2023 Hail Impact Research and Testing

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MIDWEST ROOFING CONTRACTORS ASSOCIATION

WJE

2023 Hail Impact Research and Testing

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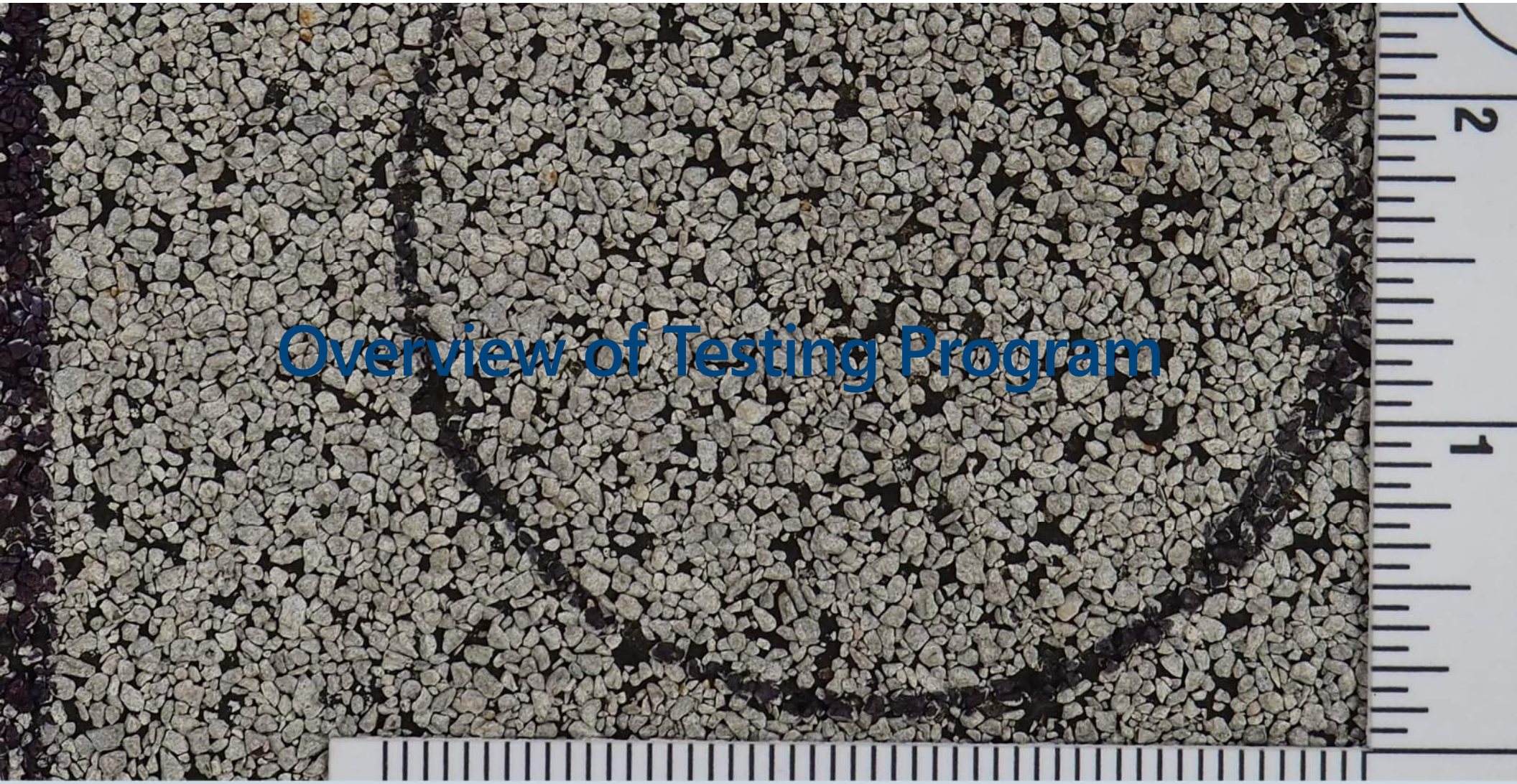
Today's Goals:

- Provide overview of MRCA's 2023 research project
- Summarize results of impact testing
- Answer questions



Overview of Testing Program

Problem Statement

- How does hail impact affect granule surfaced, modified bitumen membranes of various ages?

Testing Objective

- Determine the extent of damage caused by hail impact to granular surfaced, modified bitumen membrane of various ages through physical testing and laboratory review and analysis.

ASTM D3746

Designation: D3746/D3746M – 85 (Reapproved 2022)

Standard Test Method for Impact Resistance of Bituminous Roofing Systems[1]

This standard is issued under the fixed designation D3746/D3746M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the resistance of bituminous roofing systems to impact loads at any desired temperature, with a missile of the weight, size, and shape specified herein.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see Section 6.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D2829/D2829M Practice for Sampling and Analysis of Existing Built-Up Roof Systems

3. Summary of Test Method

3.1 This test method subjects 305 by 305-mm [12 by 12-in.] specimens of a roofing system (insulation and membrane complete with top surfacing) to a series of four impacts, one in each quadrant, from a standard missile falling freely from a predetermined height with an impact energy of 30.0 J [22 lbf·ft]. Damage to the membrane is assessed by visual examination of the felts after solvent extraction of the bitumen.

3.2 The effect of specimen temperature on impact resistance can be studied by running the test in an environmental chamber at any desired temperature.

4. Significance and Use

4.1 This test method provides a means of evaluating roofing systems for resistance to impact loads of many kinds. It should also be useful in developing performance criteria for roofing systems.

5. Apparatus

5.1 *Vertical Guide Tube,* 1.22 m [4.0 ft] long by 60 mm [2⅓ in.] in inside diameter, suitably positioned over a 610-mm [24-in.] square, horizontal test table constructed of wood 2 by 4s on edge, through-bolted and fitted with a centering jig to ensure proper alignment of the specimen beneath the guide tube (see Fig. 1). The guide tube is adjustable in height to accommodate differing specimen thicknesses and maintain constant missile impact energy. Provision is made at the top of the guide tube to support the missile during alignment of the specimen, and for instantaneous release of the missile to free-fall within the guide tube until contact is made with the specimen. Gravel screens are attached to the edges of the test table to retain any loose gravel that might fly from the impact area.

5.2 *Missile* (see Fig. 2), consisting of a steel cylinder 50 mm [2 in.] in diameter by 150 mm [6 in.] long, with a case-hardened hemispherical head. The mass of the missile is adjusted to 2.27 kg [5.0 lb] by the addition of lead shot to a cavity machined into the cylindrical portion and sealed with a screw cap.

6. Safety Precautions

6.1 Employ suitable devices for eye protection when carrying out steps in 10.1 – 10.7.3.

6.2 Use a fume hood when extracting specimens with 1,1,1 trichloroethane or xylene in 10.7.3. Trichloroethane and xylene are toxic and good ventilation should be provided.

[1] This test method is under the jurisdiction of ASTM Committee D08 on Roofing and Waterproofing and is the direct responsibility of Subcommittee D08.20 on Roofing Membrane Systems.

Current edition approved May 1, 2022. Published May 2022. Originally approved in 1978. Last previous edition approved in 2015 as D3746/D3746M – 85 (2015)[ε1]. DOI: 10.1520/D3746_D3746M-85R22.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

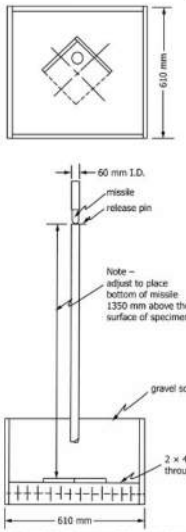


FIG. 1 Guide Tube, Test Table, and Centering Jig

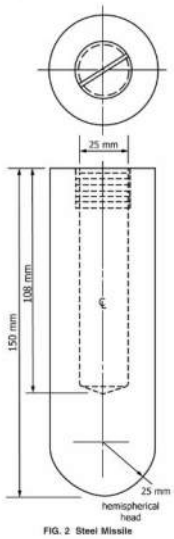


FIG. 2 Steel Missile

7. Sampling

7.1 *Field Samples*—Cut test specimens directly from an actual roof, following the instructions in 8.1. Package each specimen separately in a sealed plastic bag.

7.2 *Laboratory Samples:*

7.2.1 Condition all components at 50 ± 5 % relative humidity and 25 ± 1 °C [77 ± 2 °F] for 24 h prior to constructing the sample membrane.

7.2.2 Prepare sample membranes at least 0.90 by 1.20 m [3 by 4 ft] as required by the roofing system specification being tested, including insulation and top surfacing. The quantity of material in each layer of the membrane shall be within 10 % of that specified and the entire sample shall be within 5 %.

8. Test Specimens

8.1 Test specimens may be taken directly from an actual roof or cut from a laboratory-prepared sample using a 305 by 305-mm [12 by 12-in.] metal template as described in Practice D2829/D2829M and shall include all of the aggregate and insulation in the area of the specimen. Any loose aggregate must be distributed evenly over the surface of the specimen prior to testing.

NOTE 1—When the roofing system specimen contains roof insulation, it is recommended that a buffer strip be removed around the metal template area prior to removal of the specimen in order to reduce damage to the insulation. The buffer zone should be a "V" type wedge extending to the bottom of the specimen thickness to be removed for testing. The inside top of the "V" wedge area should be the edge of the metal template. It is normally 75 to 100 mm [3 to 4 in.] wide. Pressure is normally applied to the template to keep it from moving while cutting the "V" wedge.

9. Conditioning

9.1 Condition the apparatus and all specimens at the desired temperature for a minimum of 8 h prior to testing.

10. Procedure

10.1 Place the test specimen in position beneath the guide tube so the missile will strike the center of one quadrant.

10.2 Place the missile in the top of the guide tube supported by the instantaneous release mechanism.

10.3 Adjust the height of the guide tube so the bottom of the missile is 1350 mm [53 in.] above the surface of the specimen and lock the guide tube in position.

10.4 Release the missile, allowing it to fall and strike the specimen.

10.5 Return the missile to its support in the top of the guide tube, and rotate the specimen 90° to center the second quadrant beneath the guide tube.

10.6 Repeat 10.4 and 10.5 until all four quadrants of the specimen have been subjected to impact.

10.7 *Damage Assessment:*

10.7.1 Remove any slag or gravel surfacing from the specimen carefully with a hot scraper, such as a putty knife.

10.7.2 Record the extent of obvious damage to the membrane, such as dents or fractures, by photograph or sketch and written description.

10.7.3 Cut the four impact areas from the specimen using a hot knife. Staple the felts in each area together and extract the bitumen by immersing in warm 1,1,1 trichloroethane in a fume hood. *Do not heat the trichloroethane to boiling.* (For tarred felt and pitch membranes, use xylene in place of trichloroethane.)

10.8 *Rating of Impact Damage:*

10.8.1 Rate the impact damage which occurs in each ply in each of the four quadrants by assigning the number which most accurately describes the impact damage, as follows:

0 = no damage;
2 = dents, indentations only;
4 = any cracks or splits

10.8.2 After assigning the numbers to all plies within each quadrant, add up all the numbers and divide by four times the number of plies to obtain an average for the membrane.

11. Report

11.1 The report shall include the following:

11.1.1 Source and type of all materials employed in the sample roofs,

11.1.2 Complete description of the construction tested,

11.1.3 Age of the specimens,

11.1.4 Test temperature,

11.1.5 Average damage incurred over the four impacts defined by means of a pictorial representation and a written description,

11.1.6 Overall numerical average which rates the membrane's impact damage in the specific system tested, and

11.1.7 Date of test and operator's signature.

12. Precision and Bias

12.1 No statement is made about either the precision or the bias of this test method since the result merely indicates the rating of impact damage by this procedure.

13. Keywords

13.1 impact; loads; missile; resistance; roofing systems; temperature

ASTM D3746

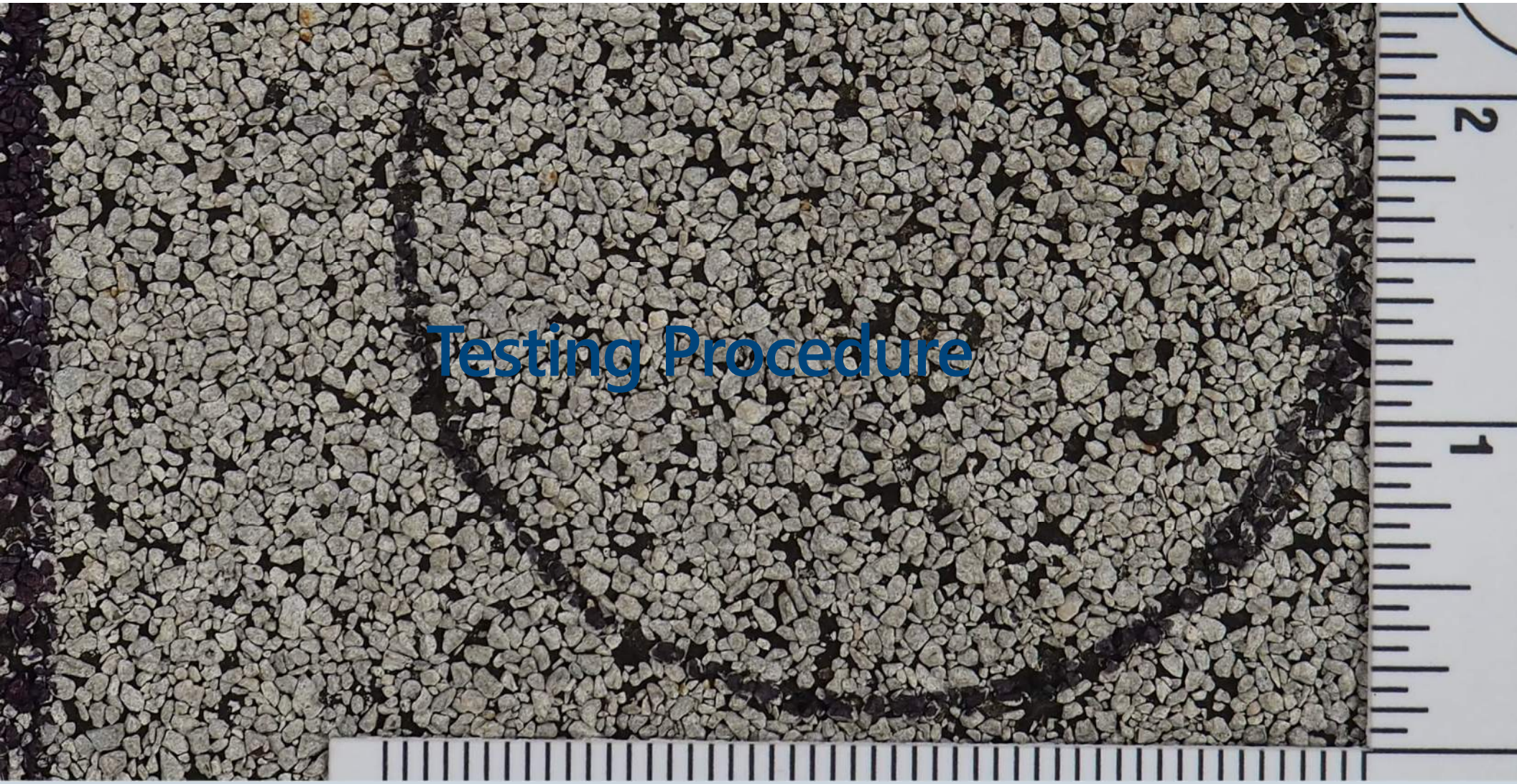
- 12″ x 12″ membrane sample
- Sample divided into 4 zones
- 5 lb, 2″ dia. steel missile
- Impact sample from 53″ height
- Missile equates to 2″ dia. hailstone
  - Both have impact energy of 22 ft lbs (30 J)

Sample Procurement

- All samples provided by MRCA T&R Committee members
- 2-ply modified bitumen membrane from single manufacturer
- Membrane applied in cold adhesive
- 2 cover board types – gypsum and wood fiber
- Samples of various ages – new, 5-year-old, and 10-year-old
- Samples came from in-service roofs in lieu of artificial weathering
  - New samples were fabricated for the testing program

Testing Procedure

1. Unpack and document samples as received
2. Trim to 12″ x 12″ sample size and divide samples into (4) 6″ x 6″ zones with 3″ dia. circles as impact zones
3. Weights and granule counts (image analysis) pre-impact
4. Impact with 5 lb steel missile per ASTM D3746
5. Weights and granule counts (image analysis) post-impact
6. Desaturation of membrane samples
7. Microscopy of cross-sections



Testing Procedure

1 – Document Samples

- As-Received Samples
  - (3) 16″x16″ mod bit with gypsum cover board – 10 yrs old
  - (3) 16″x16″ mod bit with wood fiber cover board – 10 yrs old
  - (3) 16″x16″ mod bit with gypsum cover board – 5 yrs old
  - (3) 16″x16″ mod bit with wood fiber cover board – 5 yrs old
  - (3) 16″x16″ mod bit with gypsum cover board – new
  - (3) 16″x16″ mod bit with wood fiber cover board – new

1 – Sample Naming Convention

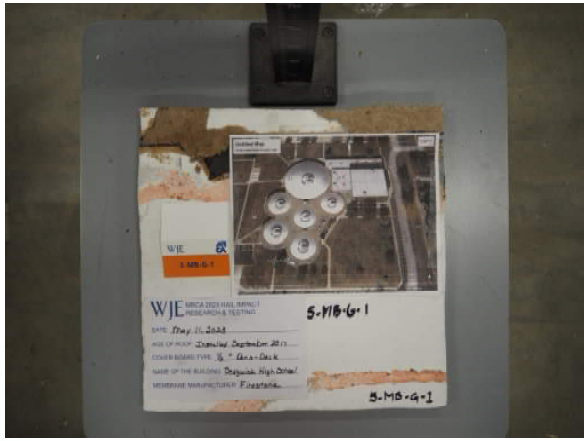
- Label created for each sample

Sample Age		Membrane Type		Cover Board Type		Sample No.	
N	New	MB	Modified Bitumen	G	Gypsum Cover Board	1	Sample No. 1
5	5 Years Old			W	Wood Fiber Cover Board	2	Sample No. 2
10	10 Years Old					3	Sample No. 3

1 – Photograph Samples

- Sample Photos (as received)

5 and 10 year old samples
wood fiber cover board
(Jim Ramser, T&R member)

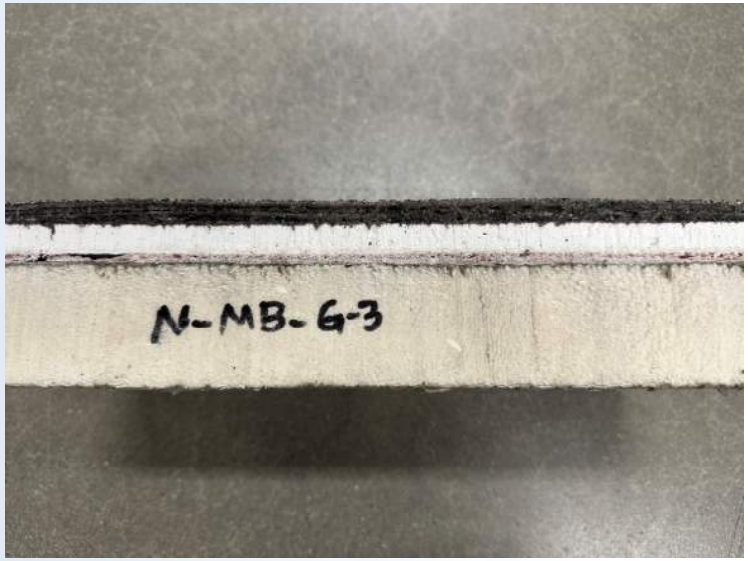


5 and 10 year old samples
gypsum cover board
(Kurt Steinkuhler, T&R member)

New samples
gypsum/wood fiber cover board
(Chris Daly, T&R member)

