# ARMA'S NEW APPROACH FOR EVALUATION OF ASPHALT SHINGLE WIND RESISTANCE

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For several years there has been pressure on shingle manufacturers to increase the wind resistance rating of their product. The most commonly suggested approach has been to simply increase the fan speed of the current test methods (ASTM D3161 and UL 997). The Asphalt Roofing Manufacturers Association (ARMA) Research Committee formed a High Wind Task Force to evaluate the situation and recommend an appropriate course of action. It was quickly determined that increasing the fan speed of the standard tests was unacceptable due to the method's inability to mimic the complexity of actual wind conditions. The task force addressed two issues: how to measure shingle tab uplift resistance and quantification of the uplift forces exerted by the wind.

To measure the uplift resistance, a test method was refined and proven through round-robin testing. The method allows for flexibility in sample conditioning temperatures for a thorough sealant evaluation. In order to quantify the uplift forces, ARMA is sponsoring a research study at Colorado State University (CSU). Some of the round-robin test results and the research plan are presented.

**KEYWORDS**

ARMA (Asphalt Roofing Manufacturers Association), ASTM D 3161, High Wind Task Force, Meteorological Wind Tunnel (MWT), shingle tab uplift resistance, wind speed, wind uplift.

## BACKGROUND

One of the important performance factors for any building or structure is the ability to withstand expected wind forces. As a rule, the model building codes in the United States require a minimum structural integrity sufficient to withstand the force generated by wind as a function of the basic wind speed, gust response factor, exposure as influenced by surrounding terrain and building height. The basic wind speed specified for structural design ranges from 31 to 40 m/s (70 to 90 mph) in large portions of the United States, and may be 45 m/s (100 mph) or higher in hurricane-prone areas.

Historically, residential roofing shingles have been tested and certified wind resistant at a maximum wind speed of 27 m/s (60 mph). Two test methods, which are essentially identical, commonly used to measure this performance are ASTM D 3161 and UL 997. These tests are rather simple and straightforward. A small, rectangular deck (1.27m x 1.68m) (50 in. x 66 in.) is covered with shingles applied in accordance with the manufacturer's instructions. This deck is then heat conditioned for 16 hours at 57°C-60°C (135°F-145°F). After returning to room temperature, the deck is maintained at a 17 percent (2:12) slope while air at a velocity of 27 m/s (60 mph) is horizontally blown against the leading edges of the shingle tabs for a period of two hours. A passing result is obtained if the assembly restrains full shingle tabs from lifting, tearing loose or disengaging. Use of this testing criteria served the residential roofing market for many years.

However, beginning about five years ago and with gradually increasing intensity since, there has been pressure brought to bear upon shingle manufacturers to increase the wind speed of their shingle products. This pressure primarily manifested itself through the code bodies and various insurance groups. The first proposals discussed to achieve higher ratings were simply to increase the air velocity of the traditional ASTM D 3161 and UL 997 test methods. This approach, however, was not appealing to the technical representatives of most shingle manufacturers, many of whom are members of the ARMA Research Committee.

With the current shingle product, there are instances of shingle blow-off at wind speeds less than the rated 27 m/s (60 mph). After discounting those instances with obvious explanations such as application errors, cold weather application or manufacturing defects, there remains a body of empirical evidence of failures. These failures primarily fall into a largely predictable pattern on roofs, such as near eaves, rakes and edges. This pattern was also demonstrated and documented as a result of Hurricane Hugo.[1]

The empirical evidence was pointing to a basic weakness in the ASTM D 3161 method. Natural wind includes factors of variable intensity, duration, direction and turbulence. Also, roof geometries can add a multiplying effect to these natural variances. In contrast, the traditional tests are a constant velocity, perpendicular approach, non-separated flow impinging on a single-planed deck maintained at a constant slope.

