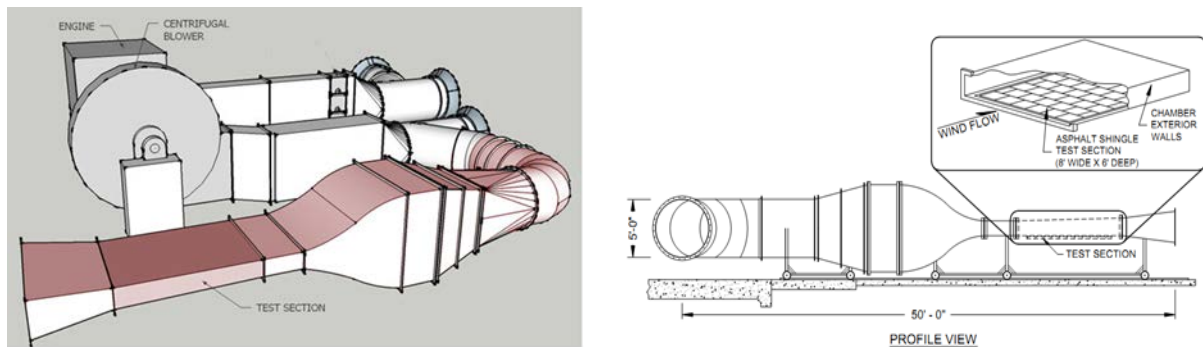


Figure 2. Conceptual rendering of the dynamic testing apparatus.

2.2.1 Effectiveness of Resealing and Roof Repair

FEMA P-757 (2009) provides evidence of premature failure of asphalt shingle roof systems. However, the root cause(s) of the failures (of Class H rated shingles in estimated maximum wind speeds of 110 mph) was not identified. A possible factor may be the inadequate performance of the self-sealing adhesive on the shingles. The commonly held assumption is that in properly installed asphalt shingle roofs, all tabs are sealed and the self-sealing adhesive strips are fully activated. However there is little data available to confirm this. The industry recognizes that cooler weather (between September and April) can delay shingle sealing until warm summer temperatures return. Left unsealed, the seals may accumulate a layer of airborne dust that could further delay or prevent sealing. To avoid this, shingle manufacturers may specify using field-applied adhesives (applied in quarter-sized dabs to the back corner of each tab) when shingles are applied during cold months, or if immediate sealing is desired. A forensic investigation will be conducted to quantify the extent of unsealed tabs in typical asphalt shingle roof installations. The study will also identify and record the location and numbers of unbonded tabs on the roof, and determine (if possible) the plane within the adhesive that failed (i.e. adhesive, cohesive failure in adhesive strip or cohesive failure within the shingle). The results of this forensic study will be used to establish the expected parameters (e.g. % of unbonded tabs) and to develop specimens for wind simulation testing in the dynamic testing apparatus that are representative of a typical asphalt shingle roof. The results of this experiment will lead to the development of an effective maintenance approach to reseal unbonded tabs and minimize future shingle tab sealant failures.

2.2.2 Effect of Fastening Schedule and Edge Detailing

There are two ASTM test methods available for evaluating asphalt shingle resistance to fastener rupture and tearing: a) ASTM D 4932-89 (2006), used to determine fastener rupture and tear resistance of roofing materials, including asphalt shingles, and b) ASTM D 3462 (2010a) for determining the fastener pull-through resistance for gravel-surfaced shingles made with glass felt. Of these tests, the latter test has been more commonly used by asphalt shingle manufacturers and reported in their specifications. Both methods determine the required force to pull a fastener through the shingle under specific laboratory conditions, and they are predominantly used on new (unweathered) shingle specimens. To the best of the authors' knowledge, no tests results are available that establish the tear, rupture or pull-through resistance of fasteners installed in weathered or aged asphalt shingles. This experiment will seek to calibrate the tear and rupture resistance of asphalt shingles as established from standard tests against the wind resistance of asphalt shingles that are subjected to dynamic wind speed fluctuations. A secondary goal is to

