

Test Procedure for

MAGNESIUM SULFATE SOUNDNESS OF AGGREGATE

TxDOT Designation: Tex-411-A

Effective Date: **May 2025****1. SCOPE**

- 1.1 Use this test procedure to measure the magnesium sulfate soundness loss of coarse and fine aggregate. Aggregate is subjected to 5-cycles of repeated immersion in magnesium sulfate solution followed by oven drying to dry the salt precipitated in permeable pore spaces. This provides an indication of resistance to degradation from environmental and physical conditions.
- 1.2 *This test procedure does not claim to address the safety concerns associated with its use. It is the responsibility of the user of this test procedure to establish the appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations before use.*

2. APPARATUS

- 2.1 Balance, Class G2 in accordance with [Tex-901-K](#), minimum capacity of 5,000 g.
- 2.2 Barium chloride solution, prepare 100 mL of 5% barium chloride solution by dissolving 5 g of BaCl₂ in 100 mL of distilled water.
- 2.3 Containers, numerically identified for tracking of aggregate sample throughout testing and perforated to allow free access of the solution to the sample and drainage of the solution from the sample without losing aggregate.
 - 2.3.1 Baskets of non-corrosive wire mesh, stainless steel bowls, or sieves with suitable openings are satisfactory for the samples.
- 2.4 Drainage rack or grate, stainless steel with evenly spaced rungs to allow solution to drain from samples back into the tank containing the solution.
- 2.5 Drying oven, capable of achieving and maintaining a temperature at $230 \pm 9^{\circ}\text{F}$ with an evaporation rate of at least 25 g/hr. over a 4-hr. period where the doors of the oven remain closed the entire 4 hr.
 - 2.5.1 Determine this rate by the loss of water from 1-L Griffin low-form beakers, each initially containing 500 ± 1 g of water and at a temperature of $70 \pm 3^{\circ}\text{F}$, placed in each corner and the center of each shelf of the oven.
 - 2.5.2 The evaporation requirement applies to all test locations when the oven is empty except for the beakers of water.
- 2.6 Hydrometer, conforming to the requirements of ASTM E100 or a suitable combination of graduated glassware and balance, capable of measuring the specific gravity of the solution within ± 0.001 .

- 2.7 Magnesium Sulfate salt, USP Grade, crystalline (heptahydrate) or anhydrous form.
- 2.8 Rinse Tank, non-corrosive, stainless steel, or high-density plastic (i.e., polyethylene, Nalgene); with a cover; where hot water (maintained at $110 \pm 10^\circ\text{F}$) enters near the bottom and overflows through a drain port near the top; has a large enough volume to contain all test samples and water while maintaining a water level at least one inch above the samples during the rinse cycle.
- 2.9 Temperature recorder, capable of recording the temperature of the solution at least once every 15 min. with an accuracy of 0.5°C (1°F) or better for the duration of the test.
- 2.10 Standard U.S. sieves, meeting the requirements of [Tex-907-K](#).
- 2.11 Tanks, non-corrosive, high-density plastic (i.e., polyethylene, Nalgene) with a lid with a volume greater than five times the solid volume of the immersed samples in their containers and elevated off the floor to allow airflow.
- 2.12 Water, approved drinking source.
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3. PREPARING SOLUTION

- 3.1 Use a clean tank and determine the amount of water needed for the solution.
- 3.1.1 The volume of the solution must be at least five times the solid volume of all samples immersed at any one time.
- 3.1.2 Water temperature must be within the range of $77\text{--}86^\circ\text{F}$.
- 3.2 Determine the amount of salt needed to add to the water.
- 3.2.1 When using anhydrous (MgSO_4) salt, weigh 350 g per liter of water and proceed to Section 3.3.
- 3.2.2 When using crystalline hydrate ($\text{MgSO}_4 + 7\text{H}_2\text{O}$) salt, weigh 1,400 g per liter of water.
- 3.3 Add some salt to the clean, empty tank followed by adding some water and stir the solution thoroughly. Repeat this at frequent intervals until all the salt is added to the tank.
- 3.4 Allow the solution to cool within the range of $68\text{--}75^\circ\text{F}$ and maintain the solution at this temperature.
- 3.5 Cover the tank with a lid and allow the solution to remain undisturbed at $68\text{--}75^\circ\text{F}$ for a minimum of 48 hr. before use.
- 3.5.1 Using a lid will reduce evaporation and prevent contamination of the solution.
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4. PREPARING SAMPLE

