# The Effects of
# Moisture and Heat
# on the
# Tear Strength of
# Glass Fiber-Reinforced Asphalt Shingles

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**Key Words:** Glass fiber, asphalt shingles, cracking, moisture, heat, tear strength.

## Abstract

Glass fiber-reinforced asphalt shingles have experienced cracking for some time. The issue of how to evaluate tear strength has also been discussed. What has been overlooked is the effect moisture and heat have on the tear strength of glass fiber shingles. Fifteen lots of new shingles were evaluated using a condensation cycling protocol along with heat aging. Large differences in tear strength were observed depending on which protocol was used. Shingle tear strength was found to generally be diminished by moisture cycling; the strength loss can be regained by heat conditioning.

## Author Biographies

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Renẻ M. Dupuis received his B.S., M.S., and Ph.D. in Civil Engineering from the University of Wisconsin, Madison. He began his career as a structural design engineer in private practice for Arnold & O'Sheridan, later worked as a research assistant for the Engineering Experimental Station, College of Engineering – U.W. Madison and then taught structure and materials at SUNY – Buffalo, New York. For the past 24 years he has worked as a Principal and Structural Research Inc., conducting laboratory, field, design, research, and forensic studies on roofing materials and systems. Dr. Dupuis is an active member of ASTM since 1979 and has written numerous articles on roof material performance, testing, design along with research findings. Renẻ has served on Boards of Regents with RIEI and as a technical advisor for the Midwest Roofing Contractors Association (MRCA). He received the James Q. McCawley Award (1988) from the MRCA and the Distinguished Services Citation (1995) from the University of Wisconsin – Madison for contribution to roofing industry education.

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Mark S. Graham, associate executive director, technical services, joined the NRCA staff in 1993. He holds a Bachelor of Science degree in architectural engineering from the Milwaukee School of Engineering. Prior to joining NRCA he was employed by F.J.A. Christiansen Roofing Co., Inc., in Milwaukee, Wisconsin, and later Wiss, Janney, Elstner Associates, Inc., in Northbrook, Illinois. For NRCA, he is the senior staff person responsible for the association's technical activities and is a contributing editor to *Professional Roofing* magazine. Mr. Graham is an active member of ASTM, ASHRAE, NFPA, and each of the three model building code groups.

## Introduction

Glass fiber-reinforced asphalt shingles are the predominant roof material used to cover steep-slope roof systems in the United States and Canada. Many variations of this product are available, including three-tab and laminated shingles. Field performance of glass fiber-reinforced asphalt shingles ranges from outstanding to poor; deck conditions, wind, snow and ice, and extreme heat may shorten shingles' service life. Installation methods and fastening patterns may also affect field performance.

A predominant field performance issue with glass fiber shingles is cracking. The cracking pattern on a three-tab shingle may be diagonal, vertical, horizontal or a meandering combination of the above. The mechanical and thermal loads a roof shingle experiences are many; extreme heat, large temperature swings, high winds, deck warpage and heavy rainfall are the primary agents loading a shingle. The sealant used to hold down the exposed lower portion of a shingle is vital to preventing wind uplift. If the sealant is too hard and not ductile, it prevents expansion of the shingle during extreme heat. Sealant location is also critical; applications of sealant that are close together prevent movement. Wider distribution allows for more gage length. Self-sealing turns multiple individual shingles into a unit. This will cause stress concentration to occur during temperature swings if nonuniform attachment is present either in the sealant or nailing.

The performance of glass fiber-reinforced shingles has been studied and reviewed by many authors, including Cash [1, 5, 9, 10], Ribble, et al. [3], Noone and Blanchard [4], and Terrenzio, et al. [6]. Shingle cracking has been specifically addressed by Cash [5, 10], Datta, et. al. [2], Noone and Blanchard [4], Phillips, et.al. [7], and Shiao [11]. Although temperature extremes certainly occur on roofs, Rose [8] and Cash [10] have demonstrated that attic ventilation alone cannot control or significantly affect shingle temperatures. These authors separately concluded from field studies and mathematic models that attic ventilation is limited in controlling shingle temperature. Cash has shown that color has more effect on shingle temperature during solar load than attic ventilation.