1 – Photograph Samples

- Cross sections of as received samples



2 – Trim Samples

- Samples trimmed to 12″ x 12″ test size

2 – Divide Samples into Zones

- Samples divided into zones and 3" dia. circles added

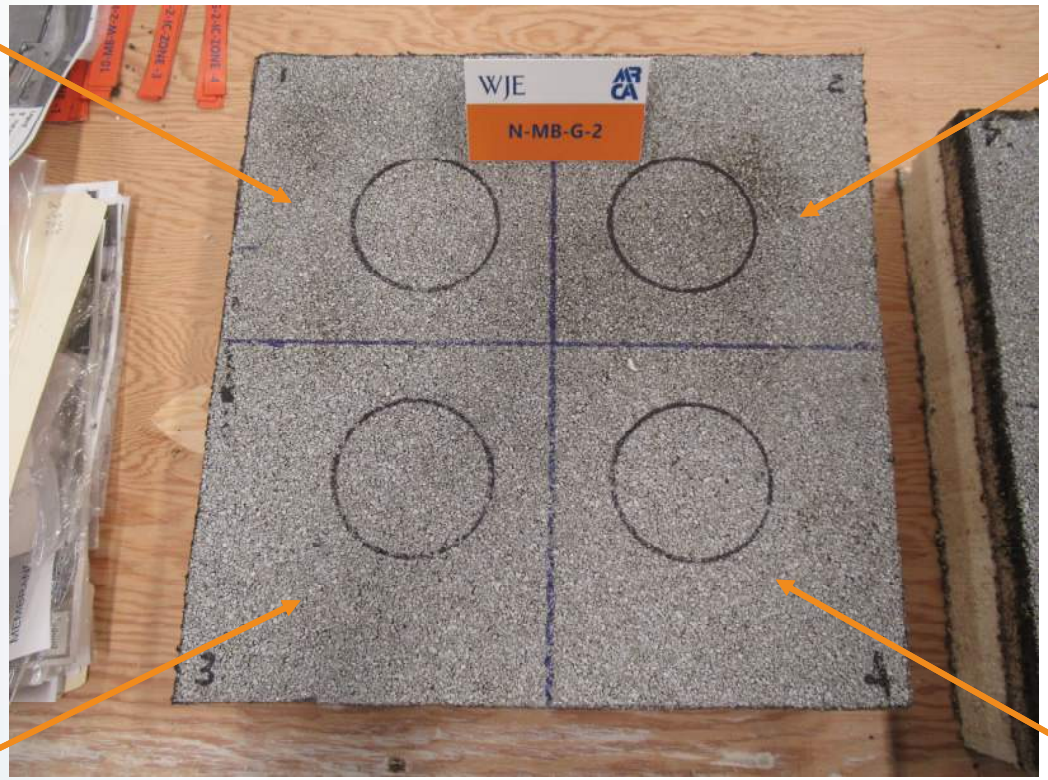
5 and 10 year old samples
wood fiber cover board
(Jim Ramser, T&R member)

5 and 10 year old samples
gypsum cover board
(Kurt Steinkuhler, T&R member)

New samples
gypsum/wood fiber cover board
(Chris Daly, T&R member)

2 – Sample Zones

Zone 1 – image analysis manual granule counts

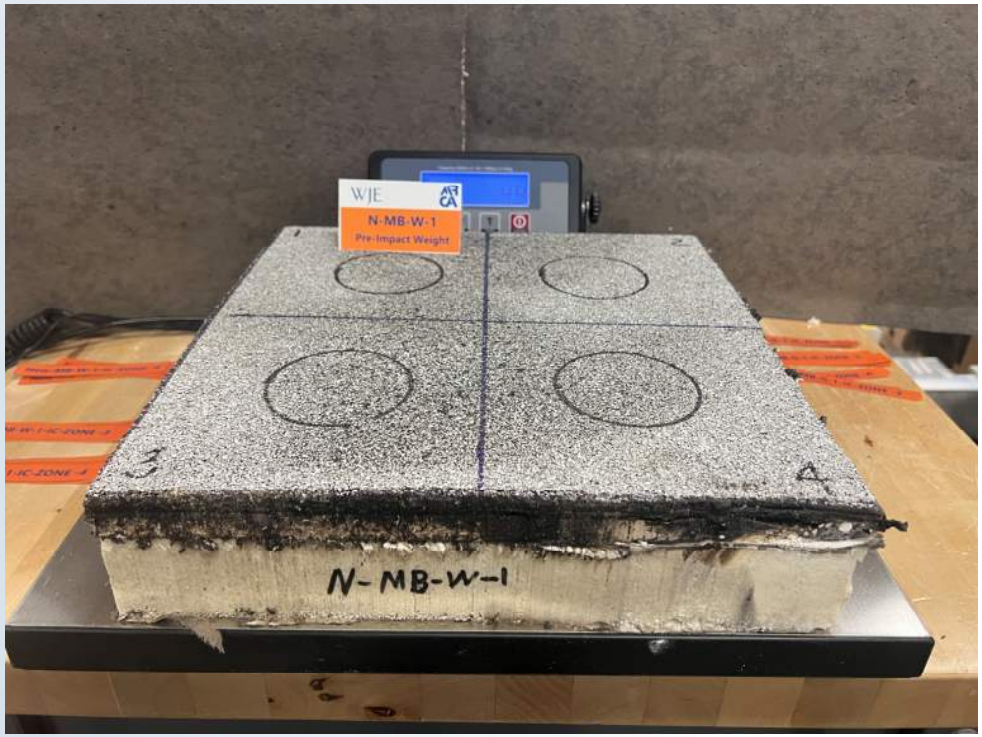


Zone 2 – image analysis

Zone 3 – image analysis desaturation

Zone 4 – image analysis cross section

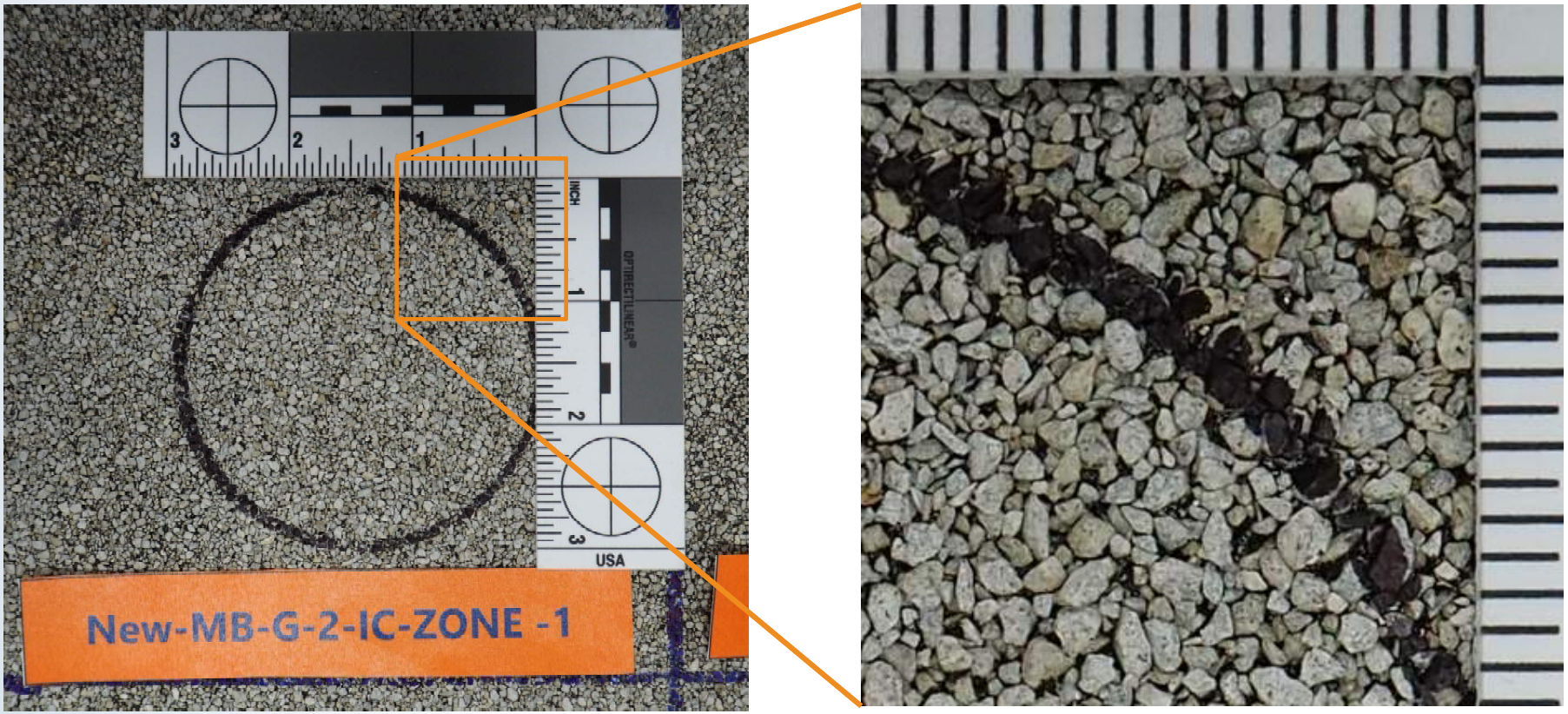
3 – Sample Weights (pre-impact)



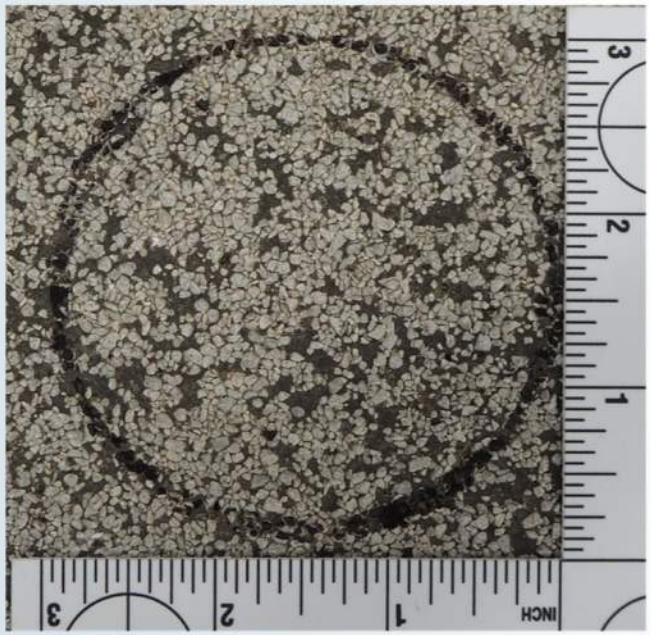
3 – Image Analysis (pre-impact)

- Granule Counts (prior to impact)
  - "Image Analysis" – Computer program is used to analyze a high-resolution photograph to identify features of interest (granules). A black and white image is created from the original color image (color thresholding). This enables the computer program to determine quantitative information regarding the image (granule counts and exposed asphalt area).

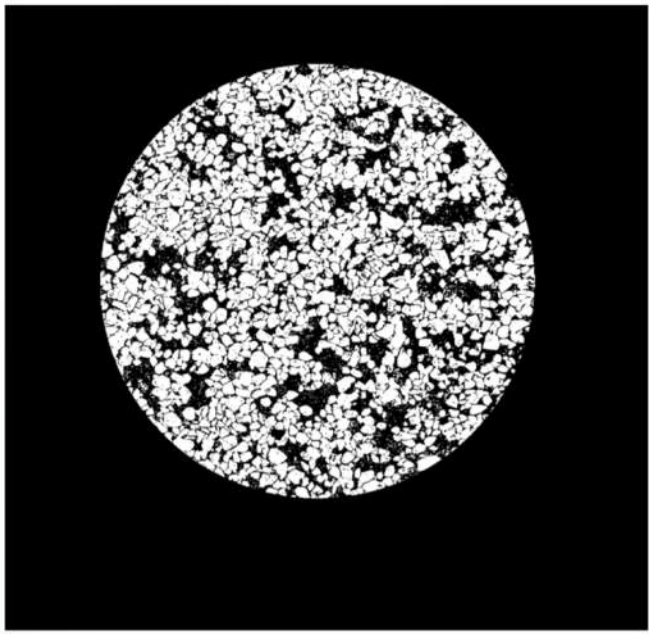
3 – Image Analysis



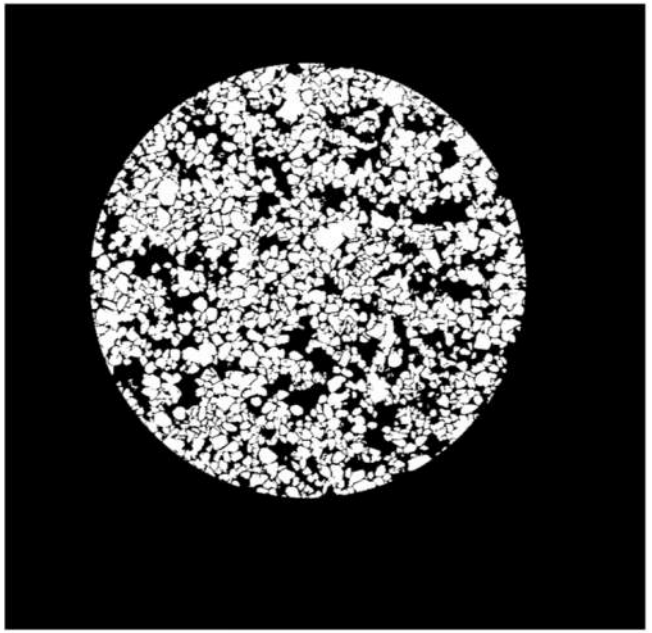
3 – Image Analysis



Initial image

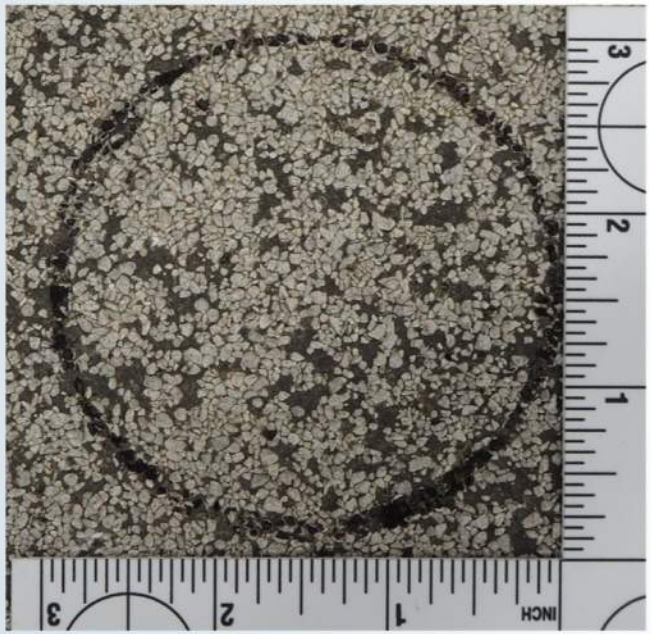


Convert to binary
(black and white)

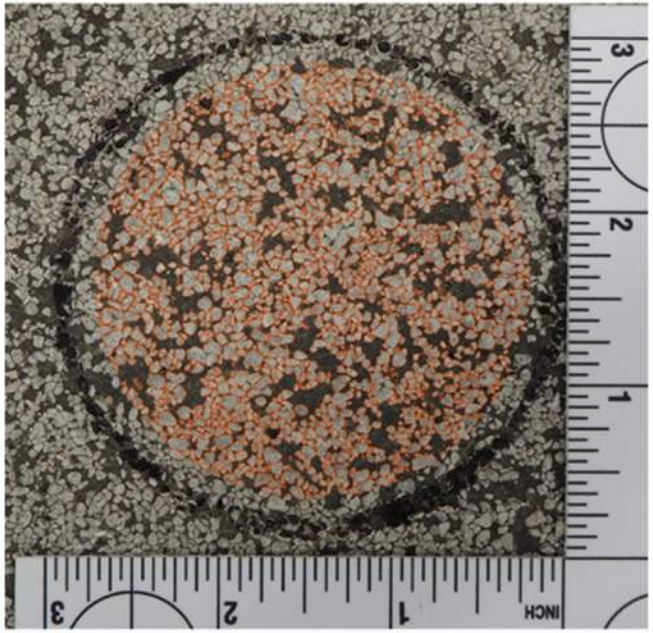


Filter out noise

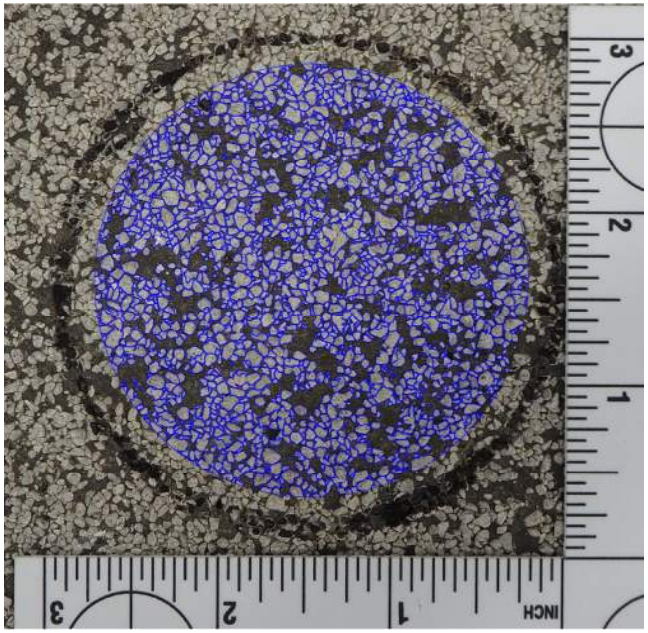
3 – Image Analysis



Initial image



Identify granules
(coarse)

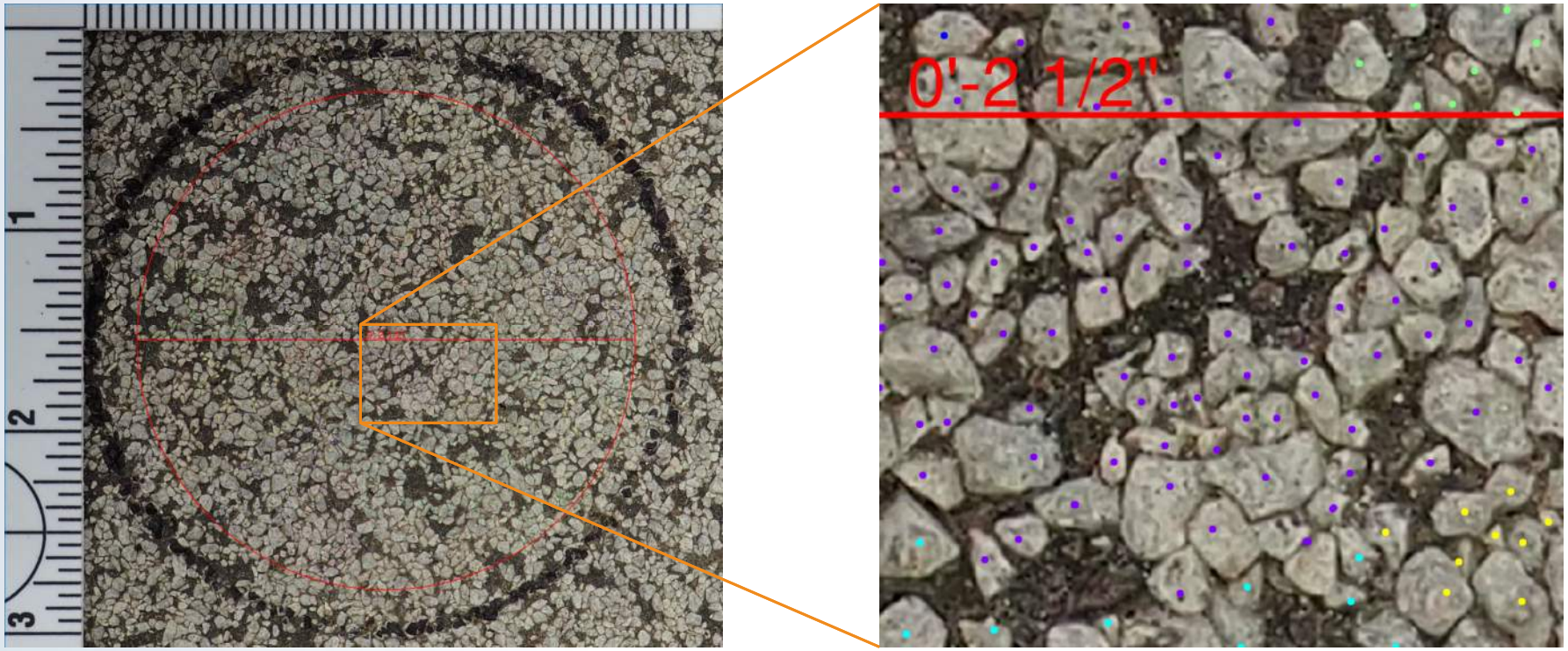


Identify granules
(fine)

3 – Image Analysis

- Manual Granule Counts
  - 2.5″ diameter area within the 3″ diameter impact zone
  - Image analysis results compared to manual granule counts, conducted on one quadrant of each sample
    - Assists in optimization of code
    - Allows for better understanding of granule systems-spacing, quality of adhesion, etc.