The above factors were the genesis behind the formation of ARMA's High Wind Task Force. Fortunately, the task force did not have to start with a blank slate. Research work performed by Lamb and Noe[2] at Colorado State University (CSU) laid a good foundation for understanding the basic forces that are in play. Most of the other previously published work on wind forces studied large, separated flows with the emphasis directed toward the uplift pressure effects on monolithic commercial roofing. Lamb's work demonstrated that the very nature of shingled roofs allowed for nearly instantaneous pressure equalization. It was found that the forces affecting shingles were the local flows within 50mm (2 in.) of shingle surfaces. As air flows over shingles, positive pressure is created at the leading edge and beneath the tab, while air flowing over the top creates a zone of low pressure. If these net effects are greater than the combined forces of shingle weight, stiffness and sealant bond strength, failure is imminent. Thus, the challenge for ARMA came into focus. The ultimate goal is establishing a relationship between wind speed and shingle tab uplift resistance. This relationship must also factor in the complications of shingle and roof geometry along with natural wind effects. The approach being used is to separate the project into two tasks. The first task, largely completed, is development of a test that quantifies shingle tab uplift resistance. The second task, just beginning, is a wind tunnel research study that will help define the uplift forces. This work is intended to provide the relationship between model building code wind loads and the corresponding required shingle tab uplift resistance.

## TAB UPLIFT RESISTANCE

The test developed to quantify uplift resistance uses two pieces of shingle that are 95mm (3.75 in.) wide. The pieces are overlapped in such a manner that the factory-applied sealant is covered as it would be in an actual roof application. The specimens can then be subjected to heat conditioning at any temperature and duration selected by the tester. Following the heat conditioning, the overlaid samples can be further conditioned at another temperature, typically the temperature at which the test will be conducted. The samples are then positioned in a machine that will exert a peeling force mimicking the action of the uplift motion caused by wind forces (Figure 1). The measured quantity includes the factors of shingle weight, stiffness and sealant bond strength. If the sealant bond is strong enough, the test measures the force necessary to tear the shingles apart. The test offers the user great flexibility with conditioning, and as such, is a useful research and development tool. Recently, a task group in ASTM D.08.02 began the process of turning this test method into an ASTM Standard.

The ARMA High Wind Task Force organized a round-robin test program to refine the test and determine the repeatability and reproducibility. The round-robin involved six testing labs and seven different sets of shingle samples. Each testing lab pulled 10 test specimens from each sample set. Figure 2 is a histogram of the average ($n = 10$) uplift resistance for each sample set as reported by the six labs. Figure 3 shows the data clustered in their sample sets and illustrates the test's reproducibility. The conditioning for these tests allowed for 16 hours at 57°C (135°F) followed by two hours at 22°C (72°F). These conditions were chosen to provide a relative measure between the uplift resistance and the conditions specified by ASTM D 3161. In an analysis of the entire population of data, one standard deviation equaled 30.8 percent of the mean. Of this variation, 63 percent resulted from differences in the shingle samples, 13 percent was from differences in the testing facility, and 24 percent was testing error.

The ARMA task force has also devised minor variations to the basic test method in such a manner to mimic common shingle application deficiencies. These include over- and under-driven fasteners, or improperly positioned fasteners. Although the task force has not yet performed a round-robin, preliminary results indicate that upwards of 80 percent of the bond strength provided by the sealant can be lost due to these conditions. This work will be expanded and should reinforce the importance of proper manufacturing coupled with proper application in order to result in good uplift resistance.

Appendix 1 contains the ARMA tab uplift test procedure.

## RESEARCH PROGRAM

As noted earlier, the empirical evidence of shingle blow-off suggests that local winds over some areas of actual roofs are more intense than the approach wind speeds. Local winds are defined here as those that occur within 50mm (2 in.) of shingle surfaces.

The objectives of ARMA's work at CSU will be to establish the relationship between local wind speeds and the approach wind speed, wind direction, and building/roof geometry. This will be accomplished by wind tunnel tests on small-scale (1:25) houses. Also, the effects of wind-loading mechanisms, uplift forces on shingles, and shingle responses for the most severe local wind characteristics on full-size shingles mounted onto a small (1.12m$^2$) (12 ft.$^2$) deck in the wind tunnel will be studied. Finally, a full-scale house will be instrumented and analyzed for verification of the data obtained from the wind tunnel work.