The measurement of a shingle's ability to resist cracking or splitting has been debated heavily. Manufacturing trade associations and others have attempted to define new physical testing regimen to assess splitting resistance. Currently, the only ASTM International standard that relates to a tear strength requirement is found in ASTM D3462, "Standard Specification for Asphalt Shingles Made From Glass Felt and Surfaced with Mineral Granules," utilizing the Elmendorff tear test, ASTM D1922, "Test Method for Propogation Tear Resistance of Plastic Film and Thin Sheeting by Pendulum Method." Despite the efforts of many, no new or meaningful test has yet to come forward. As of this writing, it now appears that tensile strain energy, or tensile toughness may be the leading candidate to consider (Shiao[11]).

**Factors Effecting Tear Strength/Cracking Resistance**

This is a broad topic that must consider all elements of manufacturing, material selection and amount, as well as installation methods and fastening pattern to name a few. It can also be stated that no study to date has looked at the effect on moisture of heat aging on the tear strength of shingles.

Currently, ASTM D3462 calls for the tear test to be run on shingle samples that have been conditioned at room temperature (73°F $\pm$ 4° [23°C $\pm$ 2°]) for 24 hours. This condition is most ideal but does not address heat and moisture – two common elements every roof must deal with in the field. Heat and moisture are the most common destructive elements a shingle has to deal with, excluding installation stress, ultraviolet radiation and wind forces.

The concept of moisture affecting a glass fiber-reinforced asphalt shingle is foreign to most roofing technologists. Glass fiber-reinforced asphalt shingles are inorganic and seemingly unaffected by water. However, a shingle is a watershedding device; its downslope exposed edge is cut. Could the cut edge allow for a slow uptake of water such as that seen from a heavy morning dew, light rain or mist?

To test the concept of moisture uptake, a pilot test program was undertaken. Using the heated water tray of a QUV weather tester, shingles were exposed to a temperature cycle (dark heat - no light), between 73° F (23° C) and 122° F (50° C) for eight hours. The cycle is four hours at 122° F (50° C) and then four hours of no heat, wherein the water bath is allowed to cool back down to 73º F (23º C). This was done on a number of shingle lots purchased on the open market. It was discovered that the tear strength would decrease; in some cases, the tear strength dropped nearly 50 percent. Interestingly, heating other samples at 158° F (70° C) caused the tear strength to increase, in some cases 25 – 40 percent higher than as received. Using this concept and continuing the pilot test program led to the discovery that glass fiber-reinforced asphalt shingles tear strengths are affected by moisture and heat. In fact, the strength properties of a shingle are dynamic in that they change with heat and moisture. Their strength can, for the most part, be altered by their environment.

Scanning electron microscopic (SEM) examinations were also undertaken to see whether a ductile tear failure as reported by Shiao[11] also existed. The SEM work showed the same condition to exist at the glass/asphalt mix interface that Shiao discovered. Basically, the glass fibers pull away from the filled asphalt with few (if any) broken fibers. Micro cavities exist in the matrix of filled asphalt. This explains why moisture in minute amounts can be taken up by the shingle diminishing the bond strength between glass fibers and filled asphalt. Conversely, heat will expand the asphalt matrix, creating a tighter bond at the glass/asphalt interface.

The work reported herein confirms that a glass fiber-reinforced asphalt shingle's tear strength can be greatly affected by moisture or heat. A formal test program was undertaken by the National Roofing Contractors Association (NRCA), using a wide variety of recently manufactured 25-year, three-tab shingles. SEM exams were also conducted; tear surfaces were examined at 75 times and 1000 times their actual size.

## Shingle Selection

Glass fiber-reinforced asphalt shingles were obtained in five bundle lots from eight manufacturers. A total of 15 manufacturing lots were purchased on the open market for a total of 75 bundles of three-tab, 25-year glass fiber shingles. All were advertised to meet ASTM D3462. One lot of shingles procured contained an algae blocker. The 15 lots represent at least 12 manufacturing plants. All shingle bundles purchased were in current inventory; information regarding the respective date of manufacture of the lots purchased was not directly available.