establish the effect of crosshead displacement rate on wind resistance in laboratory tests. The study will help define how unsealed asphalt shingles resist failure at their fastener locations in extreme wind events, and will serve as a basis for additional tests on thermally aged shingles. Asphalt shingle specimens from three manufacturers will be tested. In this round of testing only new shingles will be used. The test matrix will include tests at the standard crosshead displacement rate (i.e., 1 in./min), two additional constant crosshead displacement rates and one fluctuating crosshead displacement for each test protocol. In all, 30 specimen repeats are required for each shingle type/displacement rate combination for 720 tests on 7 in. long by 4 in. wide shingle specimen pieces. The results will be analyzed to identify trends in failure resistance and compare against the wind resistance of installed shingles subject to realistic extreme wind speed fluctuations. The results will also be used to establish a correlation (if any) between the two test methods, ASTM D 4932 and ASTM D 3462. A second component of testing will be conducted on aged asphalt shingles to determine whether tear and rupture resistance is affected by thermal aging over time. The final component of the research will evaluate the performance of fasteners using the dynamic testing apparatus (Figure 2).

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 experiment began on January 27, 2011, with the goal of better understanding how weathering affects the performance of shingles in extreme wind events. Shingle samples wind rated as ASTM D7158 Class H (2008) from three major shingle manufacturers were prepared in conformance with ASTM D 6381 and placed in a forced air dark oven for continuous heating of 70 degrees Celsius (158 degrees Fahrenheit) for up to 20 weeks. Samples were 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 were conducted on asphalt samples to quantify changes that occur in the asphalt during aging. The initial uplift resistance results for specimens aged up to 7 weeks show no apparent relation between uplift resistance and thermal aging time (Figure 3). The increase in asphalt shingle stiffness over aging time shown in Figure 4 agrees with the results of Shiao et al.'s (2003) experiments of asphalt shingle thermal aging.

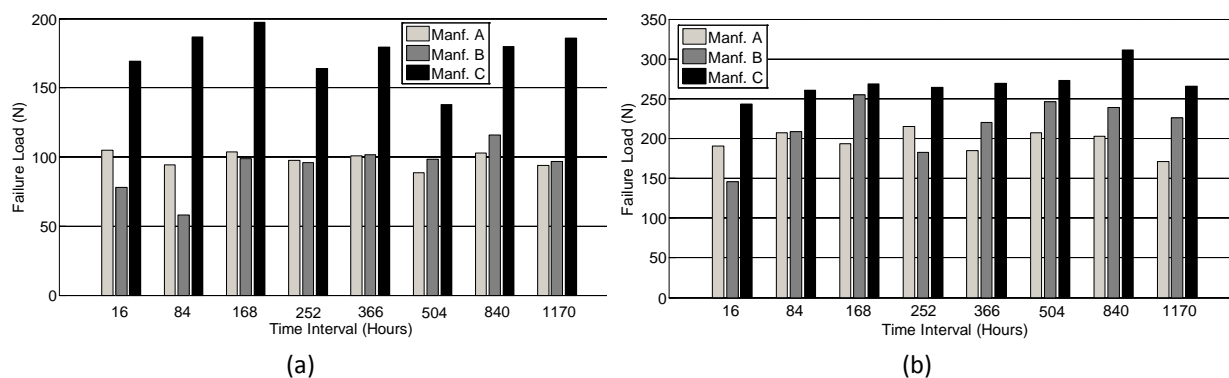


Figure 3. Initial results of ASTM D6381 (a) Procedure A and (b) Procedure B mechanical uplift tests on thermally aged asphalt shingles. (1 week = 168 hours)