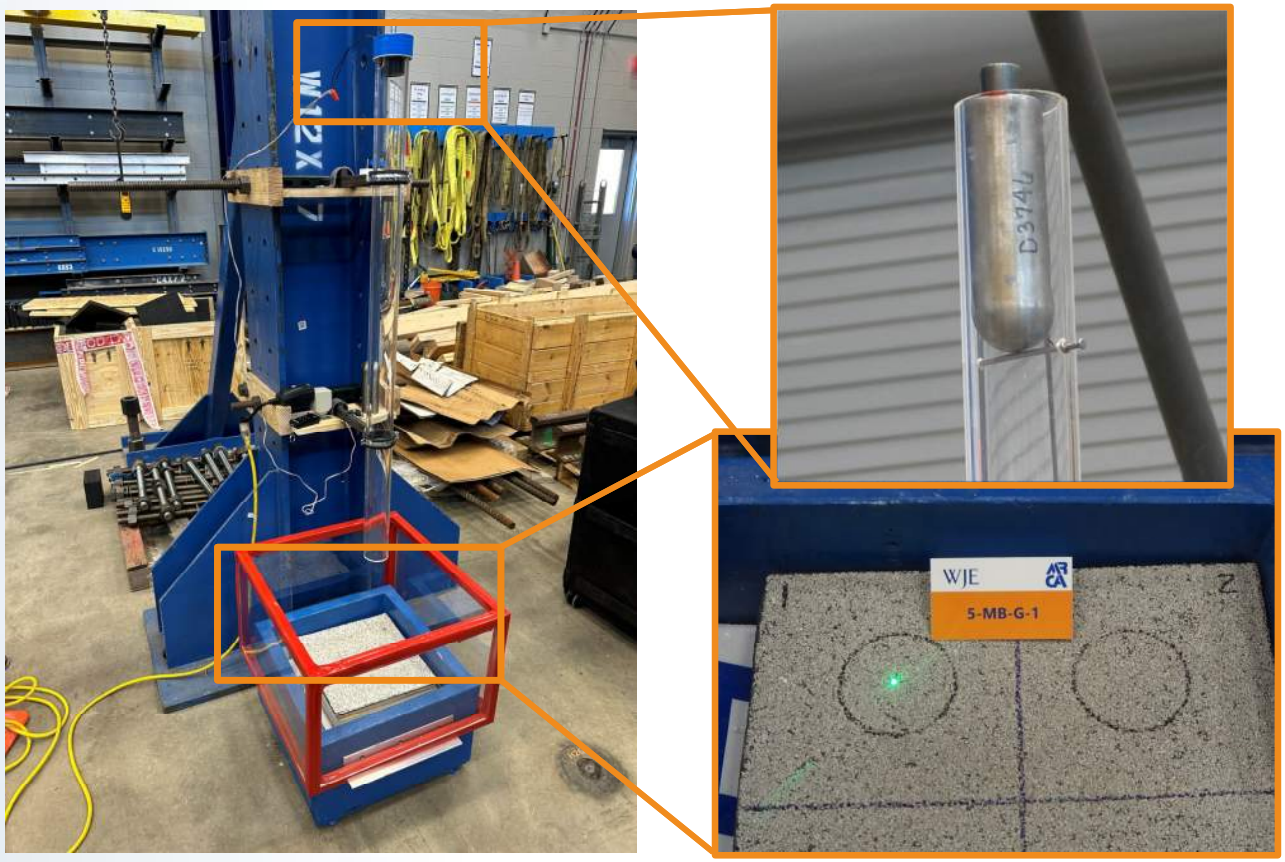
3 – Manual Counts



4 – Sample Impact

- ASTM D3746 *Standard Test Method for Impact Resistance of Bituminous Roofing Systems*
- Impact missile per ASTM

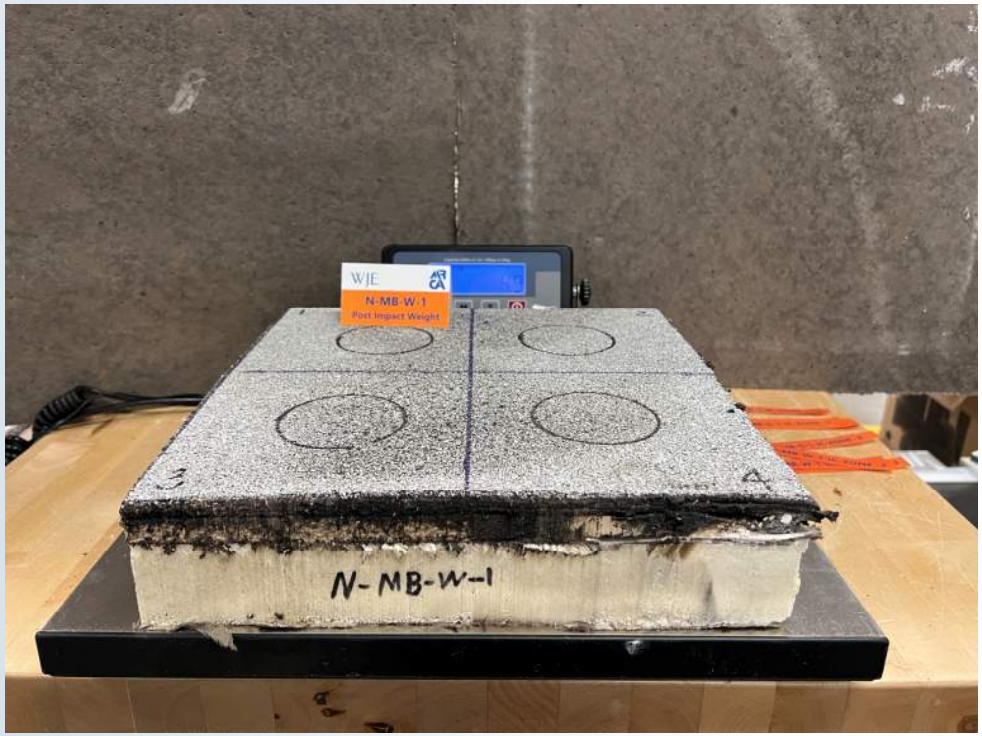
4 - Testing Apparatus

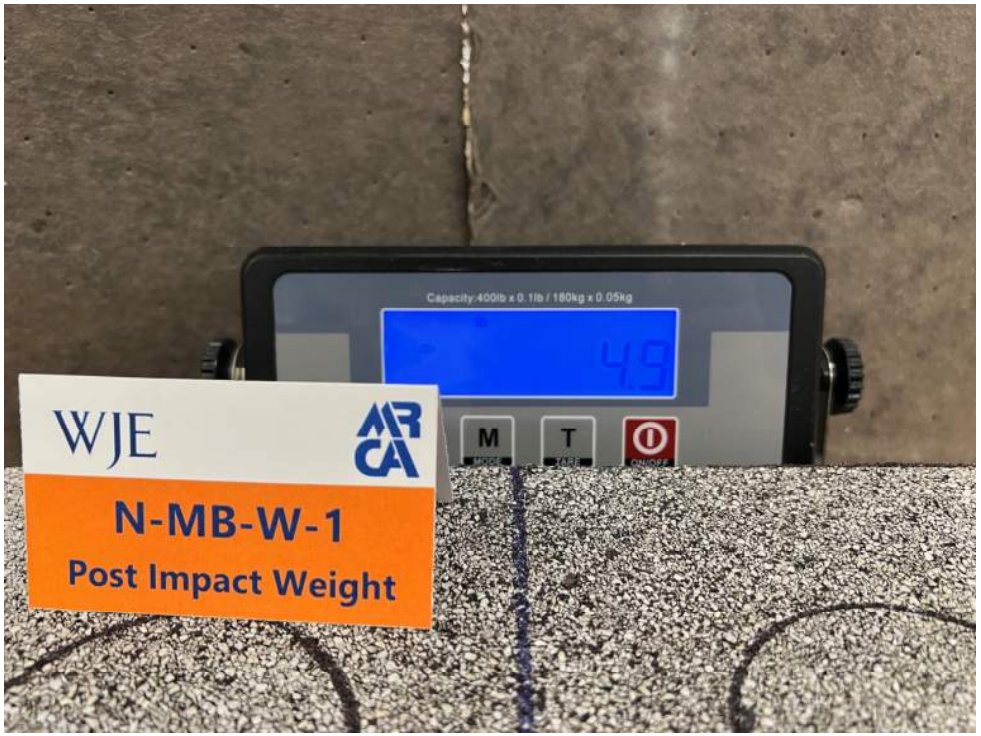


4 - Impact Testing

4 - Impact Testing

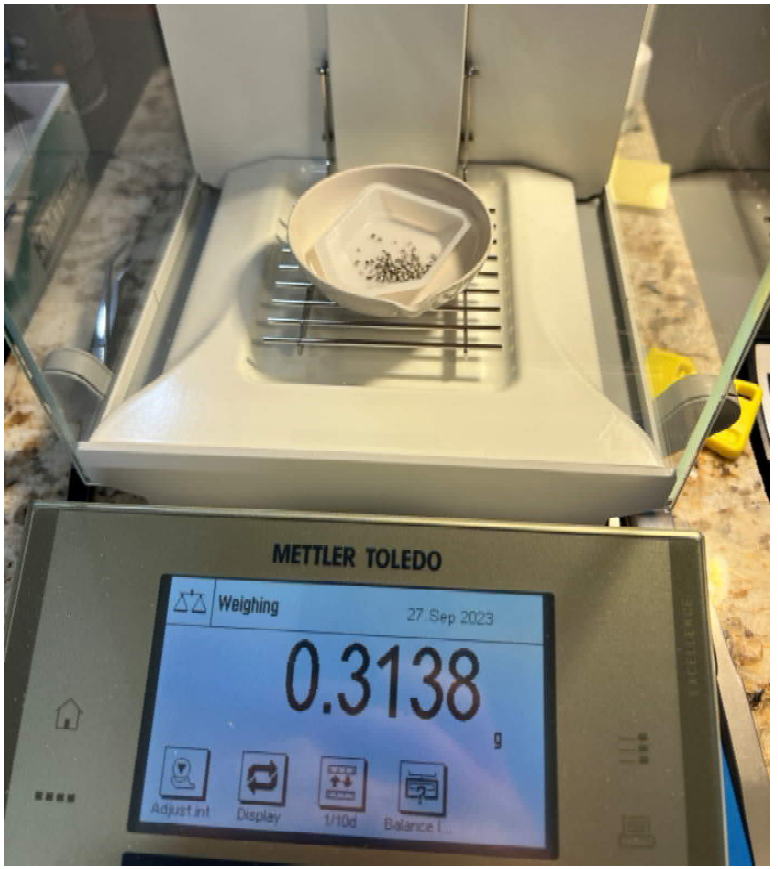
5 – Sample Weights (post-impact)



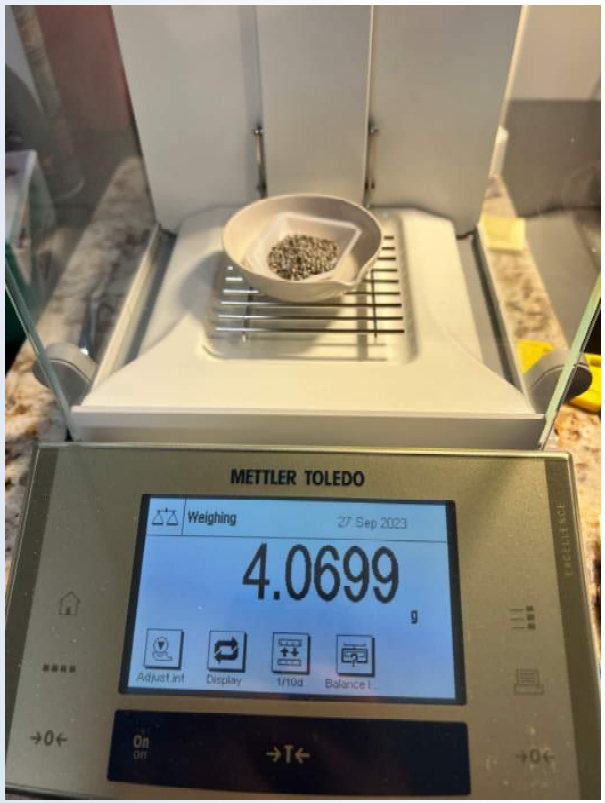


5 – Granule Weights

Number of Granules	Weight (g)
1	0.0049
10	0.0402
100	0.3138
1000	2.1115
1700	4.0699



5 – Granule Weights



5 – Granule Weights

- 2.5″ Diameter (7.85 in^2) Circle on a New Roof
  - Average Number of Granules: 2,800
  - Approximate Weight of these Granules: 6 g, or 0.013 lb
  - Approximate Number of Granules Lost After One Impact: 20
  - Approximate Weight of these Lost Granules: 0.8 g, or 0.002 lb

5 – Granule Weights

- Extrapolate to a 10′ by 10′ Roofing Square (100 ft^2)
  - Approximate Number of Granules: 5,140,000
  - Approximate Weight of these Granules: 1,100 g, or 2.42 lb
  - Approximate Number of Lost Granules (assume 10 impacts per square): 200
  - Approximate Weight of Lost Granules: 0.6276 g, or 0.0014 lb

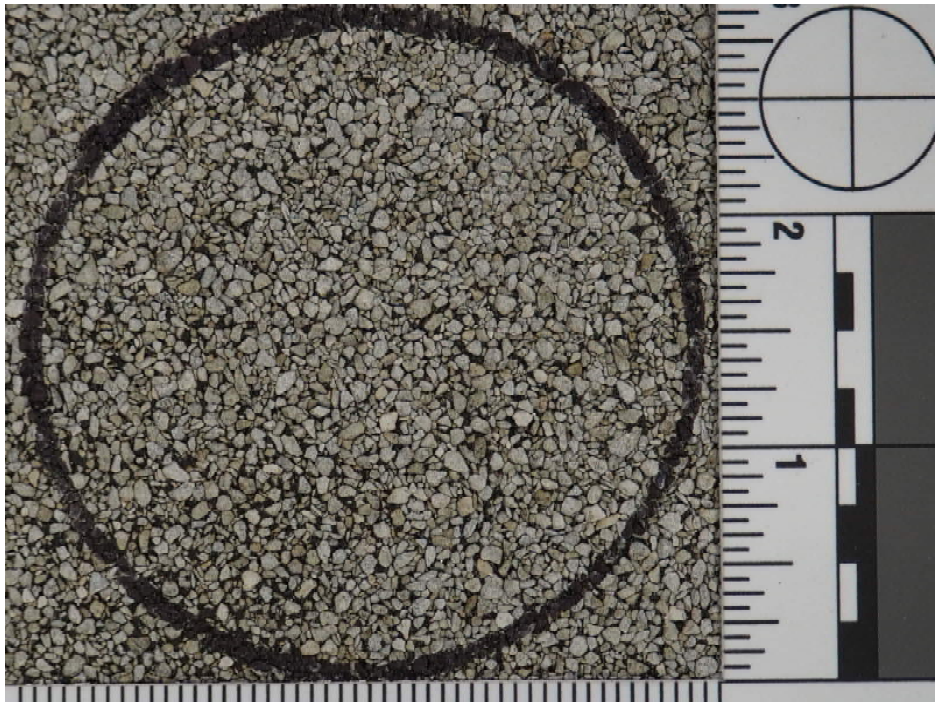
5 – Image Analysis (post-impact)

- Granule Counts (post-impact)
  - Manual and image analysis counts were conducted in the same manner as before impact
  - Allows for comparison of individual granules lost, and the additional area of asphalt exposed after impact
    - cover board
    - age of roof