The selection of shingle samples was done in the following manner:

1. Each bundle was weighed.
2. A shingle count was then made of each bundle.
3. The bundle average shingle weight was then determined for each bundle.
4. One shingle was selected at random from each bundle. If the selected shingle was within 1.5 percent of the bundle average shingle weight, it was sampled for testing.
5. Six test coupons 2 ½ inches by 3 inches (63 mm by 76 mm) were then selected at random locations from each shingle. One sample was taken from the exposed area and one from the unexposed portion of the shingle.
6. A test lot of 30 coupons was then assembled and coded from five selected shingles -- 15 exposed and 15 unexposed.

## Test Protocol

Each of the 15 lots had three sample sets of 10 - 2 ½ inch by 3 inch (63 mm by 76 mm) coupons set up for testing. The test protocol included tear testing one set randomly selected “as received.” Another set was randomly picked for the 30-day condensation cycle; the remaining sets were used for the 30-day heat-age cycle.

30-Day Condensation Cycle:
This test utilized a QUV weathering tester with all shingle samples mounted on aluminum racks at a near vertical position. No light sources were used; dark heat was provided by heating a water bath to 122° F (50° C) for four hours. At the end of the four-hour heat cycle the water bath was allowed to cool to room temperature (73° F $\pm$ 4° F [23° C $\pm$ 2° C]). The water bath lies below the aluminum racks; no rack or shingle sample touched the water bath. Tap water is automatically fed to the water bath via tubing and a float valve. Three cycles are completed in a 24-hour period. A total of 90 cycles are achieved in 30 days. The near- vertical rack system allowed any condensed water to drip off the shingle samples. At the end of the condensation cycle, the shingles had condensed

water beaded on their surface. At the end of the room-temperature cycle, shingles were observed to have moist surfaces.

30-Day Heat Cycle:
Shingle samples selected for this conditioning cycle were laid out on steel racks in a convection oven with the temperature held at 158° F (70° C) for 30 days.

## Results

The numerical test results are shown in Table 1 and graphically presented in Figure 1. Wide ranges of tear strength were found depending on manufacturer, conditions imposed (water or heat) and weight of glass-mat. As shown in Table 1, glass-mat weight (average of 3 samples) ranged from 1.68 pounds per square (82 g/m²) to 2.10 pounds per square (103 g/m²).

The highest tear strength as received was found in Sample B, Type A at 3200+ g, which was the limit of the tear tester. This product had a glass-mat weight of 2.08 pounds per square (102 g/m²). The lowest tear test as received, came from Sample F, Location A, which had a glass-mat weight of 1.99 pounds per square (97 g/m²) and a tear strength of 560 g.

The shingle samples that underwent condensation cycling had a high of 2976 g from Sample B, Type A. The lowest tear strength came from Sample D at 480 g; this product had a glass-mat weight of 1.79 pounds per square (87 g/m²).

The heat-cycle testing identified five samples testing at 3200+ g. This included Sample A, Sample B, Type A, Sample F – Location B, Sample F - Algae Blocker and Sample G. The lowest heat cycle tear strength value of 544 g was found in Sample D.

The highest average tear strength came from Sample B, Type A at 2451 g for the as-received condition. The lowest was Sample D at 835 g.

The highest average tear strength for the condensation cycled shingle coupons came from Sample B, Type A, at 2189 g. The lowest was Sample D at 586 g.

In the heat-aged category, Sample B, Type A was the highest at 2691 g average. The lowest average tear strength came from Sample D at 805 g.

One series of shingles selected from one manufacturer included three plants along with an algae blocker additive. As shown in Figure 2, the algae blocker shingle had an impressive strength gain from moisture conditioning -- nearly double its companion models. Even more interesting is the fact that it had the lowest glass-mat weight at 1.74 pounds per square (85 g/m²); the others had 1.99 pounds per square (97 g/m²), 1.87 pounds per square (91 g/m²), and 1.96 pounds per square (96 g/m²) respectively.

The scanning electron microscopic views of the various samples are shown in Figures 3 and 4. The first series shown in Figure 3 represent the different manufacturing plants. The left-hand photos show the cavities present in the filled asphalt matrix that surrounds the glass-fiber mat.

All samples demonstrate the ductile nature of the filled asphalt in that the glass fibers have pulled out and away leaving their imprints behind. No broken glass fibers or portion of strands are left in the imprints. All the samples shown in Figure 3 had been subjected to the 30-day condensation cycle.