Measurements on small-scale house models and the deck with full-size shingles will be made in the Meteorological Wind Tunnel (MWT) at CSU. The layout of this tunnel is illustrated in Figure 4 with a detail drawing of the shingle deck positioning in the tunnel in Figure 5. Following selection of the full-scale house on which wind effects will be measured, corresponding measurements on a small-scale model of that house will also be made in the MWT.

Mean wind speed and turbulence intensity measurements at a distance of 25mm-50mm (1 in. -2 in.) above the small-scale model roof surfaces will be made using a hot-wire anemometer with the sensing wire normal to the roof surface. This arrangement will measure the total wind component parallel to the roof surface. The approach mean wind speed will be measured with a hot-wire anemometer upwind of the model at a height corresponding to 10m (33 ft.) for full-scale. Locations for local measurements will be guided by flow visualization using a chemical smoke and/or an array of fine tufts attached to model roof surfaces. By observing the flow patterns as wind direction is varied, roof locations and wind directions for the most severe local wind loading will be identified.

When using the deck with full-size shingles, pressures on the upper and lower shingle surfaces will be measured by installation of pressure taps in the shingles. Pressures from the taps will be imposed on a sensitive pressure transducer by small diameter tubing. Local wind speed over the shingles instrumented for pressure measurements will be obtained by hot-wire measurements as was the case on the model roofs. This study is to be complemented by additional measurements of velocity and flow visualization near shingle tab lift up. Information obtained by these measurements will be helpful in determining the progressive nature of lift up.

The measurements taken from the full-scale house will provide essential information to validate the findings from the studies conducted in the MWT. The initial effort will be focused on house selection that will facilitate data acquisition for local wind flow over the roof and the pressure measurements on the upper and lower surfaces of selected shingles. To complete the data necessary for this part of the program, provisions to measure approach wind characteristics will be made. This may consist of a three level set of readings at one-half, one and two building heights above ground. Meteorological data at each level will include wind speed, wind direction, the longitudinal component of turbulence and temperature. The mast location for these readings will also depend upon local surroundings and prevailing wind characteristics.

Figure 6 shows the proposed time-line for the first year of the project. The nature and extent of future work will be defined in accordance with the program and fund availability.

## SUMMARY

Experience has shown that asphalt shingles can perform very well in high winds.[1] However, current test techniques do not adequately distinguish between products that can and cannot perform in high winds, nor quantify the impact of shingle application techniques on this performance. Hopefully, the result of ARMA's studies will allow for a defined relationship between wind speeds, building/roof geometry and the shingle tab uplift necessary to perform in the various wind zones in which shingles are used. There still remains the problem of the pre- seal condition that occurs between the time of application and that time when the shingles have experienced roof deck temperature high enough and long enough to thermally activate the factory-applied shingle tab sealing adhesive. Reduction of the time-temperature requirement needed to achieve tab sealing is currently an area of interest for most shingle manufacturers. After all, a quality shingle product that will seal down and stay down is in everybodys best interest.

## REFERENCES


[1] McDonald, J.R. and Smith, T.L., "Performance of Roofing Systems in Hurricane Hugo," *Professional Roofing,* August 1990.

[2] Lamb, Glenn D. and Noe, Jeffrey S., "Wind Performance of Asphalt Roofing Shingles," paper published in Structural Design, Analysis and Testing (the proceedings of the sessions related to design, analysis and testing at Structures Congress '89), American Society of Civil Engineers, N.Y., 1989.