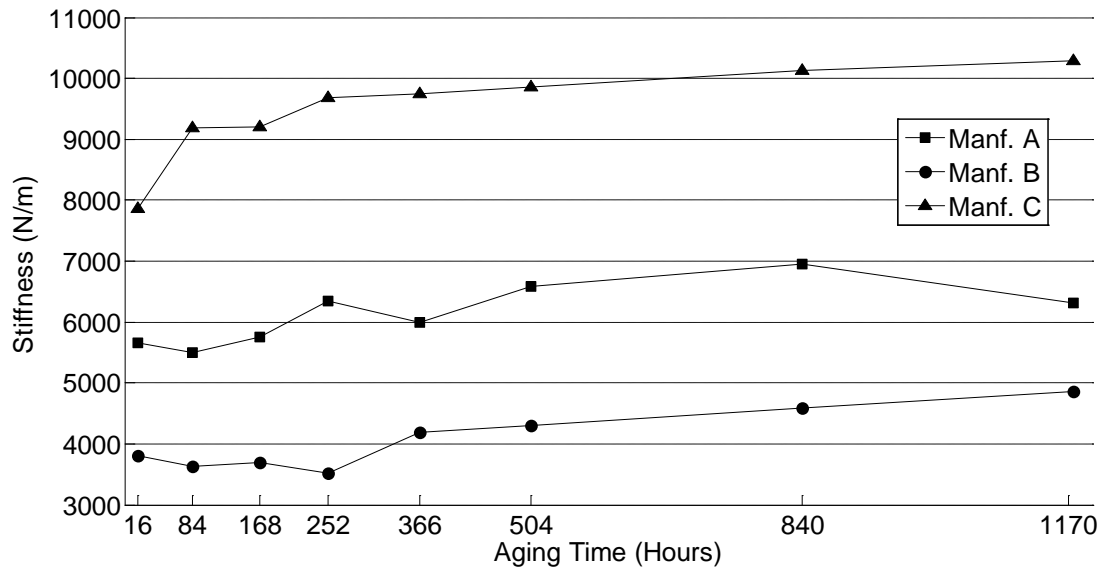


Figure 4. Initial results of asphalt shingle stiffness tests as a function of aging time. (1 week = 168 hours)

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 Fatigue Resistance of Asphalt Seals

Although dynamic loading is a recognized important issue for many building components and cladding (Letchford and Norville, 1994), the mechanical uplift resistance of asphalt shingles subjected to dynamic loading has received very little attention in the peer-reviewed literature. Prior experimental research has largely focused on static uplift tests (Shiao et al., 2004) or short duration wind loading (Peterka et al., 1997). This project will provide a statistical quantification of the expected performance of shingles subjected to a continuous, time-varying load sequence and relate that performance back to the results of simplified testing (i.e. ASTM D 7158). Two segmental, non-overlapping 20 minute mean velocity records will be derived empirically from historical hurricane track and intensity records for two representative sequences (Figure 5):

- a. Case 1) a compact intense hurricane representative of a design level event
- b. Case 2) a broader non-design level event hurricane

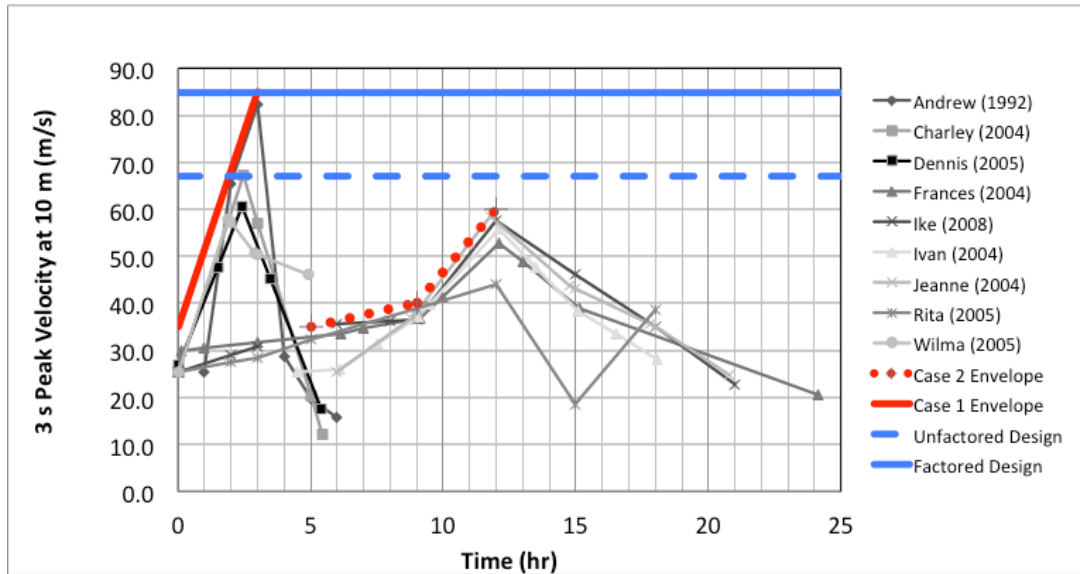


Figure 5. Peak gust values for historical hurricanes and current design requirements