Figure 4 shows similar SEM views taken from 30-day heat-aged shingle samples. Note that the algae blocker sample appears to have more glass fibers remaining embedded in the asphalt than its companion product.

## Discussion of Results

It is clear that newly manufactured glass fiber-reinforced asphalt shingles possess a wide range of tear strength values when tested in “as-received” conditions. Although all the shingle products tested were represented by their manufacturers’ as complying with ASTM D3462, only six of the 15 lots of asphalt shingle products tested surpassed the 1,700 g minimum value required in the standard.

The condensation cycling and heat conditioning test results show that glass fiber-reinforced asphalt shingles’ tear strength values are affected by their environment. After condensation cycling, four of the lots of asphalt shingle products tested demonstrated tear strength values in excess of 1,700 g. Three of the six lots of asphalt shingles that were originally found to comply with ASTM D3462 when tested “as-received,” fell below the 1,700 g tear strength threshold after condensation cycling. After heat conditioning, 10 of the 15 lots of asphalt shingle products tested surpassed the 1,700 g tear strength threshold.

The research also confirmed earlier findings that the mechanism for shingle cracking is not necessarily tied to reinforcing mat weight and the fracturing or breakage of glass-fiber strands in reinforcing mats. Instead, ductile tear-type failures with unbroken glass fibers pulling out of shingles’ asphalt were found.

It is also clear that weight of the reinforcing mat used in a glass fiber-reinforced asphalt shingle is not directly relational or proportional to the product’s tear strength.

The authors do not necessarily consider the results, particularly those after condensation cycling and heat conditioning, for the algae blocker shingle product to be representative of all algae-inhibitor asphalt shingle products.

## Conclusions

This research demonstrates the dynamic nature of tear strength of glass fiber-reinforced asphalt shingles.

It is the authors' opinion the condensation cycling and heat conditioning used in this research is somewhat representative of the environment that asphalt shingle products will encounter when in service on roofs.

Knowing that tear strength of a glass fiber-reinforced asphalt shingle can be altered (decreased or increased) by exposure to heat and moisture, it can be seen why, for example, shingle cracking is often more frequently seen on the southern exposures of asphalt shingle roofs.

Consider, for example, a wet or rainy period followed by a warm, sunny day. Glass fiber-reinforced asphalt shingles may not have adequately dried and regained their strength but are faced with resisting the forces of temperature-induced thermal expansion of the roof. The sealant tab adhesive then becomes a crucial element. Relatively elastomeric and flexible shingle tab adhesives with some gage distance between adhesive strips may allow for some movement of individual shingles and not force stress concentrations that may cause shingle cracking. Conversely, shingles with relatively hard, inflexible, continuous or near-continuous adhesive strips will likely not allow for adequate movement of individual shingles. As a result, vertical or near-vertical tears in individual shingles may develop.

Also consider dark-colored shingles, such as those with black, near-black or other dark-colored granules. Such dark-colored shingles invite greater solar load and heat gain. As a result, drying of these shingles should be hastened and, as a result, the periods where these shingles are exposed to moisture--and the resulting lower strength--should be shorter. However, the possible advantage of dark-colored shingles may be offset by the fact that they will also experience greater temperature-induced thermal expansion, which can result in greater stress concentrations and possible cracking as described previously.

## Recommendations

The work presented in this paper, when combined with the research of others, shows a need for improvements in the manner of testing and assessing the true strength characteristics of glass fiber-reinforced asphalt shingle products.

When considering the performance of glass fiber-reinforced asphalt shingles, the authors recommend that condensation cycling and heat conditioning be considered when conducting strength tests. The test parameters used in this research are offered as a guideline.

Considering the significant increase in tear strength values after condensation cycling and heat conditioning for the single product included in this research using an algae-inhibitor, this appears to warrant further study.