5 – Pre/Post Impact Comparison

N-MB-G-1

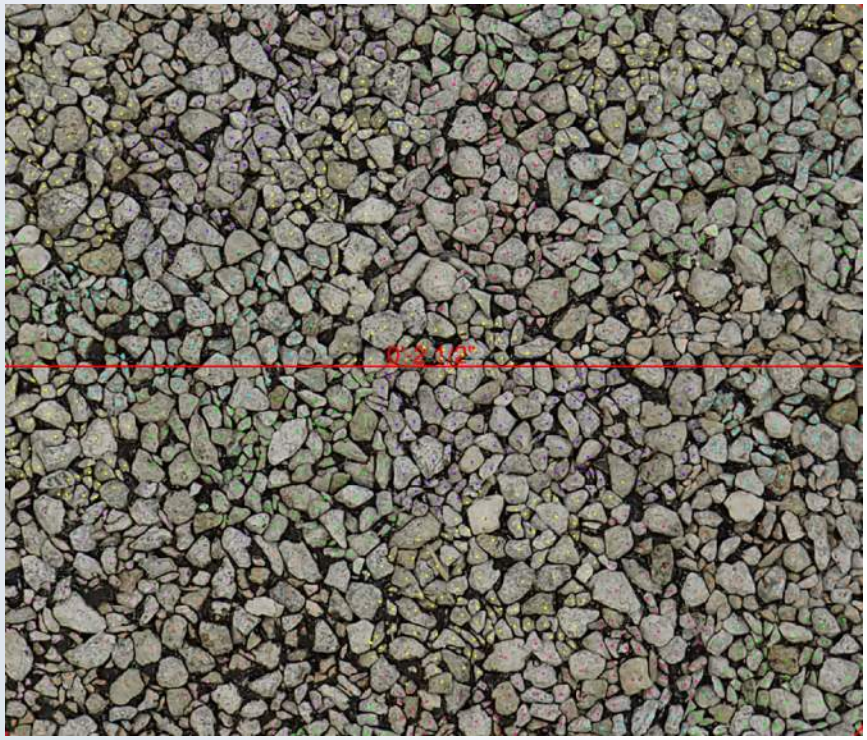
Pre-impact



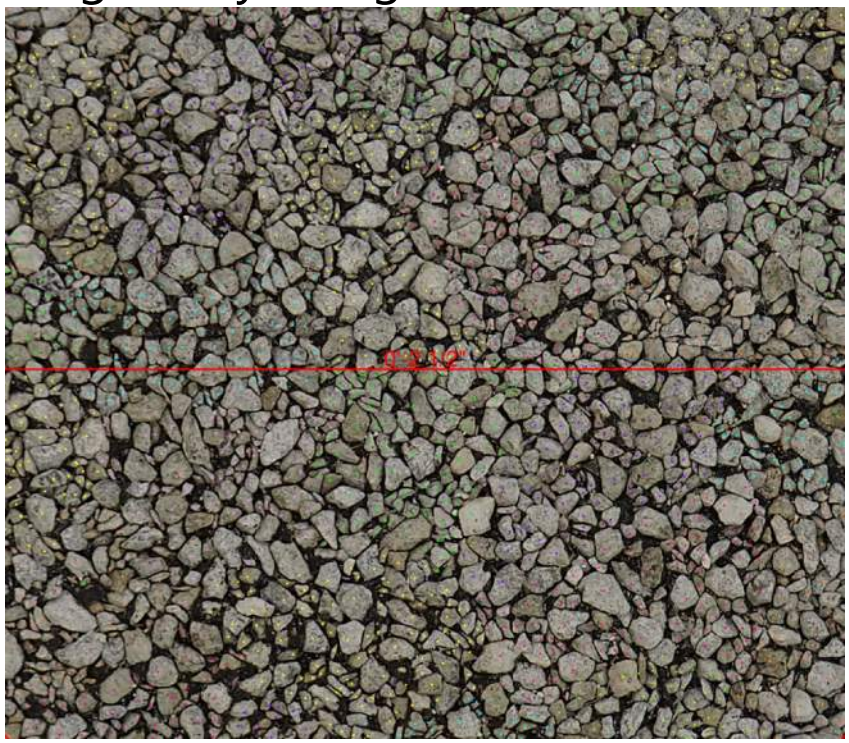
Post-impact

5 – Pre/Post Impact Comparison

N-MB-G-1. Not much noticeable change; very few granules lost



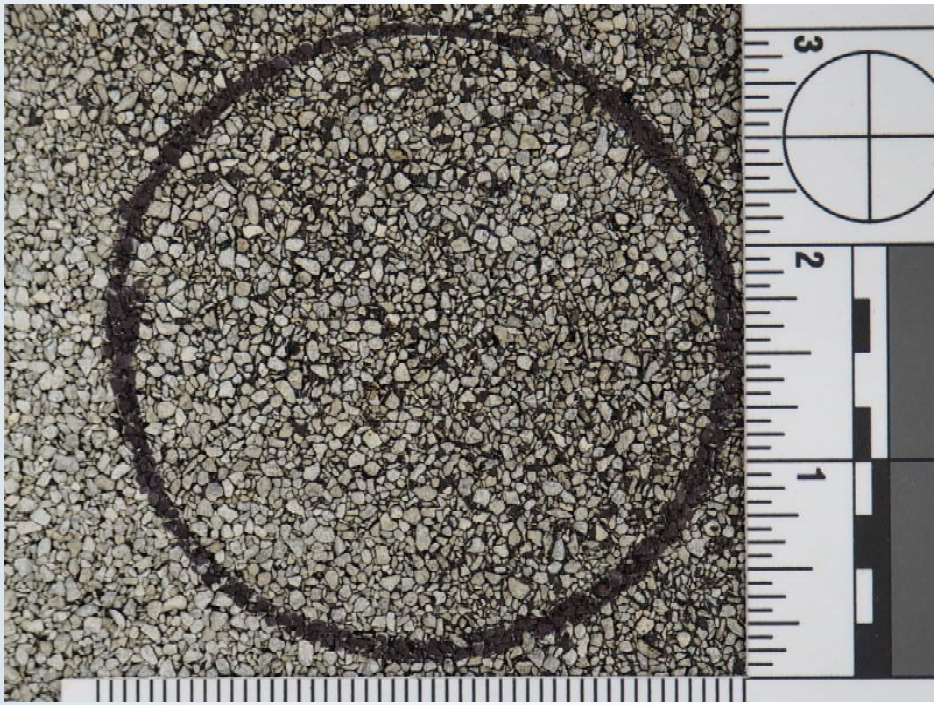
Pre-impact



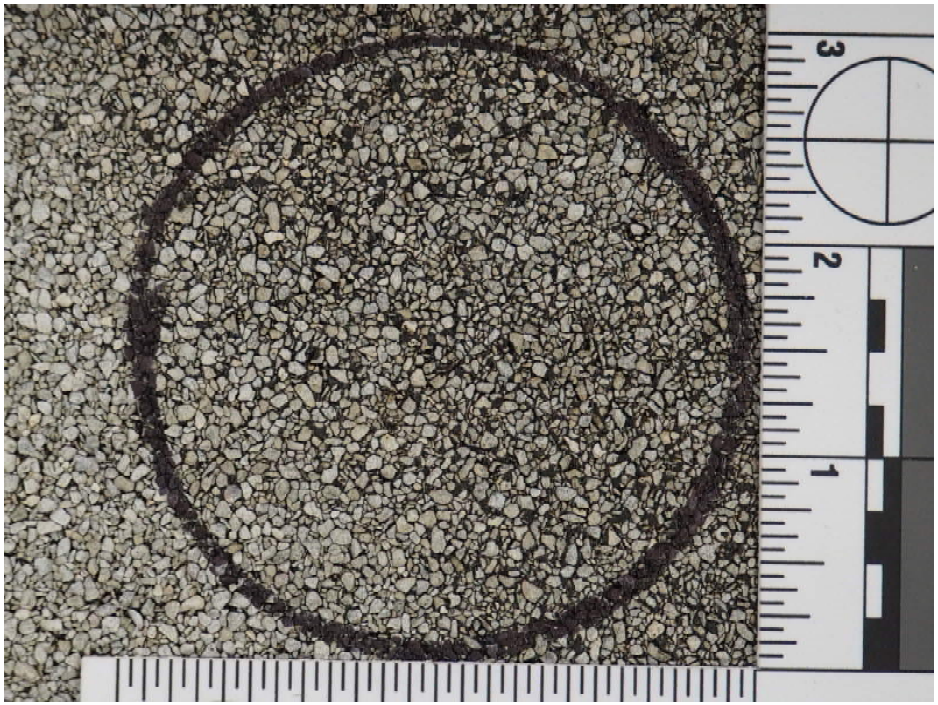
Post-impact

5 – Pre/Post Impact Comparison

N-MB-W-1



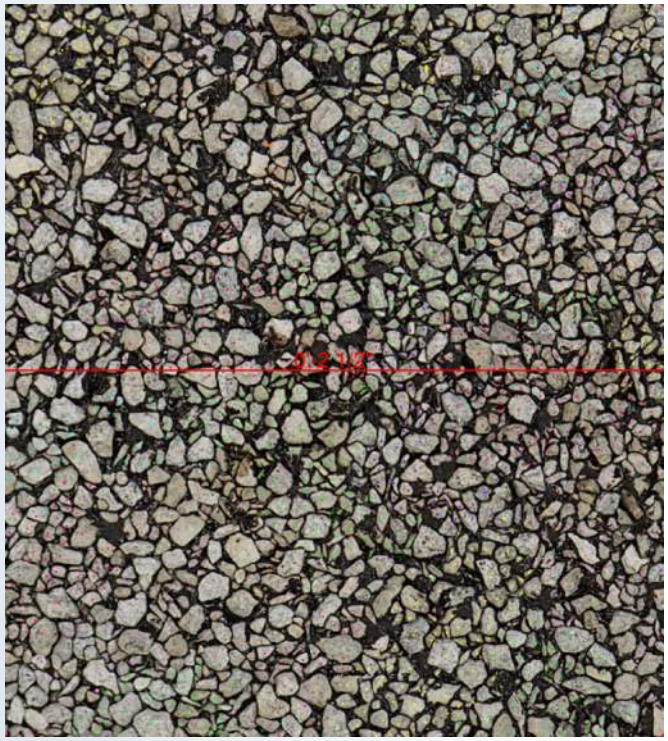
Pre-impact



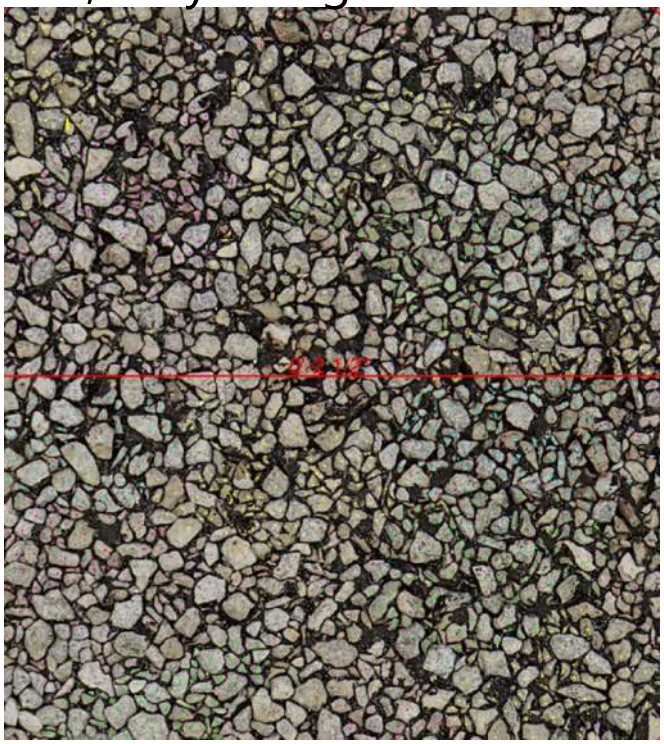
Post-impact

5 – Pre/Post Impact Comparison

N-MB-W-1. Not much noticeable loss; very few granules lost



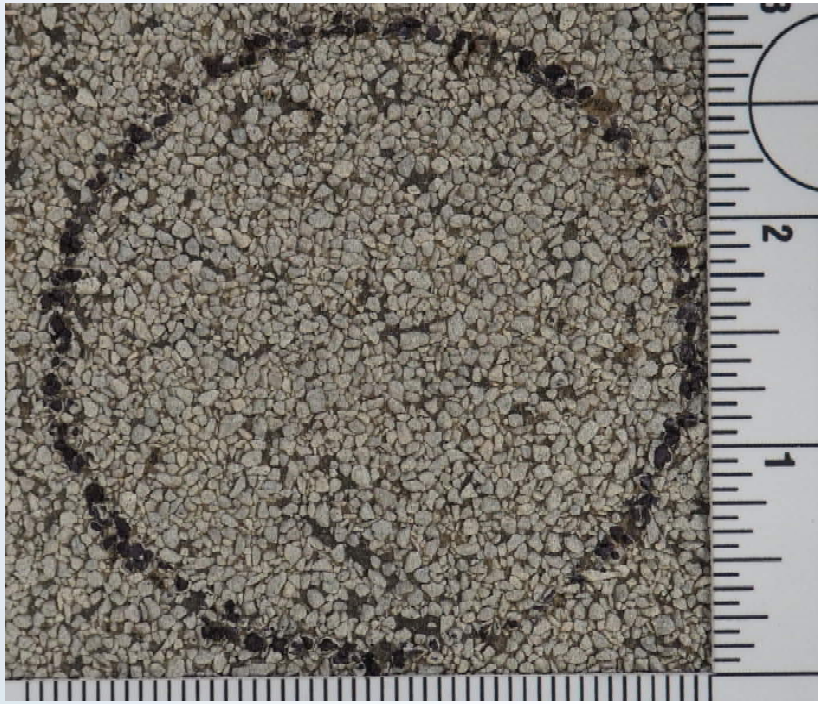
Pre-impact



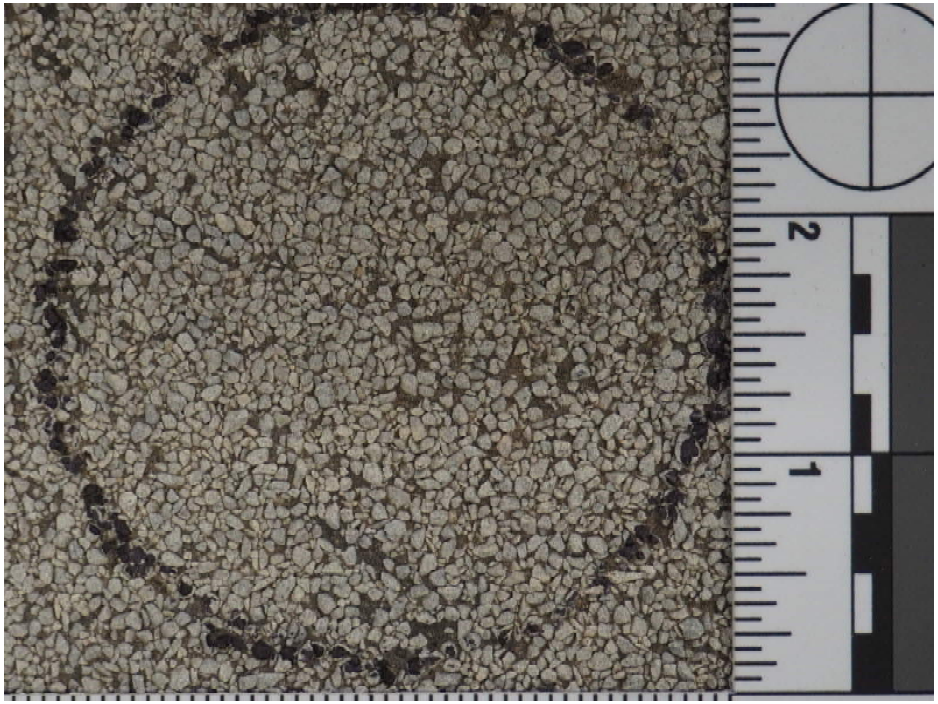
Post-impact

5 – Pre/Post Impact Comparison

5-MB-G-1



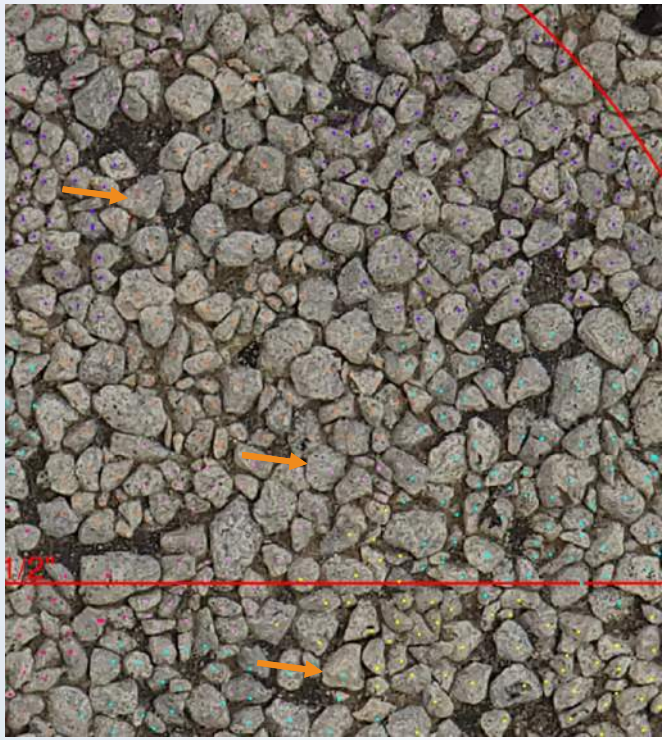
Pre-impact



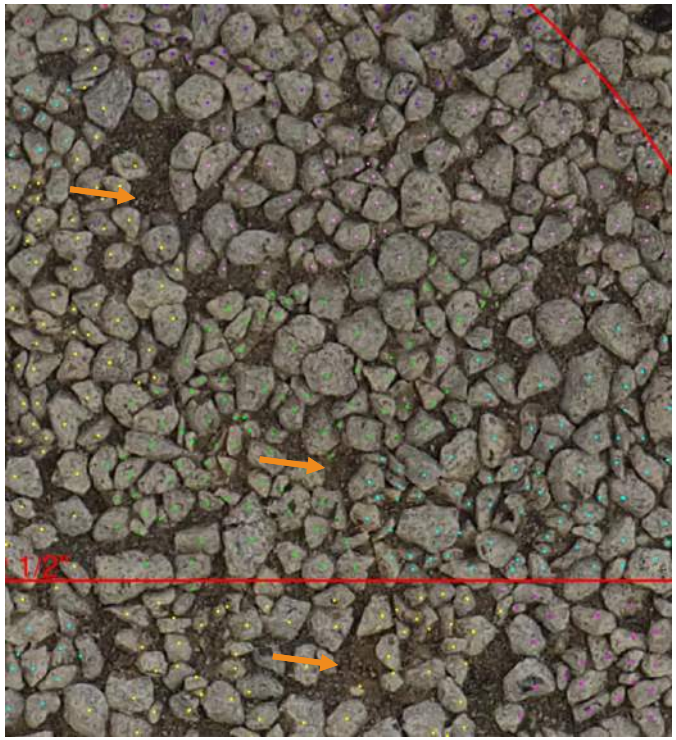
Post-impact

5 – Pre/Post Impact Comparison

5-MB-G-1. Areas with fewer granules are visible, but still few lost



Pre-impact



Post-impact

5 – Pre/Post Impact Comparison

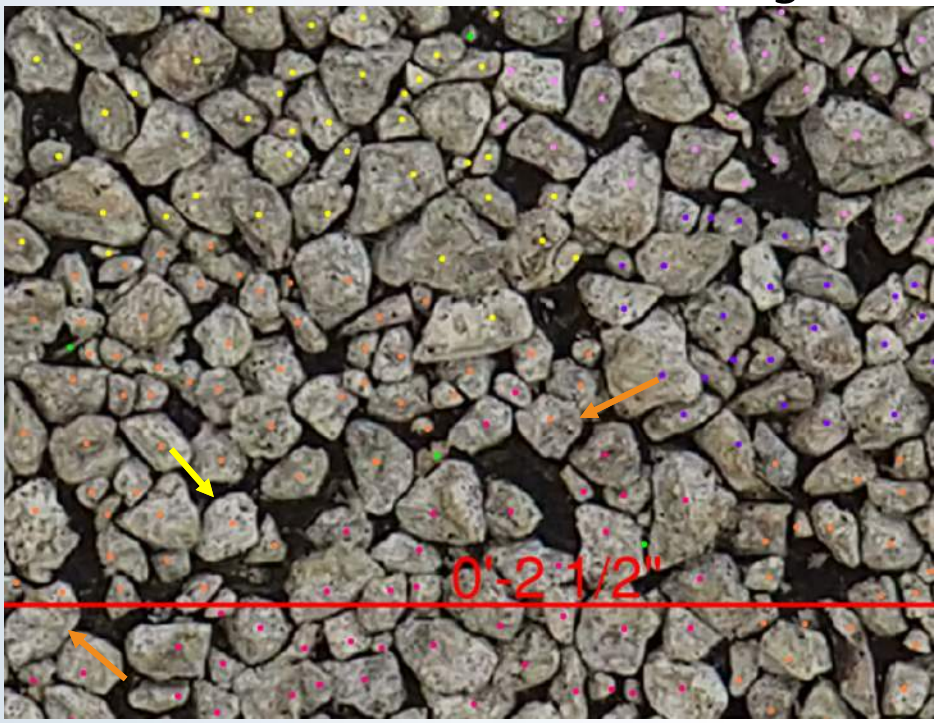
5-MB-W-1

Pre-impact

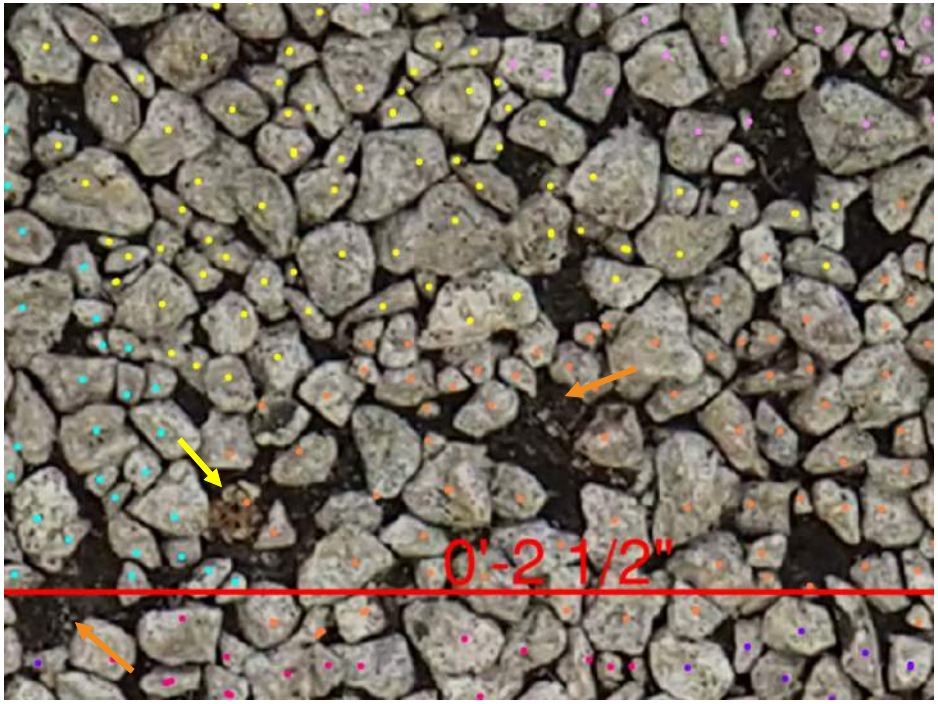