The fluctuating velocity parallel to the roof plane will be extracted from wind tunnel particle image velocimetry (PIV) measurement experiments described in Section 2.1. The velocity sequences will be converted to test load sequences by adapting the Peterka et al. (1997) method for time series analysis. Separate load sequences will be developed for the Procedure A and B samples described in ASTM D 7158 (2008). The dynamic load sequence will then be applied to shingle samples using a control system that applies load with a Tritex TLM20 electric linear actuator and receives feedback from an inline load cell. Standardized mechanical uplift testing following ASTM D7158 (2008) will also be conducted on asphalt shingle specimens for comparison.

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

Two full-scale asphalt shingle wind experiments will be conducted at the Insitute for Business & Home Safety (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 airflow 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. The first test, led by Dr. Tim Reinhold (IBHS), will revisit Peterka et al.'s work by measuring simultaneous shingle uplift pressures and near surface three component wind velocities (using four TFI Cobra Probes), providing a refined asphalt shingle wind uplift model. The second experiment is directed toward quantifying damage to asphalt shingle roof systems subjected to extreme wind events. Nine hip and nine gable 6:12 half roof sections will be constructed and naturally aged at IBHS for one year. A one story base structure with plan dimensions of 12.2 m x 9.1 m (40 ft x 30 ft) will accommodate the half roof sections during testing in the IBHS Windstorm Simulator (Figure 6). Two architectural and one three-tab fiberglass shingle system will be compared for this study. Each shingle system will be subjected to three wind angles (parallel to ridge, perpendicular to ridge, and cornering) and three wind speed thresholds (estimated 40 m/s (90 mph), 50 m/s (110 mph) and 60 m/s (134 mph)) at 10 m. A forensic assessment will be carried out following each test.

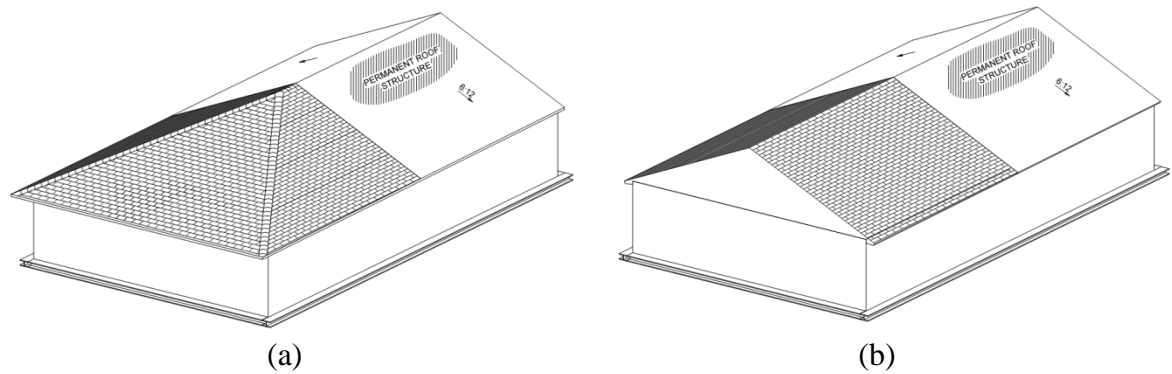


Figure 6. Half roof test sections installed on base structure (a) hip (b) gable

2.6 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 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.

3 CONCLUDING REMARKS

This paper presented 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 new and aged asphalt shingle performance in high winds. More information on this project is available at asphaltshingles.windengineer.org.

4 ACKNOWLEDGEMENTS

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