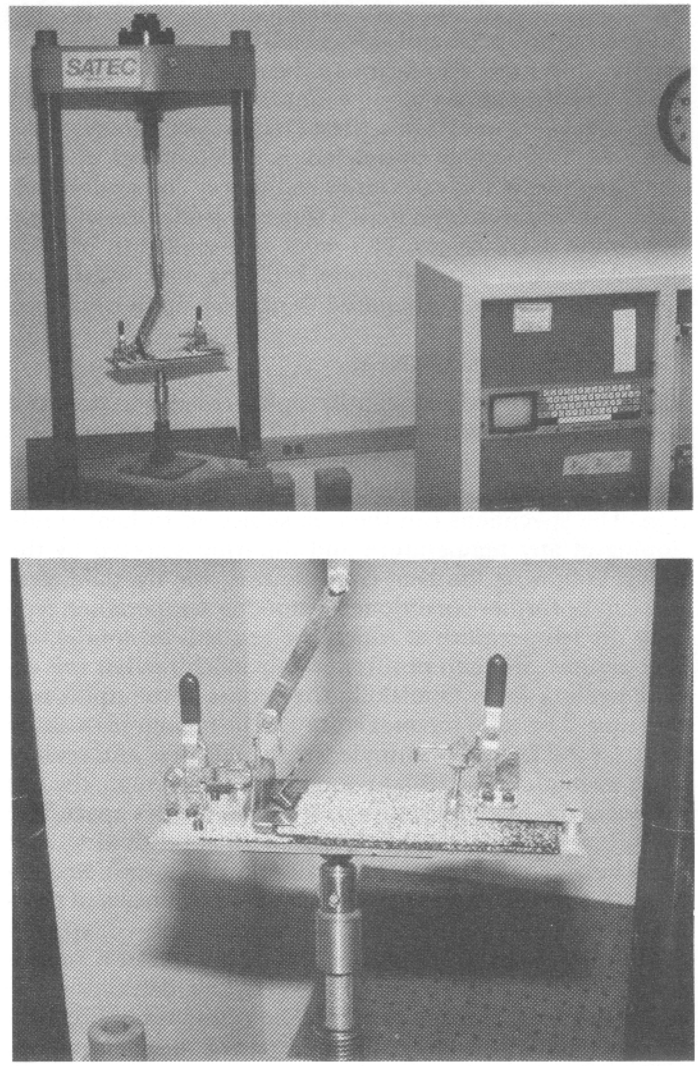


*Figure 1* Photos of samples positioned in sealant test fixture to mimic the action of wind uplift.

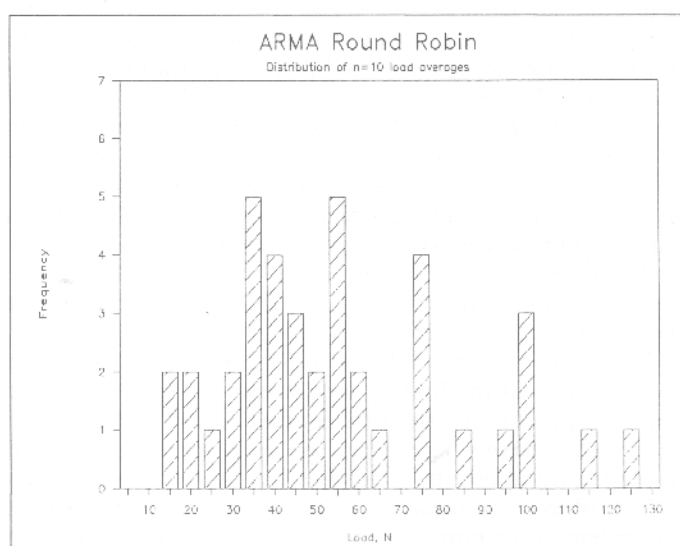


*Figure 2* Histogram of average load of all sample sets reported by all labs.