Post-impact

5 – Pre/Post Impact Comparison

5-MB-W-1. Areas with fewer granules are visible, some cracked or removed



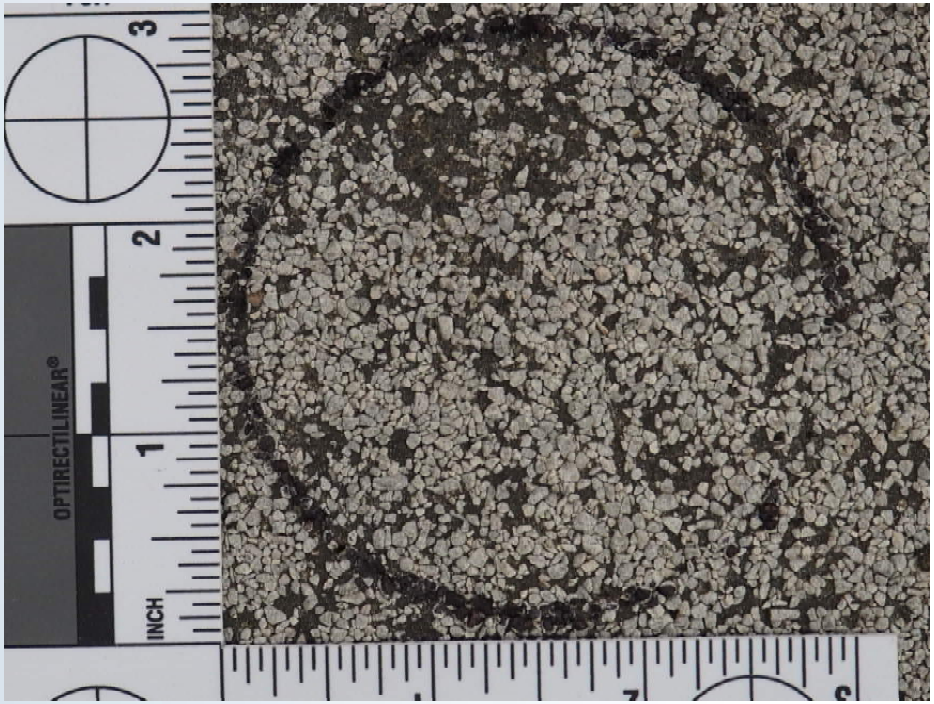
Pre-impact



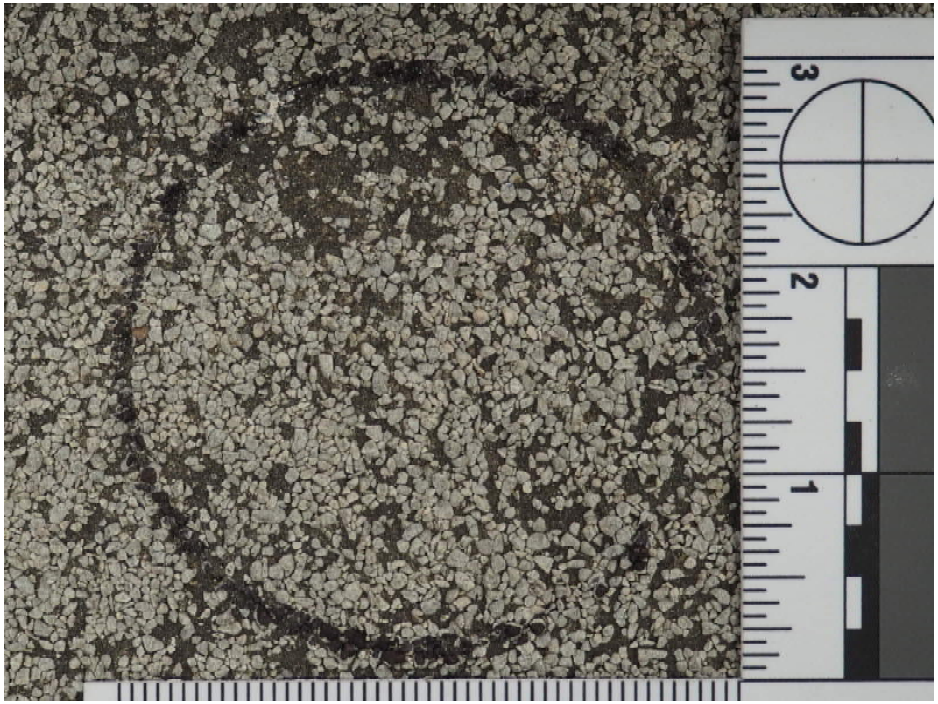
Post-impact

5 – Pre/Post Impact Comparison

10-MB-G-1



Pre-impact



Post-impact

5 – Pre/Post Impact Comparison

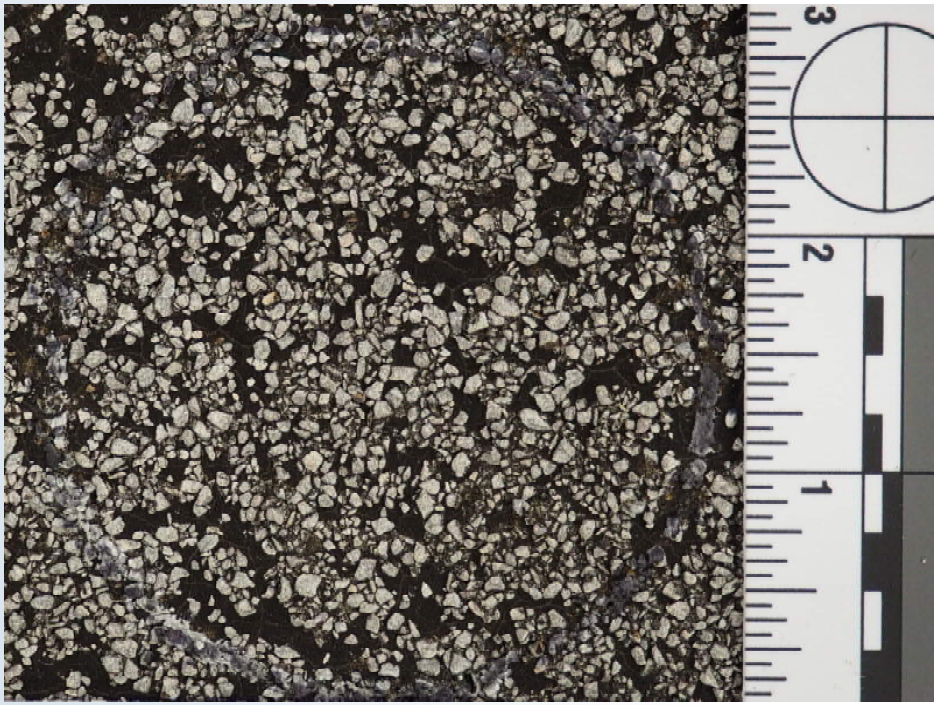
10-MB-G-1. Granules breaking or changing shape, resulting in more granules

Pre-impact

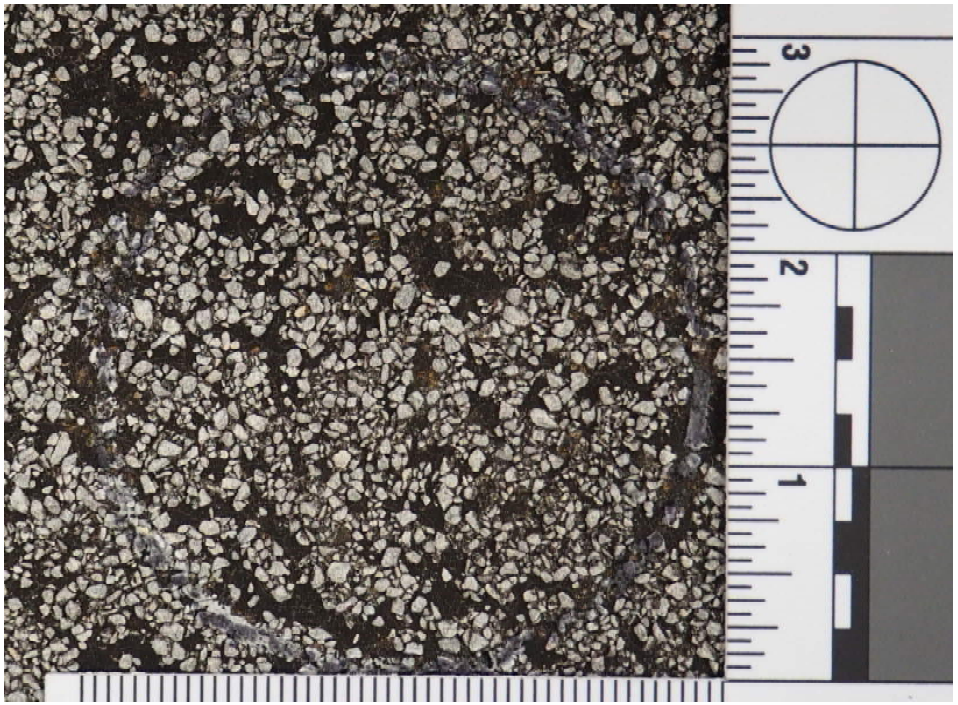
Post-impact

5 – Pre/Post Impact Comparison

10-MB-W-1



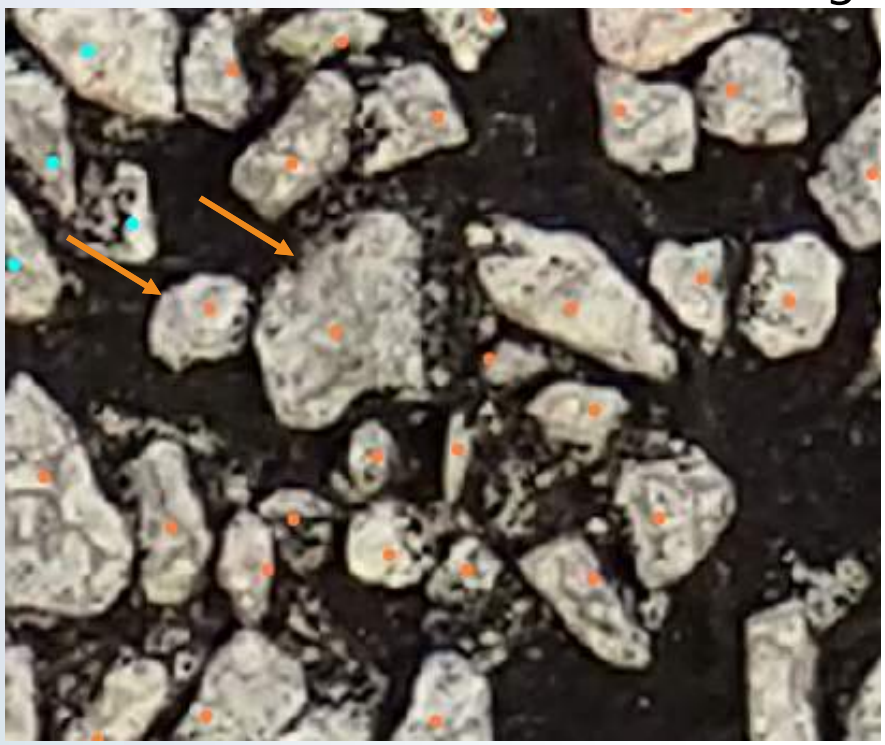
Pre-impact



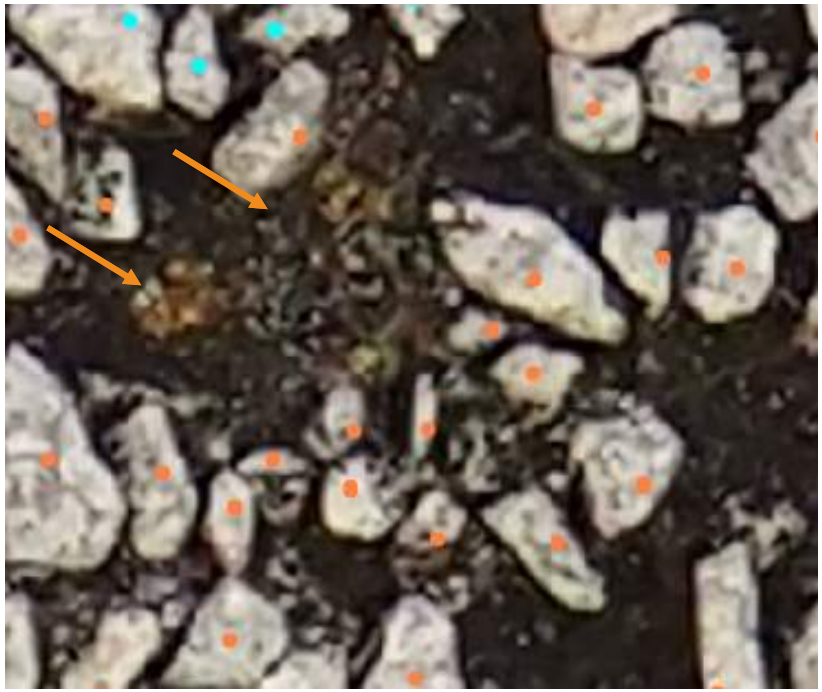
Post-impact

5 – Pre/Post Impact Comparison

10-MB-W-1. Granules breaking or being crushed, in addition to loss



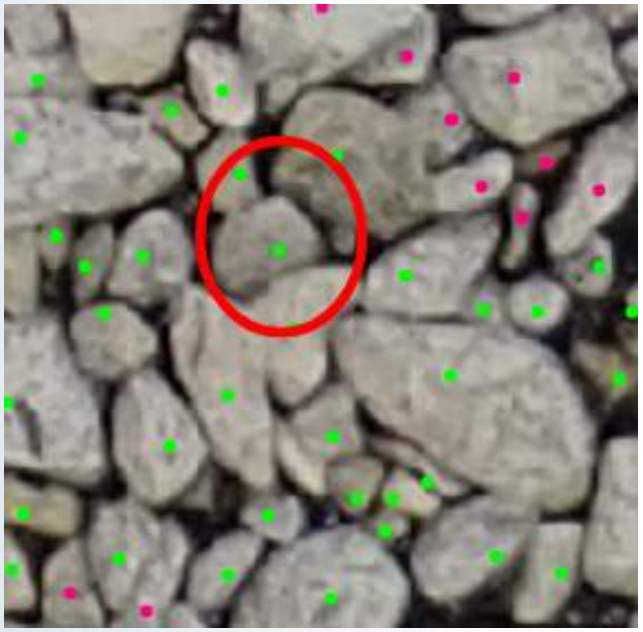
Pre-impact



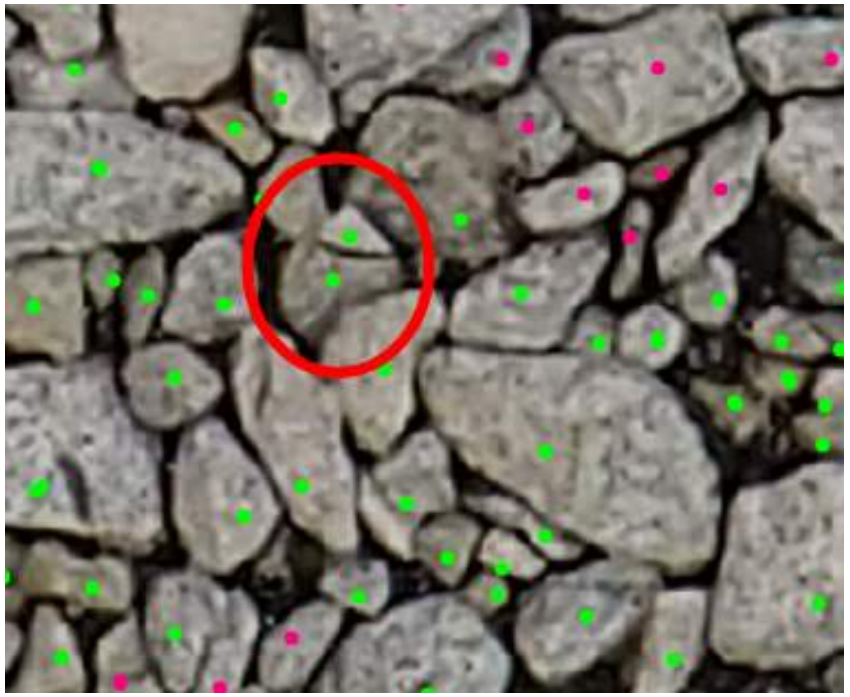
Post-impact

5 – Pre/Post Impact Comparison

N-MB-W-3. Cracking of granules observed



Pre-impact



Post-impact

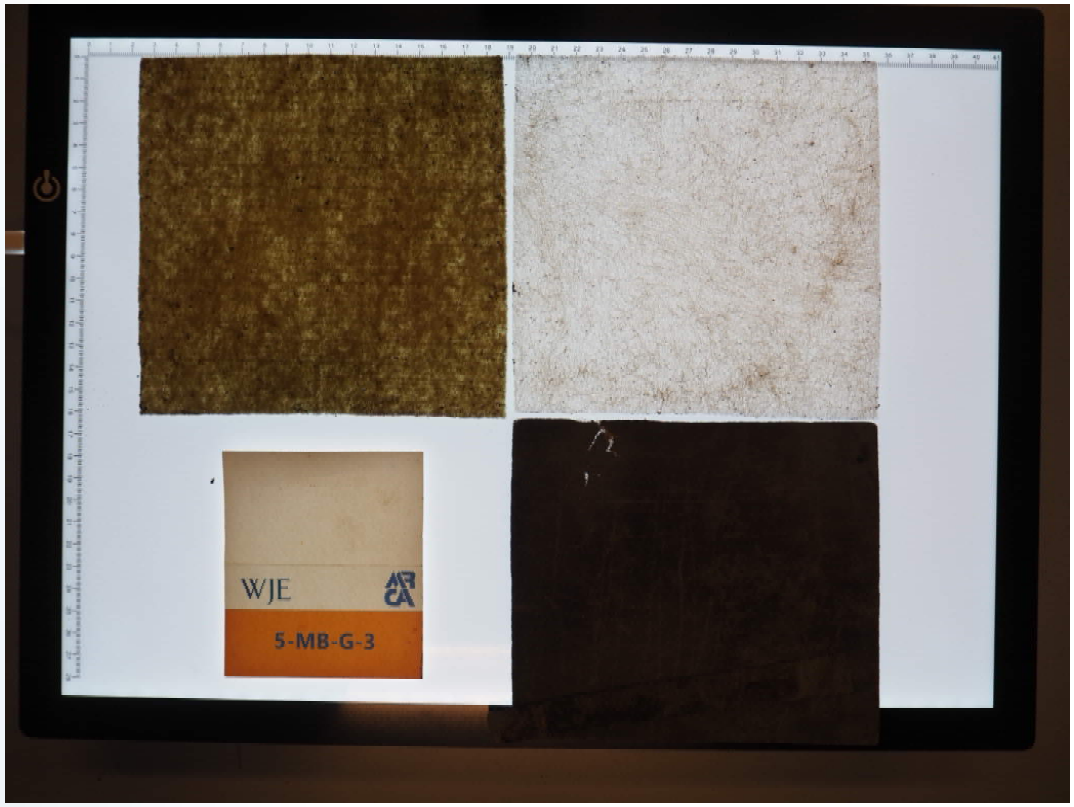
6 - Desaturation

- Desaturation – process of removing the asphalt from the membrane to expose the reinforcement