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| Shingle Sample | ASTM D3462 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Felt Mass (lb/100 ft²) | Tear Resistance, g | | | | | | | | |
| | | As Received | | | 30 Days Condensation | | | 30 Days Heat Aged | | |
| | | Low | High | Average | Low | High | Average | Low | High | Average |
| Sample A | 1.88 | 1136 | 2688 | 1909 | 1248 | 1680 | 1512 | 1376 | 3200+ | 2114 |
| Sample B Type A | 2.08 | 1312 | 3200+ | 2451 | 1280 | 2976 | 2189 | 2096 | 3200+ | 2691 |
| Sample B Type B | 2.10 | 1408 | 2912 | 2019 | 1392 | 2400 | 1800 | 1504 | 2880 | 1930 |
| Sample C Location A | 1.68 | 1184 | 1792 | 1451 | 992 | 1664 | 1362 | 1312 | 1952 | 1658 |
| Sample C Location B | 2.01 | 1216 | 1984 | 1547 | 880 | 1824 | 1370 | 1344 | 2496 | 1766 |
| Sample C Location C | 2.10 | 1120 | 2624 | 1846 | 1344 | 2336 | 1664 | 1696 | 2368 | 1992 |
| Sample D | 1.79 | 592 | 992 | 835 | 480 | 736 | 586 | 544 | 960 | 805 |
| Sample E | 1.75 | 992 | 1472 | 1186 | 864 | 1824 | 1123 | 704 | 1728 | 1245 |
| Sample F Location A | 1.99 | 560 | 1408 | 952 | 544 | 1280 | 899 | 832 | 2528 | 1371 |
| Sample F Location B | 1.87 | 1024 | 2080 | 1542 | 800 | 1632 | 1090 | 1088 | 3200+ | 1774 |
| Sample F Location C | 1.96 | 656 | 1728 | 1157 | 576 | 1376 | 974 | 800 | 1984 | 1302 |
| Sample F Algae Blocker | 1.74 | 1344 | 2016 | 1614 | 1312 | 2656 | 1936 | 960 | 3200+ | 1810 |
| Sample G | 1.87 | 1712 | 2688 | 2107 | 1376 | 2752 | 1974 | 1712 | 3200+ | 2392 |
| Sample H Location A | 1.74 | 1312 | 2688 | 1946 | 1056 | 2112 | 1638 | 1312 | 2496 | 1728 |
| Sample H Location B | 1.79 | 1408 | 1760 | 1619 | 1344 | 2112 | 1653 | 1296 | 2336 | 1896 |