- 4.1 Sample coarse and fine aggregate in accordance with [Tex-221-F](#) or [Tex-400-A](#). Sample select backfill for retaining walls and stone rip rap in accordance with [Tex-400-A](#).
- 4.2 Dry the sample until it is sufficiently dry for sieving.
- 4.3 Sieve the sample into different size fractions using the sieves listed in Tables 1–6 for the required application and specification.
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- 4.3.1 When testing backfill, determine the gradation of the backfill in accordance with [Tex-401-A](#). Use only the sieve sizes that retain 5% or more of the sample for testing.
- 4.4 Wash the aggregate from each sieve size fraction thoroughly and oven dry to constant weight at $230 \pm 9^\circ\text{F}$.
- 4.4.1 Constant weight is achieved when the loss in weight is less than 0.1% of the sample weight after 4 hr. of drying.
- 4.5 Prepare samples using the weights listed in Tables 1–6 for the required application and specification.
- 4.5.1 Record the dry weight of the aggregate and the container number for each size.
- 4.5.2 Crushing of larger aggregate sizes is allowed when the sample does not contain enough of the smaller aggregate size for testing.
- 4.5.3 When there is not enough aggregate for any larger size as required in Tables 1–5, do not test for this size.

Table 1
Sieve Size Sample Weights for Concrete Coarse Aggregate

Container	Passing Sieve Size	Retained Sieve Size	Weight, g
1	3/4 in.	1/2 in.	670 ± 10
2	1/2 in.	3/8 in.	330 ± 5
3 ¹	3/8 in.	No. 4	300 ± 5
–	3/8 in.	1/4 in.	180 ± 5
–	1/4 in.	No. 4	120 ± 5

1. Container 3 – Aggregate is sieved into different sizes and combined in the container.

Table 2
Sieve Size Sample Weights for Hot Mix Asphalt (HMA) Coarse Aggregate

Container ¹	Passing Sieve Size	Retained Sieve Size	Weight, g
–	1/2 in.	3/8 in.	1,000 ± 10
1	1/2 in.	3/8 in.	500 ± 10
2	1/2 in.	3/8 in.	500 ± 10
3	3/8 in.	No. 4	300 ± 5
–	3/8 in.	1/4 in.	180 ± 5
–	1/4 in.	No. 4	120 ± 5
4	No. 4	No. 8	100 ± 1

1. Aggregate is sieved and split into Containers 1 & 2. Aggregate is sieved into different sizes and combined for Container 3.

Table 3
Sieve Size Sample Weights for Surface Treatment (Seal Coat) Coarse Aggregate

Container	Passing Sieve Size	Retained Sieve Size	Weight, g
1	1/2 in.	3/8 in.	1000 ± 10
2 ¹	3/8 in.	No. 4	300 ± 5
-	3/8 in.	1/4 in.	180 ± 5
-	1/4 in.	No. 4	120 ± 5

1. Aggregate is sieved into different sizes and combined for Container 2.

Table 4
Sieve Size Sample Weights for and Microsurfacing

Container	Passing Sieve Size	Retained Sieve Size	Weight, g
1	No. 4	No. 8	100 ± 1
2	No. 8	No. 16	100 ± 1
3	No. 16	No. 30	100 ± 1
4	No. 30	No. 50	100 ± 1

Table 5
Sieve Size Sample Weights for Stone Rip Rap

Container ¹	Passing Sieve Size	Retained Sieve Size	Weight, g
-	2-1/2 in.	1-1/2 in.	5000 ± 300
1	2-1/2 in.	2 in.	3000 ± 300
2	2 in.	1-1/2 in.	2000 ± 200

1. Aggregate is sieved into different sizes and split into Containers 1 and 2.

Table 6
Sieve Size Sample Weights for Select Backfill

Container ¹	Passing Sieve Size	Retained Sieve Size	Weight, g
1	3 in.	2-1/2 in.	7000 ± 1,000
2	2-1/2 in.	2 in.	3000 ± 300
3	2 in.	1-1/2 in.	2000 ± 200
4	1-1/2 in.	1 in.	1000 ± 300
5	1 in.	3/4 in.	500 ± 10
6	3/4 in.	1/2 in.	670 ± 10