6 - Desaturation

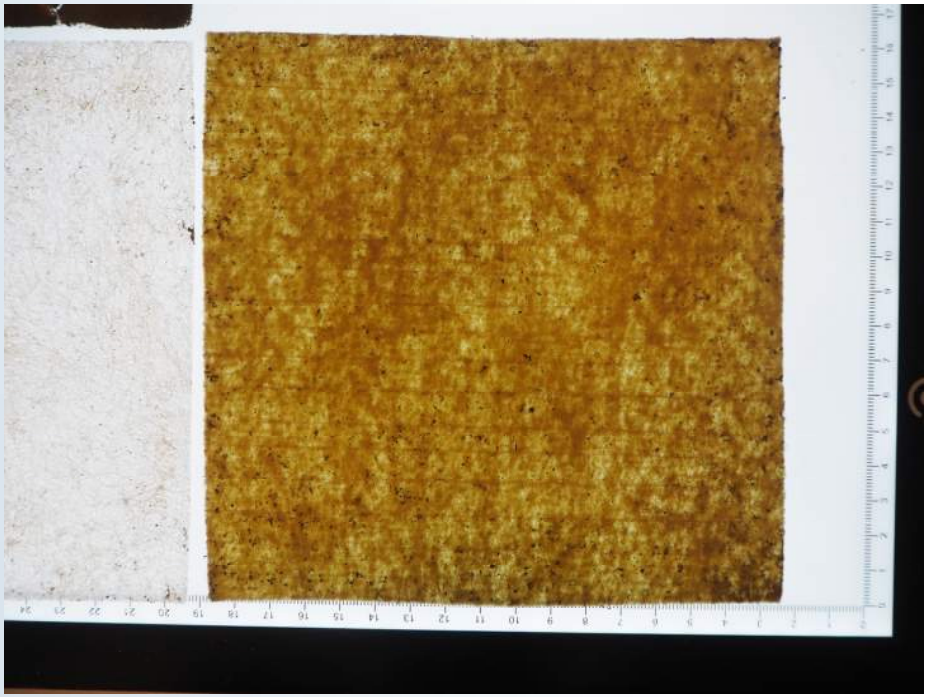
6 - Desaturation

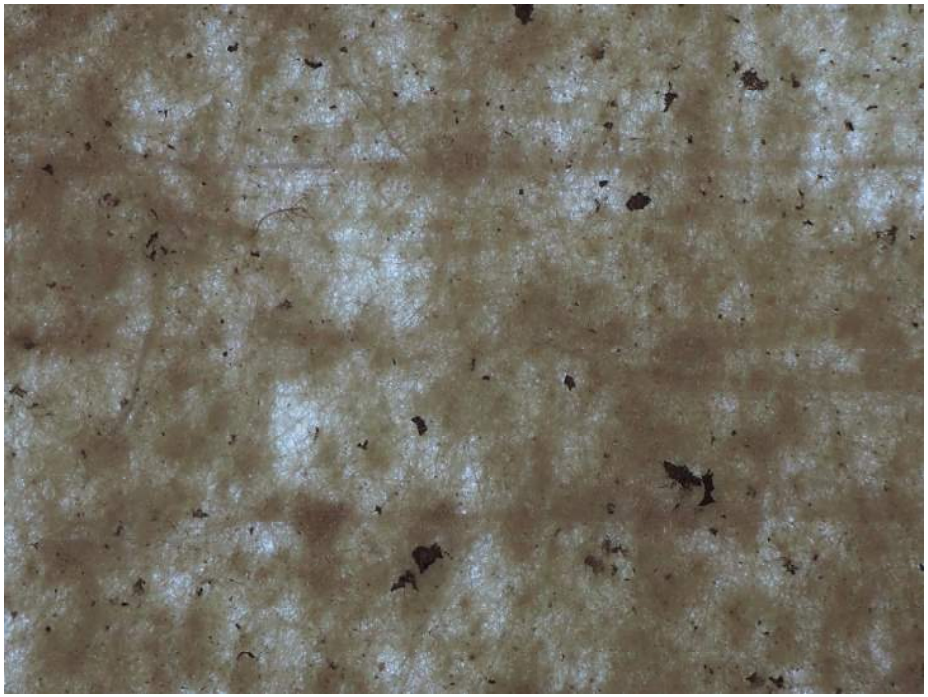
6 - Desaturation



6 - Desaturation

- Cap sheet - polyester and fiberglass dual reinforcement





6 - Desaturation

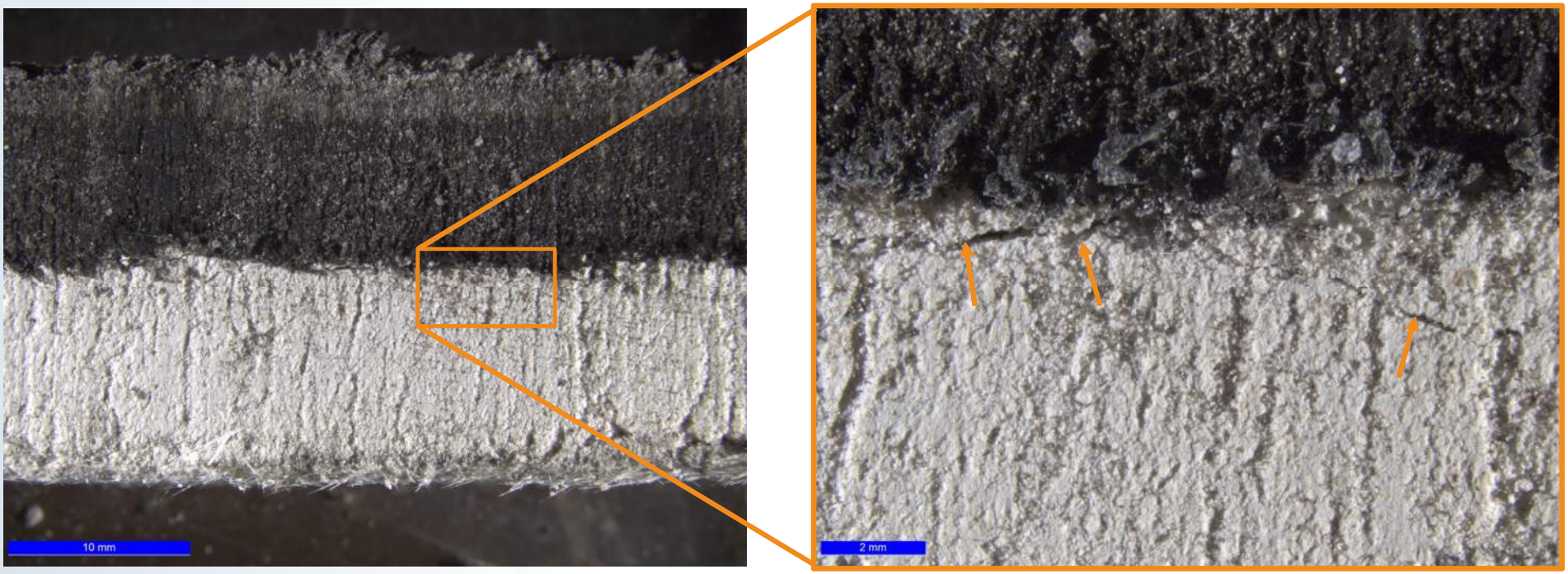
- Base sheet - fiberglass reinforcement

7 - Microscopy

- Cross sections of zone 4
  - Gypsum (N, 5, 10)
  - Wood Fiber (N, 5, 10)

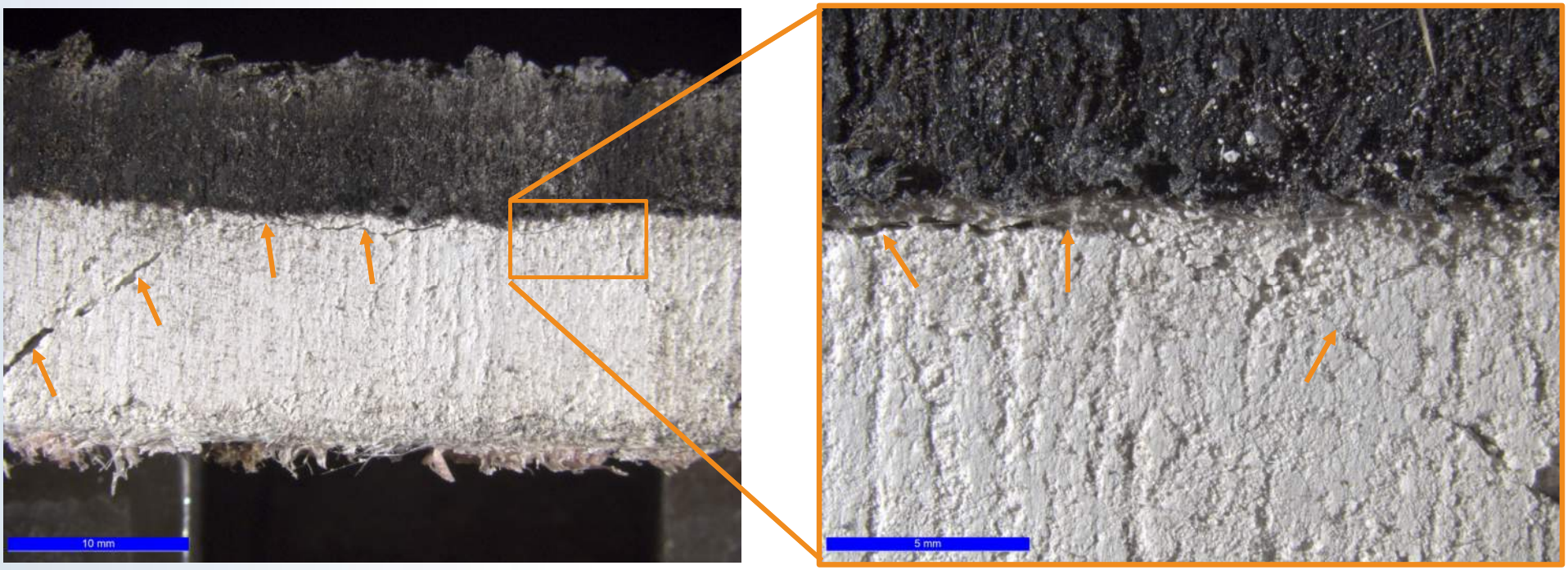
Sample Substrate	Cracking of Cover Board	Delamination within Cover Board
Gypsum	9 of 9	6 of 9
Wood Fiber	0 of 9	1 of 9

7 - Microscopy



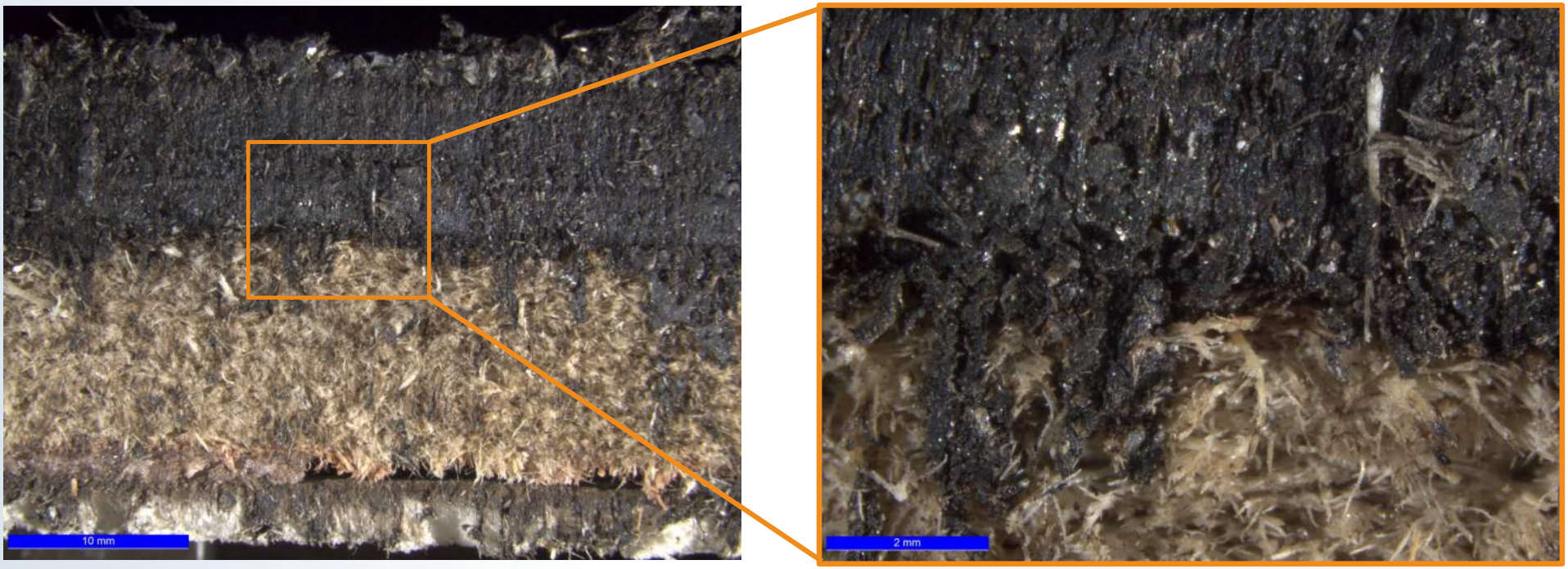
5-MB-G-1- Surface-parallel cracking just below surface of gypsum; potential radial cracking, too fine to determine if radial cracks are full depth of gypsum

7 - Microscopy



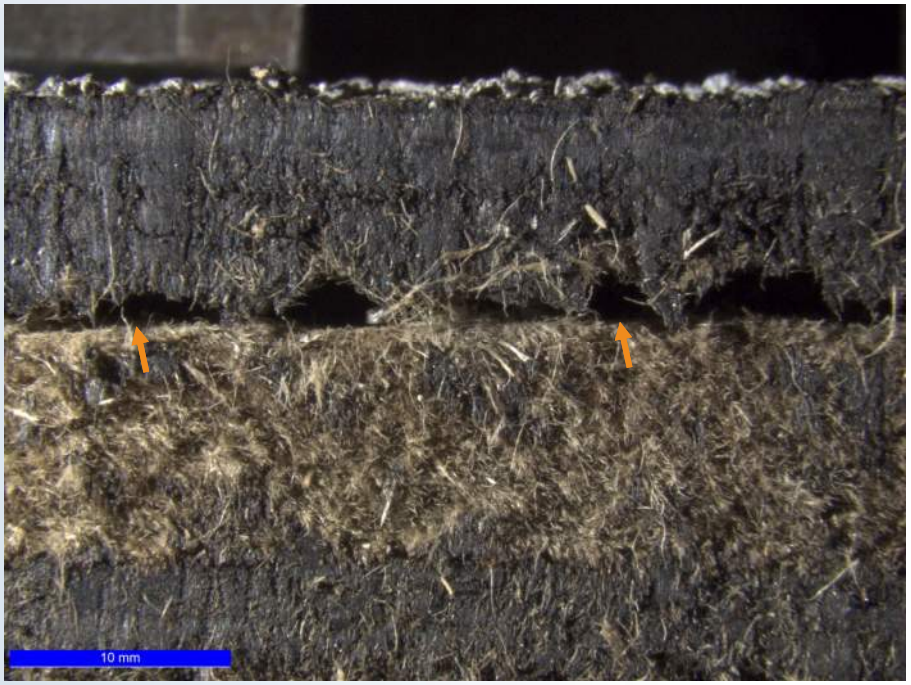
10-MB-G-3- Full separation of gypsum and bitumen at interface; radial cracking extending full depth of gypsum from impact site

7 - Microscopy

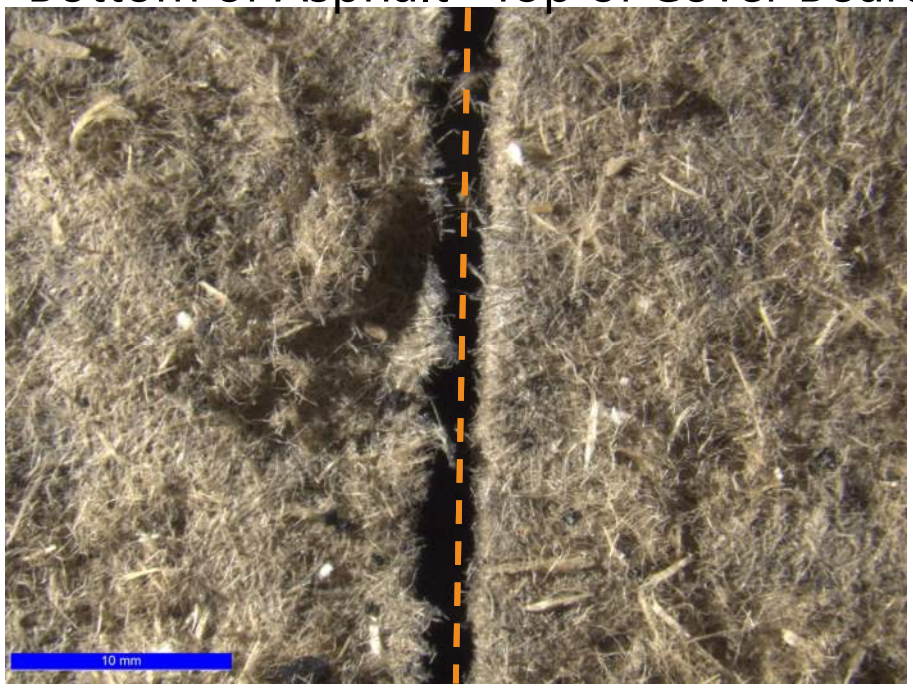


N-MB-W-1- No visible cracking or separation of the asphalt from the wood fiber board