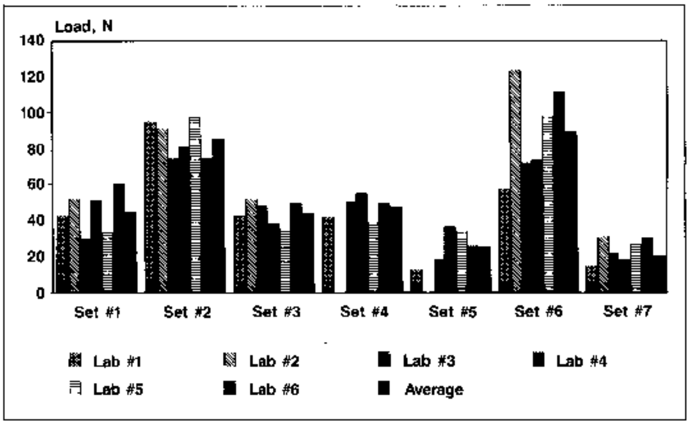


*Figure 3* *Illustration of test reproducibility.*

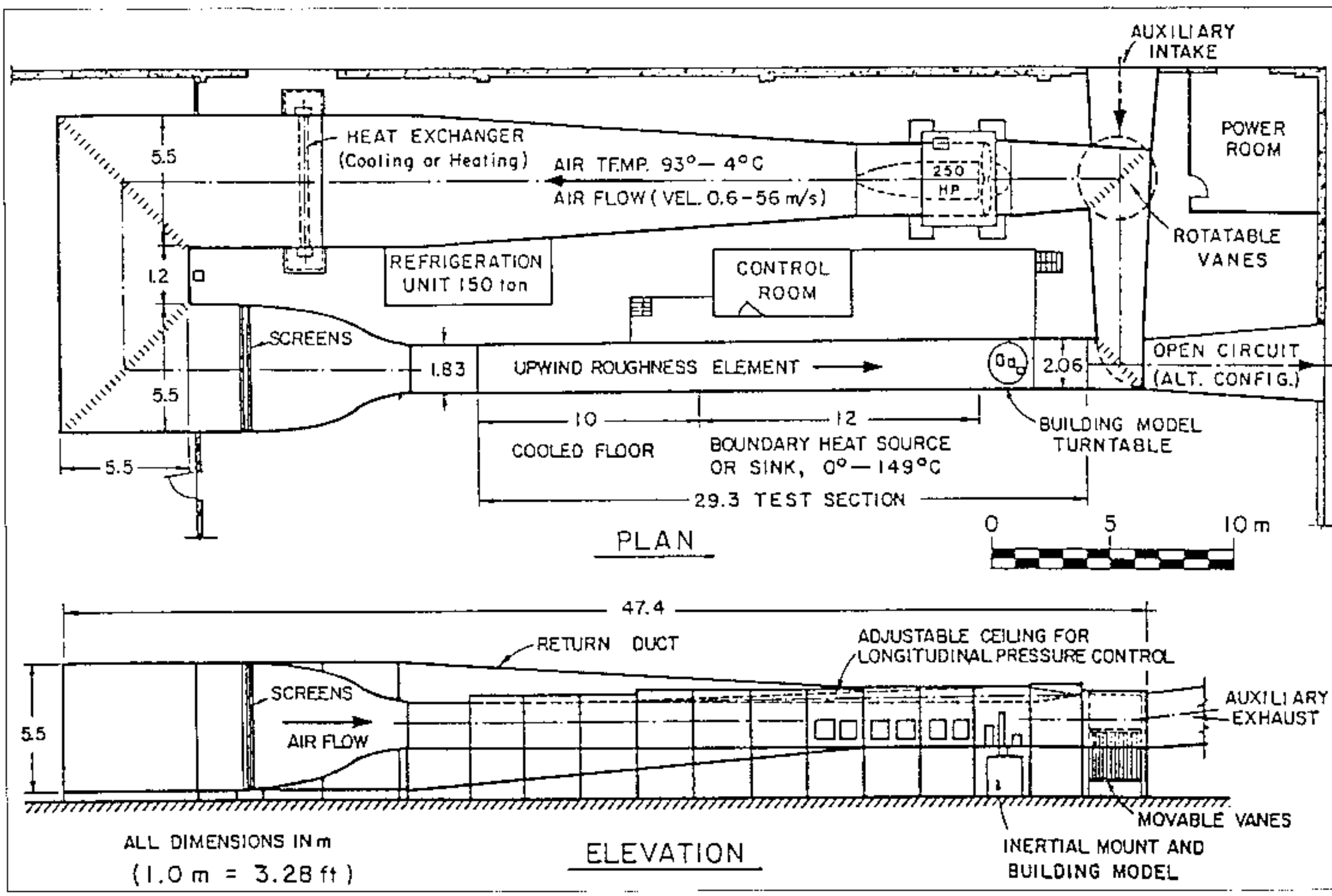


*Figure 4* *The Meteorological Wind Tunnel, Fluid Dynamics and Diffusion Laboratory, Colorado State University.*

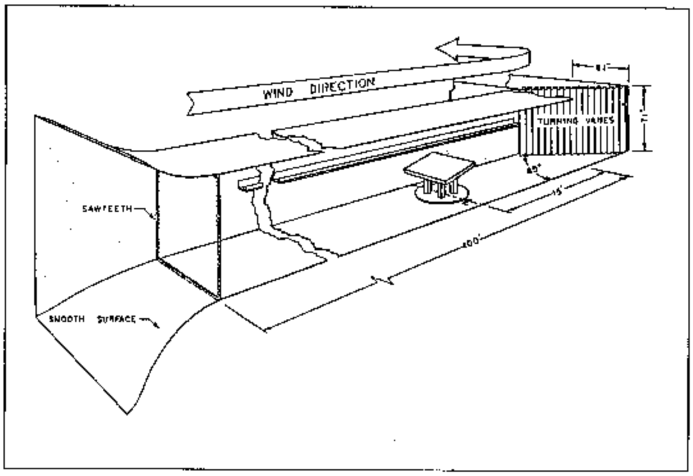


*Figure 5* *Section of MWT showing full-size shingle deck.*

| Task | Months Following Award of Contract | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1.1 Wind-tunnel Tests -- Small-scale Houses | | | | | | | | | | | | |
| a. T-shaped house | | | | | | | | | | | | |
| i. Model design and construction | xxxxxxx | | | | | | | | | | | |
| ii. Flow visualization, roof-surface wind speed meas., data analysis | x | xxxxxxx | | | | | | | | | | |
| b. Complex geometry house | | | | | | | | | | | | |
| i. Model design and construction | xxx | xxx | | | | | | | | | | |
| ii. Flow visualization, roof-surface wind speed meas., data analysis | | | xxxxxxxx | xxxxxxxx | | | | | | | | |
| c. Design model shingles | | | | | | —— | —— | —— | —— | | | |
| 1.2 Wind-tunnel Tests -- Shingles on Test Deck | | | | | | | | | | | | |
| a. Deck preparation and instrumentation of shingles | | | | xxxx | xxxx | | | | | | | |