Container ¹	Passing Sieve Size	Retained Sieve Size	Weight, g
7	1/2 in.	3/8 in.	330 ± 5
8 ²	3/8 in.	No. 4	300 ± 5
—	3/8 in.	1/4 in.	180 ± 5
—	1/4 in.	No. 4	120 ± 5
9	No. 4	No. 8	100 ± 5
10	No. 8	No. 16	100 ± 5
11	No. 16	No. 30	100 ± 5
12	No. 30	No. 50	100 ± 5

1. Containers are only used for sieve sizes that retain more than 5% (Section 4.3.1).

2. Aggregate is sieved into different sizes and combined for Container 8.

5. PROCEDURE FOR 5-CYCLE LOSS

- 5.1 Before initial use, break up any salt cake in the tank and stir the solution thoroughly.
- 5.1.1 Aggregates containing carbonates of calcium or magnesium may be chemically attacked by fresh sulfate solution, potentially resulting in high measured losses. When this is suspected, before the start of testing place a container of aggregate containing carbonates in the tank for a minimum of 24 hr. Use a minimum of 1,300 g of any sieve size or a combination of sieve sizes.
- 5.2 Measure the specific gravity and temperature of the solution and document before placing the test samples into the solution.
- 5.2.1 Use a hydrometer to measure the specific gravity. The specific gravity must not be less than 1.295 nor more than 1.308.
- 5.2.2 Refer to the temperature recorder to verify the temperature of the solution. The solution must be at a temperature within the range of 68–74°F.
- 5.3 Stack the containers for each sample on top of each other and place them in the prepared solution such that they are covered with a minimum of 1/2 in. of solution for 17 ± 1 hr.
- 5.3.1 When testing lightweight aggregate, use suitable weighted wire grids placed over the samples or stacked sieves to contain the aggregate particles from floating out of the container during the immersion period.
- 5.4 Cover the tank with a lid to reduce evaporation and prevent contamination.
- 5.5 After the immersion period of 17 ± 1 hr., remove the lid from the tank and slowly remove the stacked containers from the solution such that no aggregate particles are lost.
- 5.6 Allow the samples to drain for 15 ± 5 min.
- 5.7 Stir the solution thoroughly to break up any partially bonded salt in the tank while the test samples drain.

- 5.8 Cover the tank with a lid.
- 5.9 Separate the containers from the stack.
- 5.10 Place the containers in an oven at $230 \pm 9^\circ\text{F}$ and dry to constant weight as defined in Section 4.4.1.
- 5.11 Allow the samples to cool to room temperature within a range of $68\text{--}75^\circ\text{F}$.
- 5.12 Repeat Sections 5.2–5.10 until five cycles are completed.
- 5.13 Wash the salt solution from the sample while in their containers by placing them in a rinse tank with water at $110 \pm 10^\circ\text{F}$ until the samples are completely free from salt.
- 5.13.1 Place the samples in a rinse tank and initiate the flow of water such that it flows near the bottom the tank and to overflow and cover the containers. Water must continuously circulate in the tank thereafter.
- 5.13.2 During rinsing, do not subject the samples to impact or abrasion that may degrade aggregate particles.
- 5.13.3 Determine the thoroughness of the wash by temporarily stopping the water from circulating and add drops of barium chloride (BaCl_2).
- 5.13.4 Additional rinsing is required when the BaCl_2 becomes cloudy as it descends through the water in the rinse tank.
- 5.13.5 Continue rinsing until the BaCl_2 has no reaction with the non-circulating water.
- 5.14 Remove the containers from the rinse tank.

6. DETERMINE LOSS OF COARSE AGGREGATE

- 6.1 Wash each sieve size fraction of coarse aggregate retained on the No. 4 sieve and larger.
- 6.2 Transfer the aggregate from the individual containers to the wet wash sieve listed in Table 7.

Table 7
Sieve Determination for Wet-Sieving

Retained Aggregate Sieve	Wet Wash Sieve
2-1/2 in.	2 in.
2 in.	1-1/2 in.
1-1/2 in.	1-1/4 in.
3/4 in.	5/8 in.
3/8 in.	5/16 in.
No. 4	No. 5

- 6.3 Using hands only, agitate the sieve with aggregate under running water until all undersized material passes the sieve.
- 6.3.1 Do not use any extra manipulation to pass the aggregate through the sieve during the washing process.
- 6.3.2 Do not sieve to refusal. The amount of time for washing will vary depending on the amount of breakdown caused by the test.