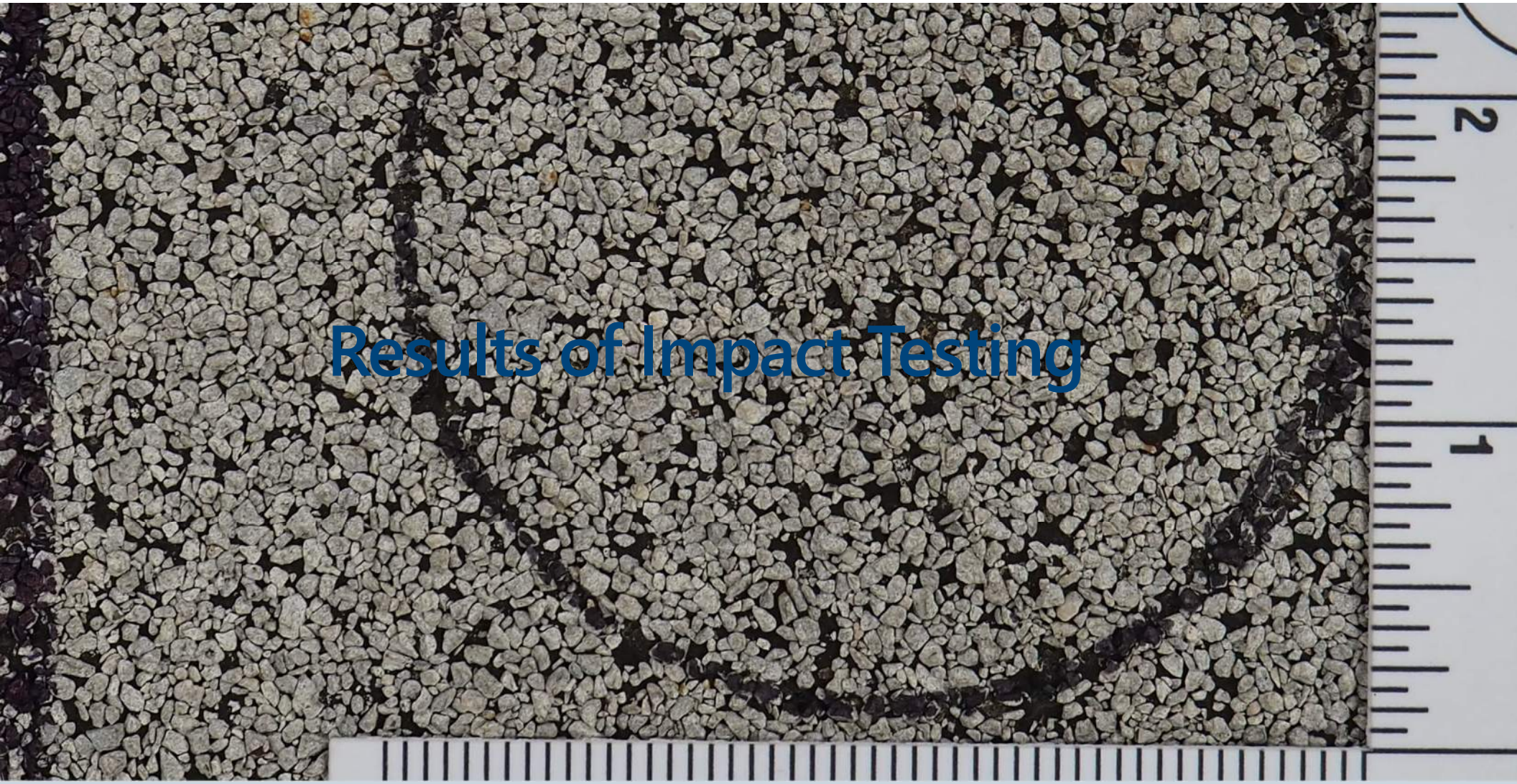
7 - Microscopy



Bottom of Asphalt Top of Cover Board



10-MB-W-2- Full separation of the asphalt from the wood fiber board on one half of observed area


Results of Impact Testing

Results of Impact Testing

- New Samples with Gypsum Cover Board

Sample	# Granules Pre-Impact	# Granules Post-Impact	Exposed Asphalt Pre-Impact	Exposed Asphalt Post-Impact
N-MB-G-1	2730	2726	32.3%	32.1%*
N-MB-G-2	2810	2772	34.2%	34.5%
N-MB-G-3	2742	2731	35.1%	36.3%
Average	**2761**	**2743**	**33.9%**	**34.3%**

*Less exposed asphalt due to granule redistribution from impact

Results of Impact Testing

- 5-year-old Samples with Gypsum Cover Board

Sample	# Granules Pre-Impact	# Granules Post-Impact	Exposed Asphalt Pre-Impact	Exposed Asphalt Post-Impact
5-MB-G-1	2150	2135	35.0%	35.6%
5-MB-G-2	2472	2464	34.2%	35.3%
5-MB-G-3	2104	2093	32.4%	34.6%
Average	**2242**	**2231**	**33.9%**	**35.2%**

Results of Impact Testing

- 10-year-old Samples with Gypsum Cover Board

Sample	# Granules Pre-Impact	# Granules Post-Impact	Exposed Asphalt Pre-Impact	Exposed Asphalt Post-Impact
10-MB-G-1	1674	1637	38.7%	40.3%
10-MB-G-2	2034	1966	39.7%	41.5%
10-MB-G-3	1827	1778	42.1%	44.8%
Average	**1845**	**1794**	**40.2%**	**42.2%**

Results of Impact Testing

- New Samples with Wood Fiber Cover Board

Sample	# Granules Pre-Impact	# Granules Post-Impact	Exposed Asphalt Pre-Impact	Exposed Asphalt Post-Impact
N-MB-W-1	2569	2546	42.7%	43.1%
N-MB-W-2	2770	2734	32.8%	32.4%*
N-MB-W-3	2822	2830**	35.0%	36.4%
Average	**2720**	**2703**	**36.9%**	**37.3%**

*Less exposed asphalt due to granule redistribution from impact
**Higher granule count due to cracking of granules

Results of Impact Testing

- 5-year-old Samples with Wood Fiber Cover Board

Sample	# Granules Pre-Impact	# Granules Post-Impact	Exposed Asphalt Pre-Impact	Exposed Asphalt Post-Impact
5-MB-W-1	2264	2238	34.0%	33.9%*
5-MB-W-2	2331	2177	33.2%	34.1%
5-MB-W-3	2143	2105	36.5%	37.2%
Average	**2246**	**2173**	**34.6%**	**35.1%**

*Less exposed asphalt due to granule redistribution from impact

Results of Impact Testing

- 10-year-old Samples with Wood Fiber Cover Board

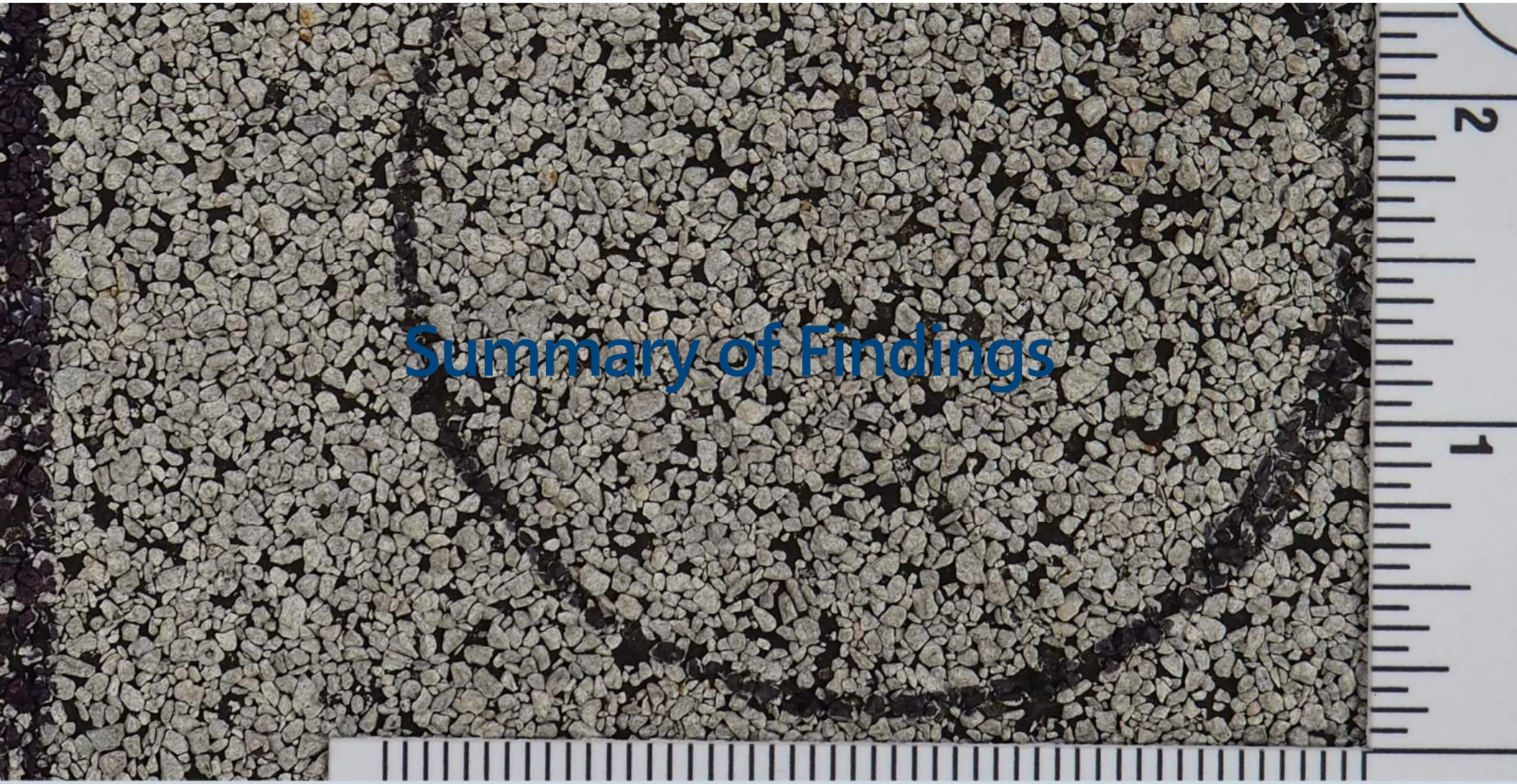
Sample	# Granules Pre-Impact	# Granules Post-Impact	Exposed Asphalt Pre-Impact	Exposed Asphalt Post-Impact
10-MB-W-1	1854	1835	57.2%	57.5%
10-MB-W-2	1550	1538	58.4%	58.2%*
10-MB-W-3	1854	1835	50.8%	51.7%
Average	**1753**	**1736**	**55.5%**	**55.8%**

*Less exposed asphalt due to granule redistribution from impact

Results of Impact Testing

- Average of all New, 5, and10-year-old Samples

Sample	# Granules Pre-Impact	# Granules Post-Impact	Exposed Asphalt Pre-Impact	Exposed Asphalt Post-Impact
N-MB-G	2761	2743	33.9%	34.3%
5-MB-G	2242	2231	33.9%	35.2%
10-MB-G	1845	1794	40.2%	42.2%
N-MG-W	2720	2703	36.9%	37.3%
5-MB-W	2246	2173	34.6%	35.1%
10-MB-W	1753	1736	55.5%	55.8%



Summary of Findings

Findings – New Samples

- Gypsum Cover Board
  - Granule counts decreased by an average of 18 due to impact.
  - Exposed asphalt area increased by 0.4% due to impact.

- Wood Fiber Cover Board
  - Granule counts decreased by an average of 17 due to impact.
  - Exposed asphalt area increased by 0.4% due to impact.

Findings – 5-year-old Samples

- Gypsum Cover Board
  - Granule counts decreased by an average of 11 due to impact.
  - Exposed asphalt area increased by 1.3% due to impact.

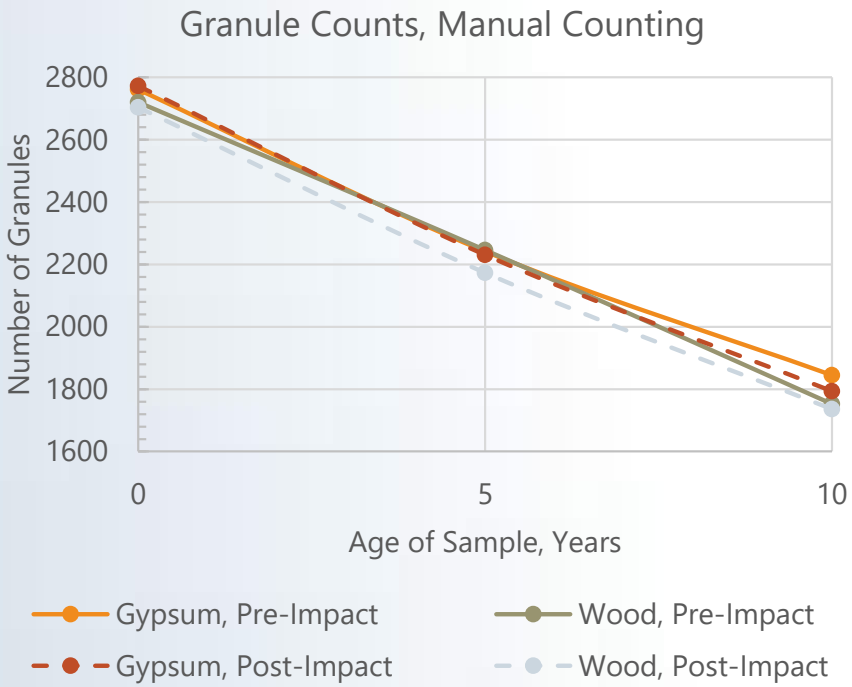
- Wood Fiber Cover Board
  - Granule counts decreased by an average of 73 due to impact.
  - Exposed asphalt area increased by 0.5% due to impact.

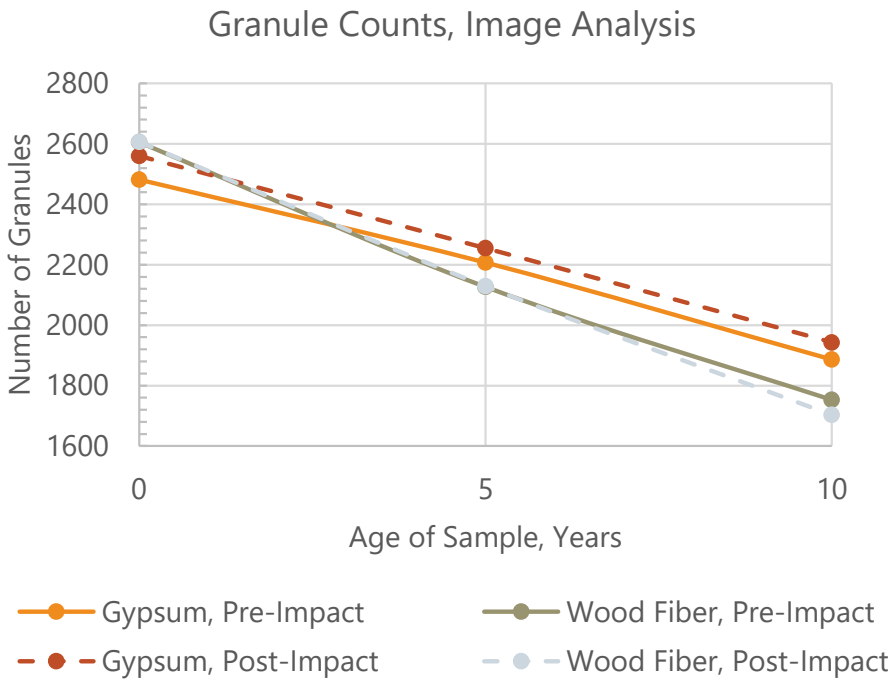
Findings – 10-year-old Samples

- Gypsum Cover Board
  - Granule counts decreased by an average of 51 due to impact.
  - Exposed asphalt area increased by 2.0% due to impact.

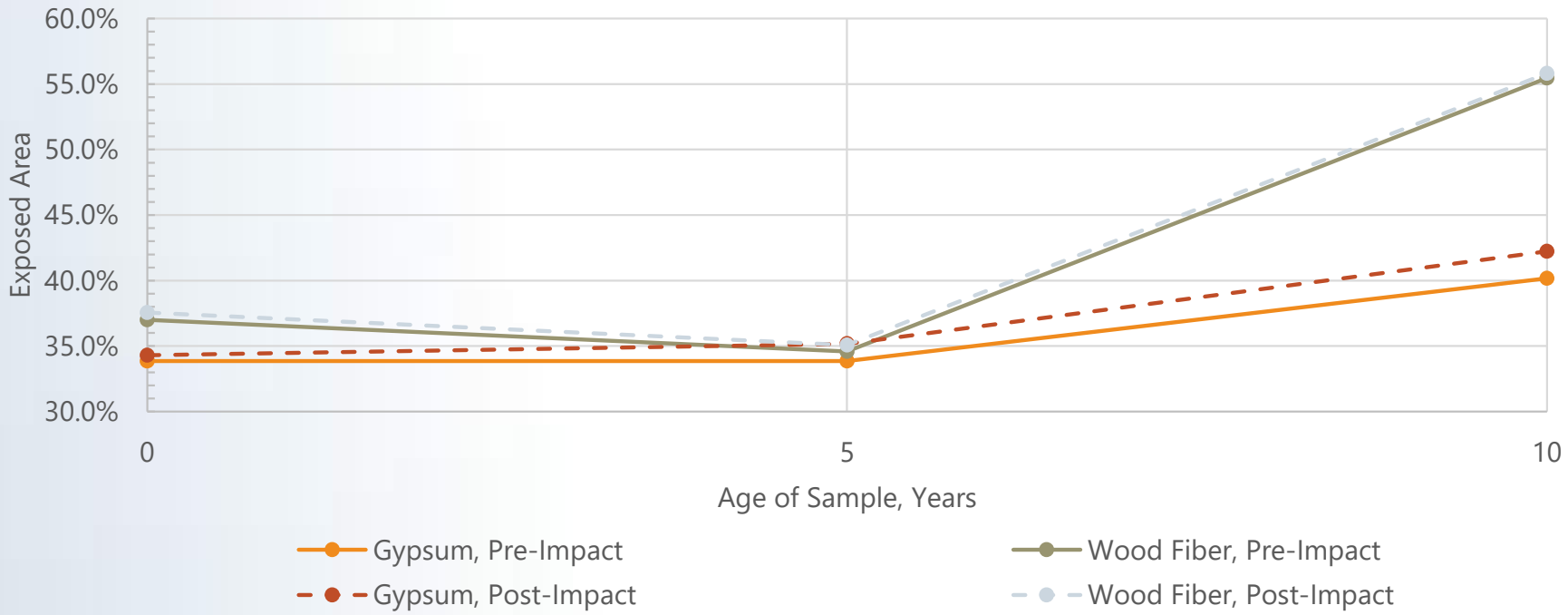
- Wood Fiber Cover Board
  - Granule counts decreased by an average of 17 due to impact.
  - Exposed asphalt area increased by 0.3% due to impact.