**Table 1 -** Test results showing weight of glass mat along with tear test for each shingle lot and condition.

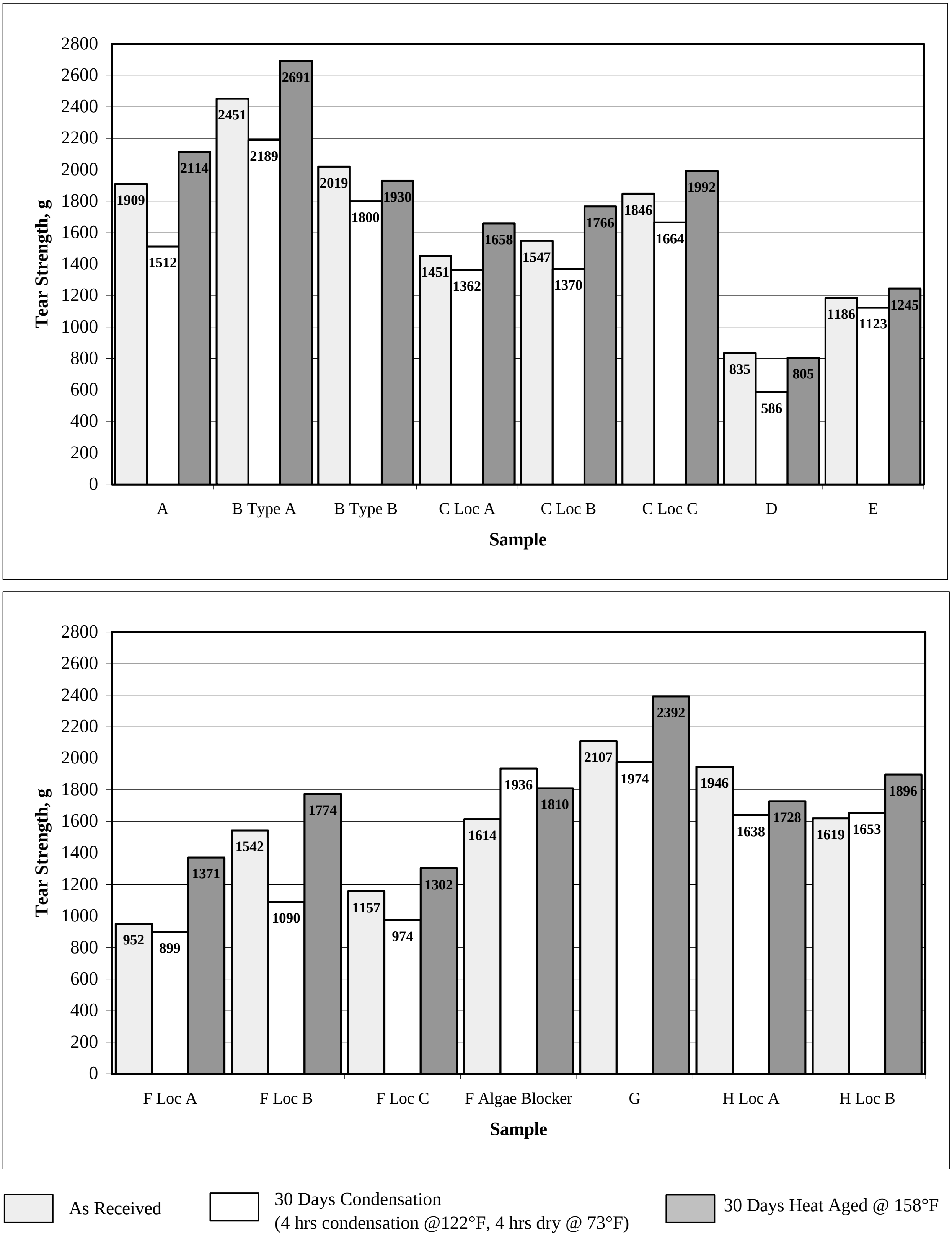


**Figure 1 -** Plot of average tear strength (grams) for 15 different shingle lots subjected to 30 day condensation or 30 days heat aging.