- 6.4 Clean the sample container that was used and return the washed aggregate sample to the clean container.
- 6.5 Repeat Sections 6.1–6.4 for each container.
- 6.6 Place the containers in an oven at $230 \pm 9^\circ\text{F}$ and dry to constant weight as defined in Section 4.4.1.
- 6.7 Allow the containers and aggregate to cool to room temperature.
- 6.8 Weigh the aggregate from each container and record to the nearest 0.1 g.

7. DETERMINE LOSS OF FINE AGGREGATE

- 7.1 Place the containers with fine aggregate passing the No. 4 sieve in an oven at $230 \pm 9^\circ\text{F}$ and dry to constant weight as defined in Section 4.4.1.
- 7.1.1 Fine aggregate is not washed or wet sieved before drying.
- 7.2 Allow the containers and aggregate to cool to room temperature.
- 7.3 Sieve aggregate from each container by hand using the sieve that it was initially retained on from Table 4.
- 7.4 Sieve to refusal for approximately 1 min. with lateral and vertical motions with a jarring action that keeps the material moving continuously over the surface of the sieve.
- 7.4.1 Continue sieving in approximately 1-min. increments until no more than 1% of the test sample by weight, passes through the sieve.
- 7.5 Weigh and record each sieve size fraction to the nearest 0.1 g.

8. CALCULATIONS

- 8.1 Calculate the individual percent loss for each sieve size fraction.

$$\text{Individual Percent Loss} = \left[\frac{(W_i - W_f)}{W_i} \right] \times 100$$

Where:

W_i = initial weight from each sieve size fraction (Section 4.5).

W_f = final weight from each sieve size fraction (Section 6.8 or 7.5).

- 8.1.1 When a sieve size fraction is not tested, use the initial and final weights from the next smaller sieve size fraction to calculate the individual percent loss for the larger sieve size fraction.
- 8.1.2 When backfill has a large amount of fine aggregate, such as when material passing the No. 50 sieve is more than 5% of the sample, do not test this material. Use the initial and final weights from the No. 50 sieve size fraction to calculate the individual percent loss for the material passing the No. 50 sieve size fraction.
- 8.2 Calculate the normalized percent loss of each sieve size fraction.

$$\text{Normalized Percent Loss} = \text{Individual Percent Loss} \times N$$

Where:

N = Normalized gradation percent shown in Table 8 for the required application and specification.

8.2.1 Calculate the normalized gradation (N) for backfill samples using only the sieves that retain 5% or more of the sample. Table 9 is an example of a calculation for the normalized gradation of a backfill sample.

8.3 Calculate the total percent loss for the sample by adding the normalized percent loss for each sieve size.

$$\text{Overall Percent Loss} = \Sigma \text{Normalized Percent Losses}$$

Table 8
Normalized Gradation for Different Applications

Application	Passing Sieve Size	Retained Sieve Size	Normalized Gradation, %
Concrete Coarse Aggregate	3/4 in.	3/8 in.	66%
	3/8 in.	No. 4	34%
Hot Mix Asphalt (HMA) Coarse Aggregate	1/2 in.	3/8 in.	28%
	3/8 in.	No. 4	42%
	No. 4	No. 8	30%
Surface Treatment (Seal Coat) Coarse Aggregate	1/2 in.	3/8 in.	28%
	3/8 in.	No. 4	72%
Microsurfacing	No. 4	No. 8	55%
	No. 8	No. 16	24%
	No. 16	No. 30	13%
	No. 30	No. 50	8%
Stone Rip Rap	2-1/2 in.	1-1/2 in.	100%

Table 9
Example Calculation of a Normalized Gradation for a Backfill Sample

Sieve Size	Individual Percent Retained	Normalized Gradation
2 in.	4%	— ¹
1-1/2 in.	11%	$11\% / 93\% = 12\%$
1 in.	19%	$19\% / 93\% = 20\%$
3/4 in.	28%	$28\% / 93\% = 30\%$
1/2 in.	22%	$22\% / 93\% = 24\%$
3/8 in.	13%	$13\% / 93\% = 14\%$
No. 4	3%	— ¹
Sum of Individual Percent Retained of sieve sizes with 5% or more of the sample.	$11\% + 19\% + 28\% + 22\% + 13\% = 93\%$	$12\% + 20\% + 30\% + 24\% + 14\% = 100\%$

- Only the sieve sizes that retain 5% or more of the sample are tested (Section 4.3.1).

9. ARCHIVED VERSIONS

- Archived versions are available.