Testing Results Summary: Granule Counts

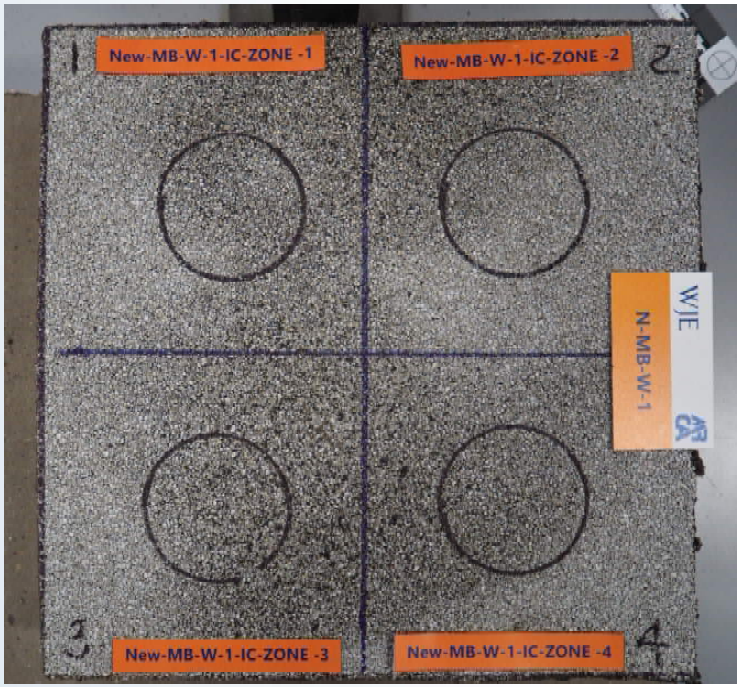


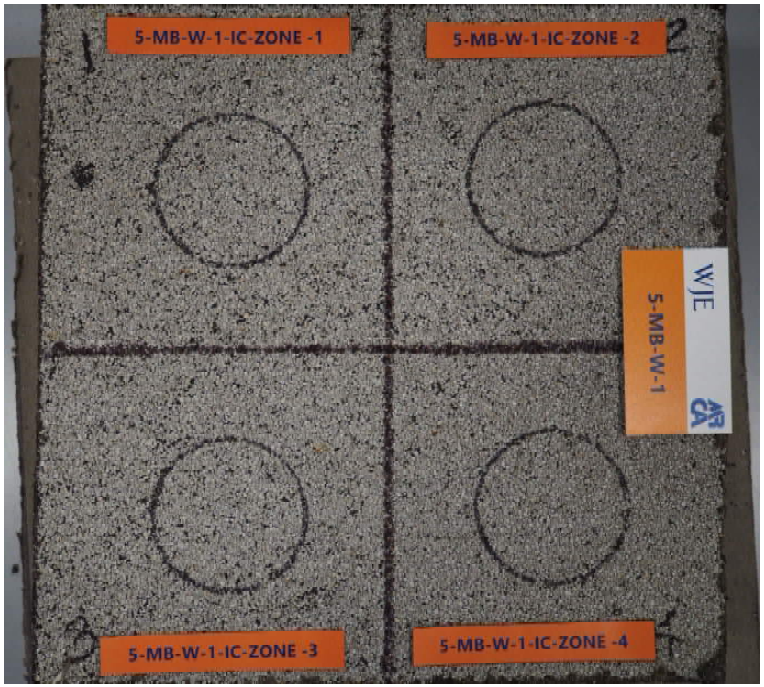


Testing Results Summary: Exposed Asphalt

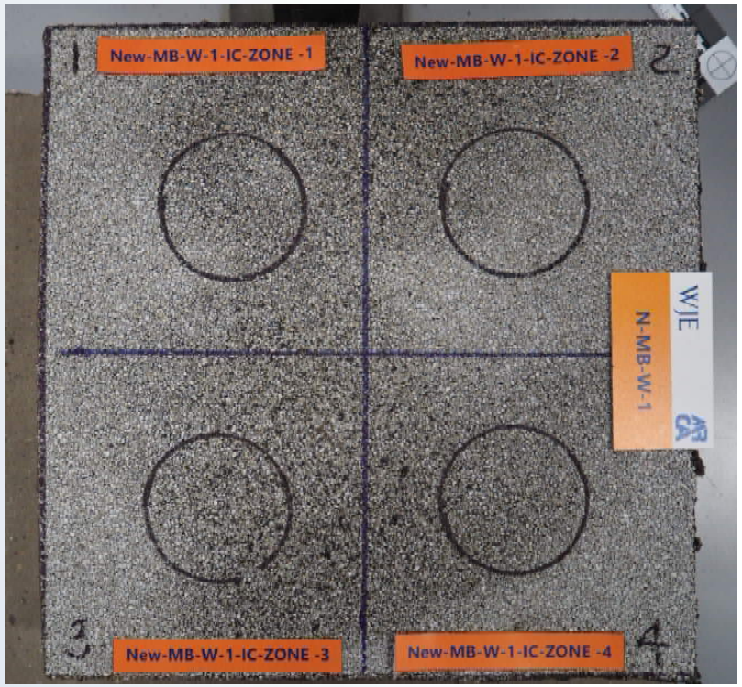


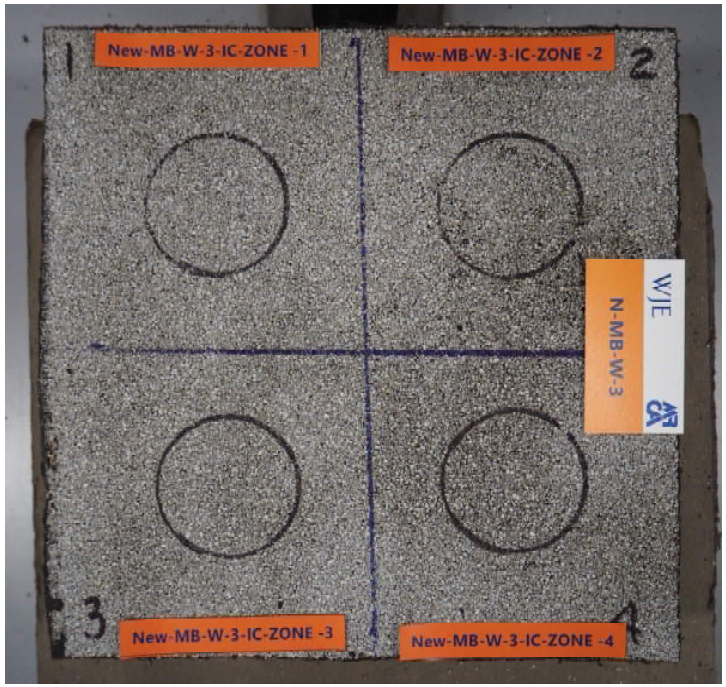
Testing Results Summary: Exposed Asphalt





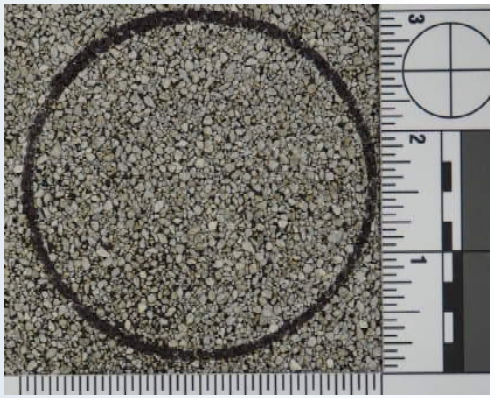
Testing Results Summary: Exposed Asphalt



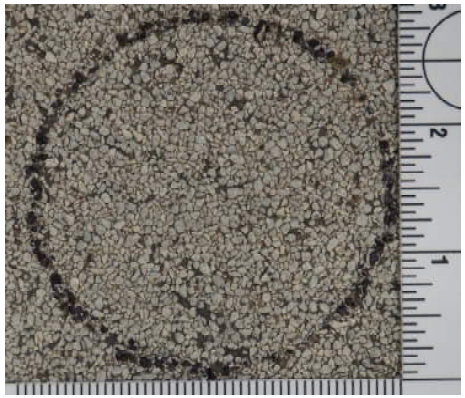


Conclusions

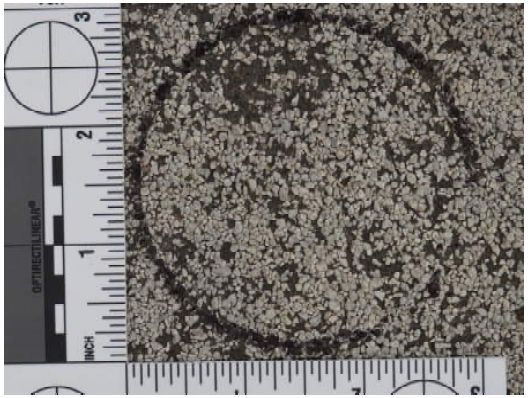
- Quantity of granules on membrane decreases with age.
- Exposed asphalt area generally increases with membrane age.
  - Larger increase between 5 and 10 years than between new and 5 years



N-MB-G-1



5-MB-G-1



10-MB-G-1

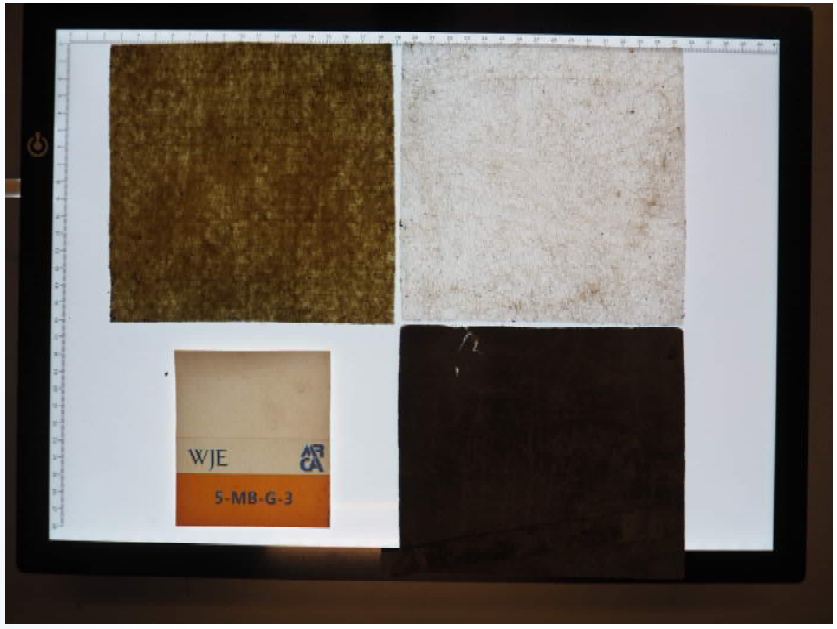
Conclusions

- Exposed asphalt area generally increases more upon impact with gypsum cover board than it does with wood fiber cover board.

Sample	Exposed Asphalt Pre-Impact	Exposed Asphalt Post-Impact	Change In Exposed Area After Impact
N-MB-G	33.9%	34.3%	+0.4%
N-MB-W	36.9%	37.3%	+0.4%
5-MB-G	33.9%	35.2%	+1.3%
5-MB-W	34.6%	35.1%	+0.5%
10-MB-G	40.2%	42.2%	+2.0%
10-MB-W	55.5%	55.8%	+0.3%

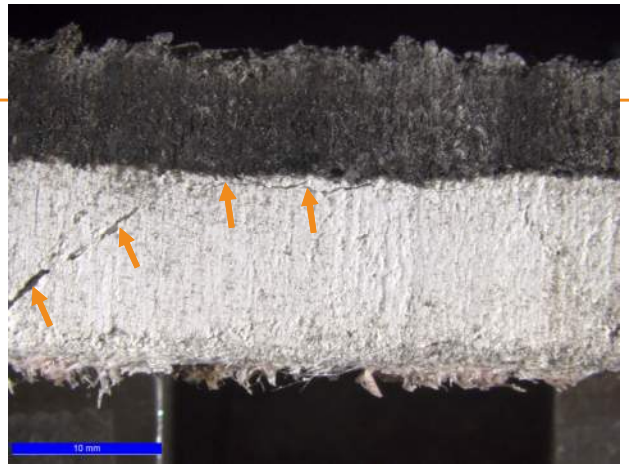
Conclusions

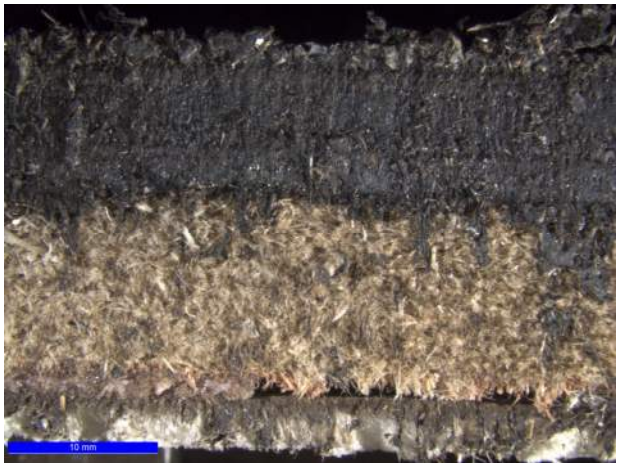
- Impacts did not fracture membrane reinforcement.



Conclusions

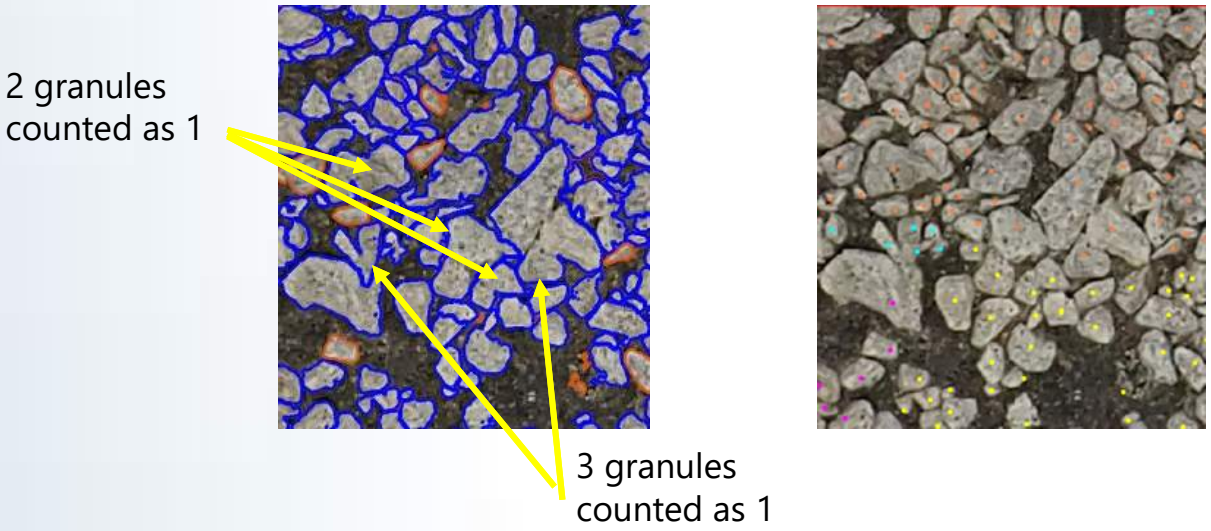
- Impact causes facer separation from gypsum core at impact sites with gypsum cover board.
- Cracking of the gypsum cover board was observed at the impact site.
- Wood fiber cover board generally appeared to be unaffected by impact.





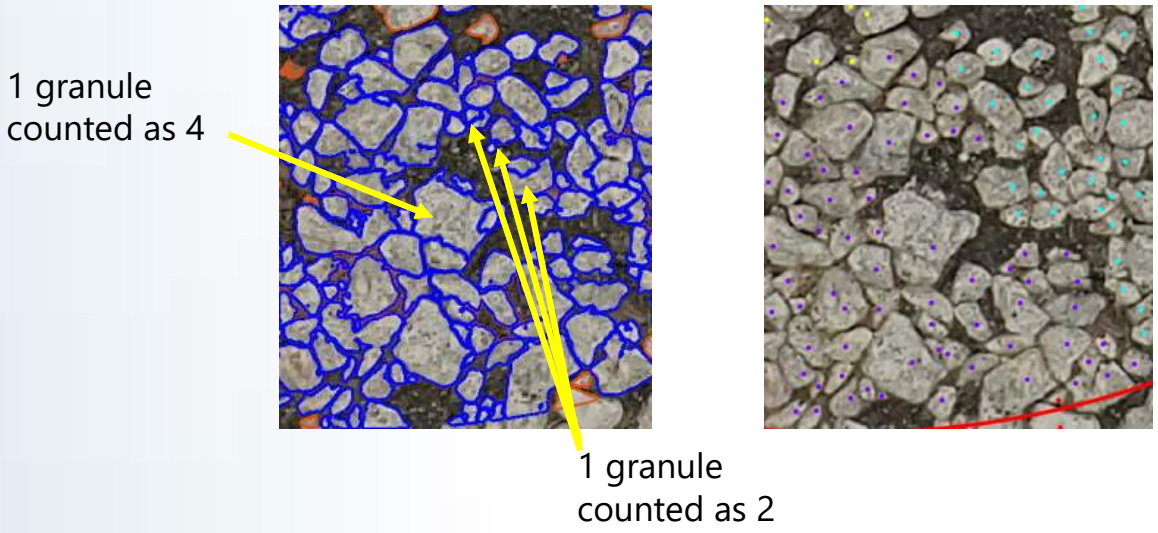
Conclusions

- Image analysis accuracy is variable due to differences within the granules (shape, color, texture, size)
  - Under-segmentation (identify too few boundaries)



Conclusions

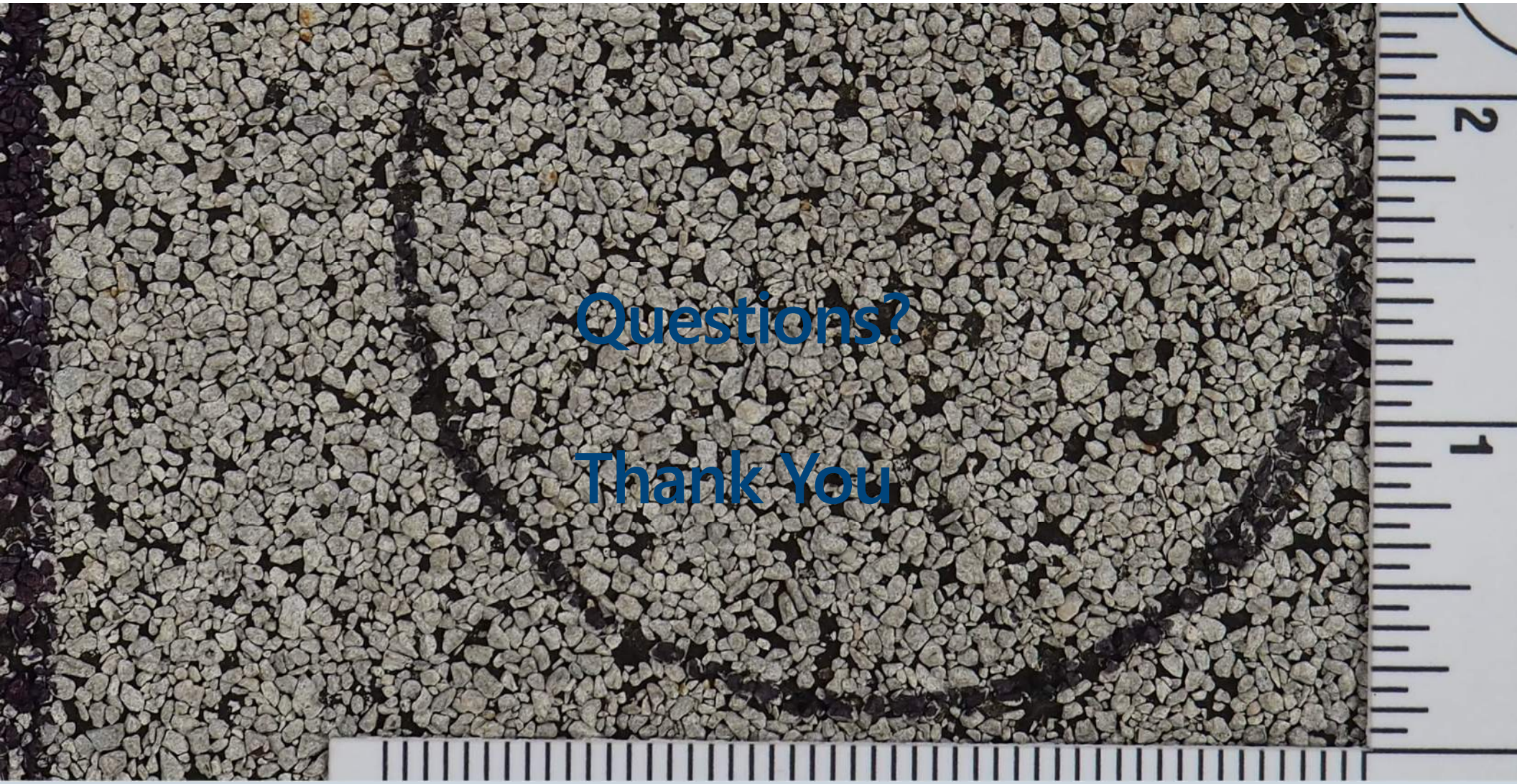
- Image analysis accuracy is variable due to differences within the granules (shape, color, texture, size)
  - Over-segmentation (identify excessive boundaries)



Future Research and Testing Ideas

- Uplift testing of impacted roof systems (w/ separated cover board)
- Impact study on different types of membrane
  - Single ply
  - Smooth surface mod bit
  - Coated membranes
- Impact study on different types of substrates
  - Polyiso
  - HD polyiso

We want your input!


Questions?
Thank You