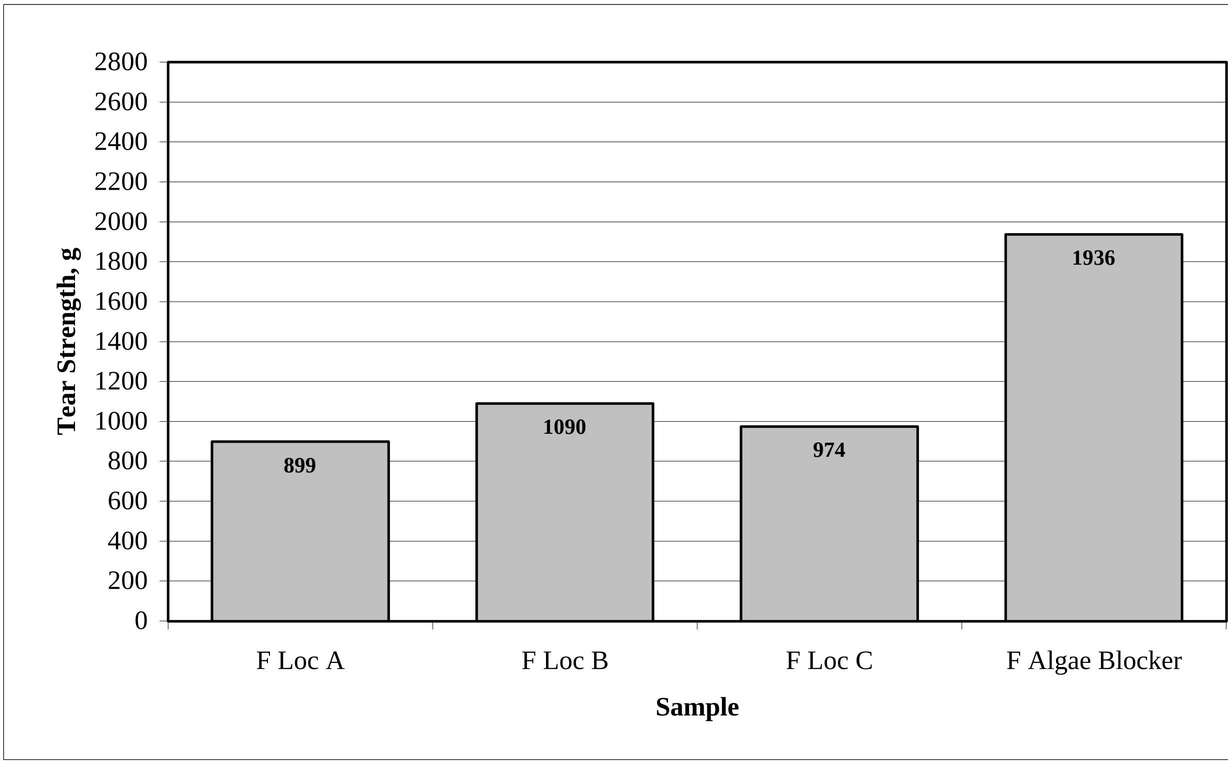


**Figure 2 -** Plot of average tear resistance after 30 day condensation cycle for one manufacturer.

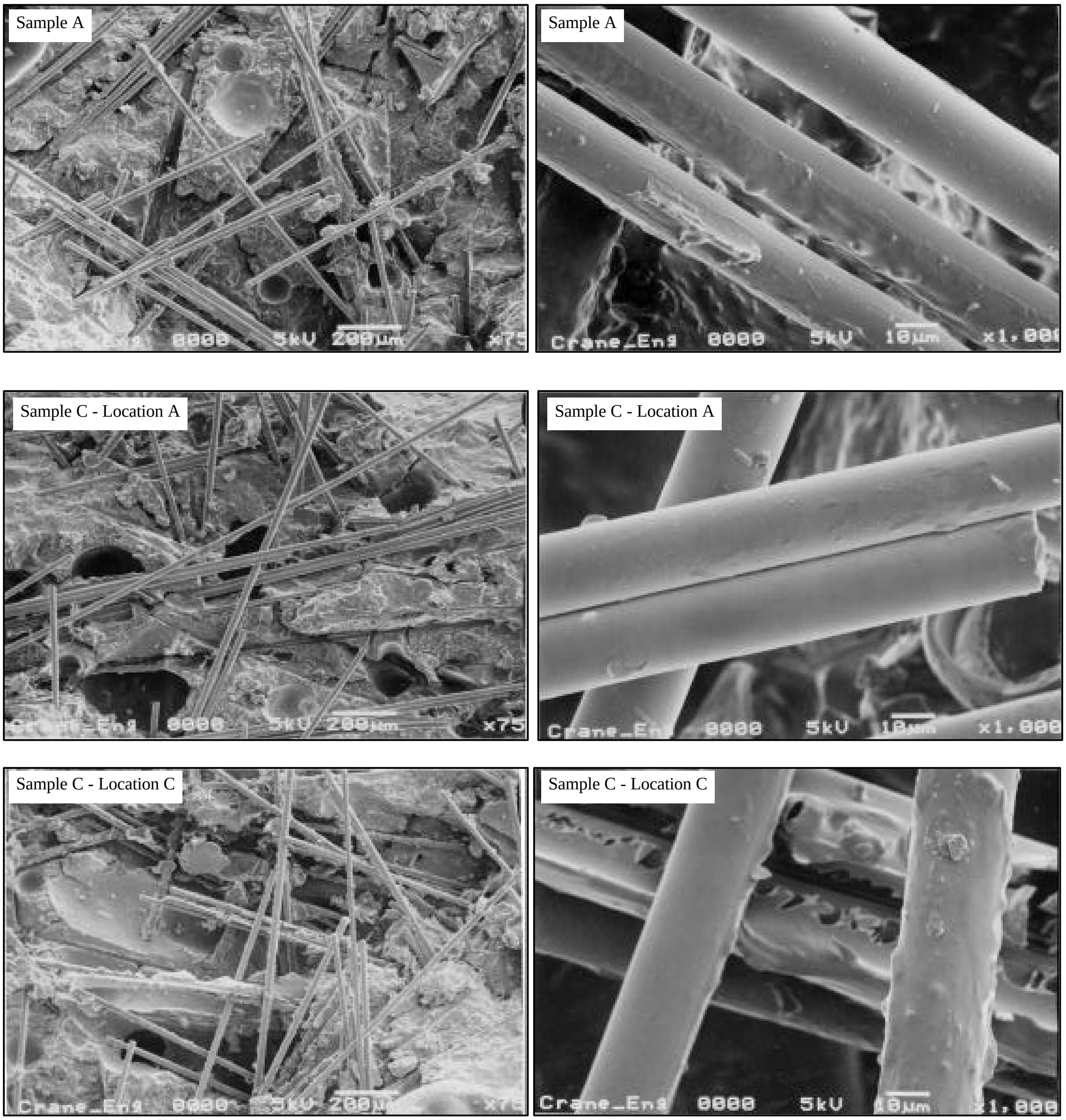


**Figure 3** - Scanning electron microscopic view of tear surface observed on shingle samples submitted to 30 day condensation cycle. Note left hand photos at x75 magnification show large and small cavities, some of which appear interconnected. Also note all samples show fiber pullout from fill asphalt mix. Photos on right hand side are at x1000 magnification. Binder and particles