| b. Flow visualization, pressure measurements, roof-surface wind speed meas., and data analysis | | | | | xxxx | xxxxxxxx | xxxxxxxx | xxxxxxx | | | | |
| 1.3 Full-scale House Study | | | | | | | | | | | | |
| a. Locate site | —— | —— | —— | —— | | | | | | | | |
| b. Prepare preliminary design | | | | | xxxxxxxx | xxxxxxxx | xxxxxxxx | xxxxxxxx | xxxxxxxx | | | |
| c. Outline meas. program and identify instrumentation | | | | | xxxxxxxx | xxxxxxxx | xxxxxxxx | xxxxxxxx | xxxxxxxx | xxxxxxxx | | |
| REPORTS | | | | | | | | | | | | |
| a. Task 1.1.a (interim data report) | | | • | | | | | | | | | |
| b. Task 1.1.b (interim data report) | | | | | • | | | | | | | |
| c. Task 1.2.b (interim data report) | | | | | | | | | • | | | |
| d. Task 1.3 (progress report) | | | | | | | | | | • | | |
| e. Final report | | | | | | | | | | | | • |
| PROPOSAL (Year 2) | | | | | | | | | | | | |
| a. Wind-tunnel Tests | | | | | | | | | | | • | |
| b. Full-scale Building Installation | | | | | | | | | | | • | |

---- Subject to redistribution of effort

*Figure 6* *Time line of the ARMA research program.*

## APPENDIX 1

## PROPOSED BOND STRENGTH—SHINGLE TAB TEST METHOD

### PURPOSE

The purpose of this method is to determine the sealant bond strength of asphalt roofing shingles. It is to be used with shingles with factory applied tab sealant.

This method can be used over a broad range of conditioning times and temperatures and testing temperatures to represent a variety of actual field conditions or to evaluate the performance of specially designed sealant systems.

### REFERENCES

ARMA round robin test results.

### SUMMARY

A test specimen is constructed from two smaller pieces of a shingle. These pieces represent one shingle lying on top of another shingle. They are bonded together by placing in an oven for not more than 16 hours at 137.5°F ±2.5°F. The specimen is then allowed to return to the appropriate test temperature.

The conditioned specimen is then pulled apart and the maximum force is recorded.

The mean force is calculated for 10 specimens and reported.

### EQUIPMENT

Tensile testing machine, Constant Rate of Extension (CRE) type with 200 lbf load cell.

Heavy duty paper cutter, steel rule die or templates (3-3/4 X 7 and 3-3/4 X 9 inches).

Bond strength shingle sealant test fixture.

Forced air convection oven capable of maintaining a temperature of 137.5°F ±2.5°F.

Sample Tray - ½ X 18 X 22 inches plywood sheet.

A refrigerator capable of cooling test specimens to 37.5°F ±2.5°F.

### SAMPLE AND SAMPLE PREPARATION

The sample shall consist of 10 specimens per test temperature, as described below.

A specimen consists of a bottom (3-3/4 X 9 inches) and a top piece (3-3/4 X 7 inches), both cut from one shingle. The bottom piece should have a sealant spot centered on the specimen. The top piece is cut from the tab area. NOTE: The sealant should be centered and maximized for each specimen. (Drawings are available from ARMA which illustrate specimen preparation).

Lightly brush any loose granules, dusting, and other foreign material from both pieces. Pick out any large granules stuck in the sealant. Lay top piece over the bottom piece.

Position the sandwiched specimens on the sample tray.

### SAMPLE CONDITIONING

Place sample tray in an oven set at 137.5°F ±2.5°F. Samples should lie flat. Leave samples in the oven for not more than 16 hours.

Remove sample tray from oven and let them return to the testing temperature of 72°F ±5°F or 37.5°F ±2.5°F for 2 hours ±15 minutes without disturbing.

### EQUIPMENT SET-UP AND CALIBRATION

CRE tensile tester

- Set-up and calibrate the testing machine with test fixture in place with the following operating parameters:
  - Crosshead Speed - 5 ipm
  - Load Cell Capacity - 200 lb maximum
  - Load Range - 20 lbs full scale Gage Length - Set to accommodate test fixture without putting excessive strain on sealant joint.

### PROCEDURE

Step 1—Open both clamps and carefully slide the conditioned specimen into the bond strength apparatus until it touches the stop buttons. Close the clamps to secure the specimen. Care should be taken not to prematurely crack or break the sealant bond. Cold samples should be taken individually from refrigerator, installed in clamps, and tested as quickly as possible.

Step 2—Position top clamp assembly under the top overlap, using the thumb to operate spring clamp. Run test and record maximum force to the nearest .2 lbs required to break bond.

Step 3—Visually examine the tested specimen and estimate the percent of sealant transfer to the nearest 20 percent.

Repeat steps 1 and 2 for the remaining specimens.

### REPORT

Report the sample mean force needed to break the bond, to the nearest .2 lb. This is the sealant bond strength. Also report the standard deviation of the ten individual values.

Report the sample mean percent of sealant transfer from the bottom piece to the top piece to the nearest 20 percent.

Report test chamber conditions if test was conducted at other than room temperature.

Report the type of dusting on the shingle.

Report any other observations about the bond performance.