remain adhered to individual glass fibers. The tear strengths were 1512, 1362 and 1664 grams respectively

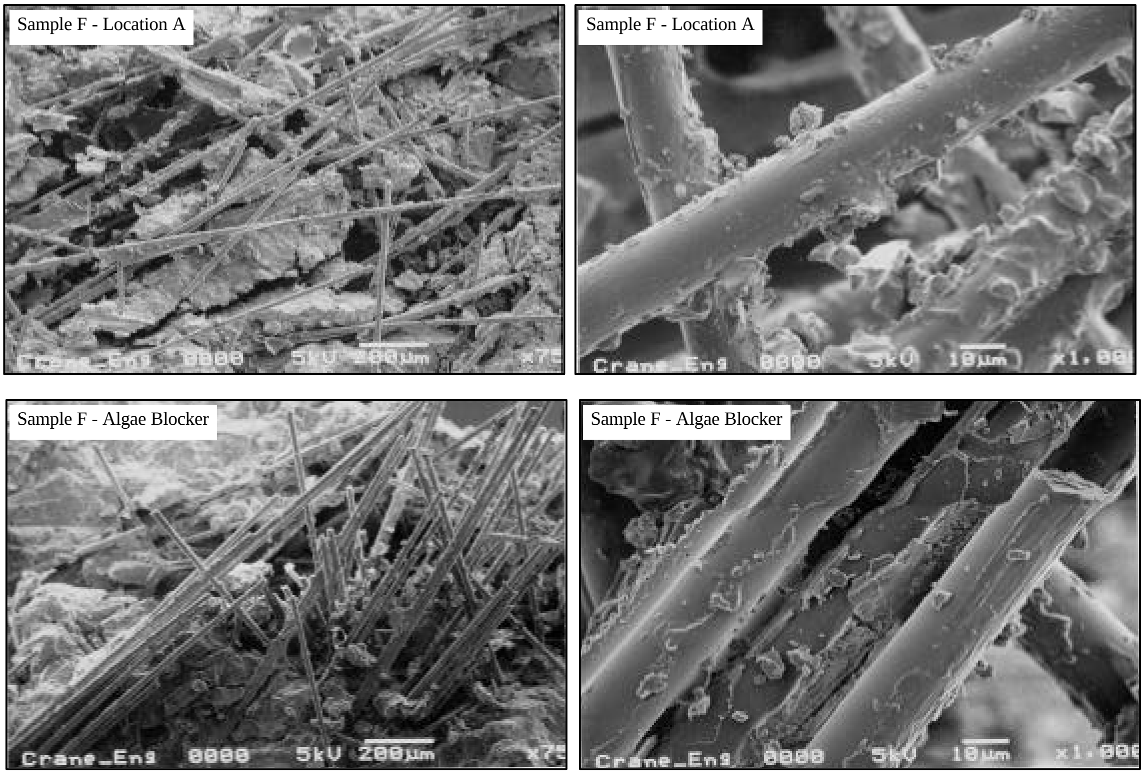


**Figure 4** - Scanning electron microscopic few of tear surface observed on shingle samples submitted to 30 day heat aging cycle at 158°F. Note left hand photos are at x75 magnification. Algae blocker sample had more fiber groups still embedded in matrix. Right hand photos are at x1000 magnification, showing binder and particles adhered to individual glass fibers. The tear strengths were 1371 and 1810 grams respectively.