Date: March 2016

Evaluation of Lightweight Pieces in Aggregates

Nebraska Department of Roads

Research Project:
Evaluation of Lightweight Pieces in Aggregates

Location: Laboratory Evaluation

Aggregate Legal Source Location:
NA

Starting Date: August 2015

Completion Date: March 2016

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Pit Site Location

Introduction:

Nebraska Department of Roads (NDOR) Material and Research (M&R) Division started an evaluation to determined injurious deleterious lightweight pieces of aggregate from a dry pit location, as a result of field observations from a project stock pile. This brief summary presents the field observation and laboratory testing evaluations to determine the percent of lightweight pieces in aggregate.

Field Observation:

While visiting a plant site, Materials & Research noticed the aggregate stockpile had large amounts of what appears to be lightweight aggregates (lightweight pieces) on Phase I of the project as shown in Figures 1 and 2. This was a concern due to the large quantities observed in the stockpile.

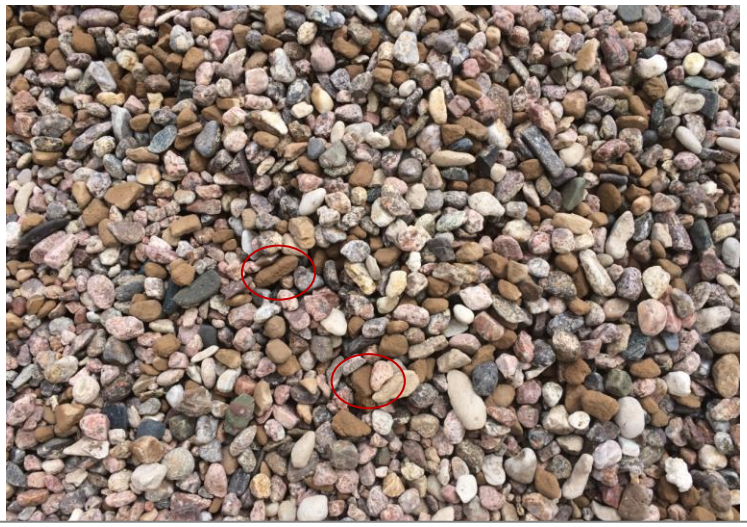


Figure 1. The red circle shows the lightweight pieces observed throughout the stockpile.

Figure 2. Lightweight Pieces

Laboratory Testing:
The research in the laboratory was to compare three different test methods of lightweight pieces, as follows:

AASHTO T-113
This test method used a high density liquid to separate light weight pieces from coarse aggregate. The liquid solution is prepared so its density is greater than the light weight pieces, but less than the aggregate. When the aggregate sample is placed in the solution the lightweight pieces will float and the coarse aggregate will sink as shown in Figure 3. The floating pieces can then be collected to evaluate the quantity as percent by volume.

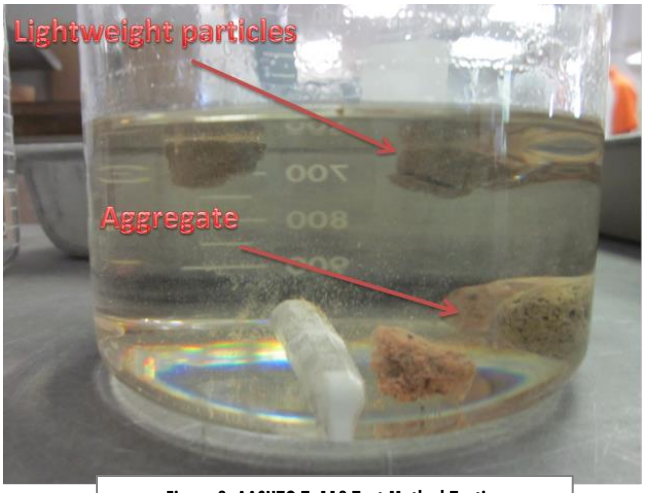


Figure 3. AASHTO T 113 Test Method Testing

NDOR Visual Test
This test method was used to identify lightweight pieces by visually selecting the lightweight piecespieces from the sample, as shown in Figure 4.


Figure 4. NDOR Visual Test

NDOR Modified AASHTO T 504
This test method is used to calculate the percent of clay lumps, shale or soft particles in aggregate samples; this test method is currently being used by the Department on our typical quarry and wet pit aggregate. The washed dried aggregate sample is separated into a series of particle size fractions. Each fraction is submerged in water for a total of 22±2 hours. The fractions are then dried to a constant weight. The calculations are based by the mass of the aggregate.

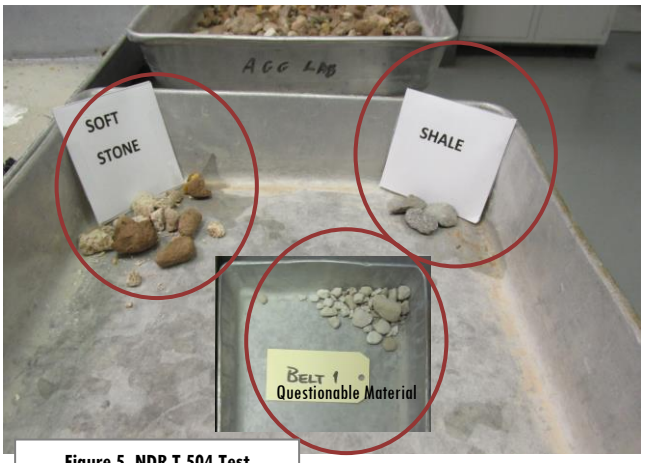


Figure 5. NDR T 504 Test

Laboratory Testing Summary:

This investigation compared three different test methods of measuring the percent composition of soft/lightweight particles in an aggregate sample. The three methods examined were Lightweight Pieces in Aggregate in accordance with AASHTO T 113, NDR Visual Test, and The Determination of Clay Lumps, Shale, and Soft Particles in Coarse Aggregate and Crushed Rock, and of Clay Lumps in Fine Aggregate and Sand-Gravel Aggregate in accordance to Nebraska's T 504. Figure 6 shows the stockpile with large amount of the lightweight pieces and figure 7 demonstrates the producers change in operation which resulted in a cleaner aggregate.

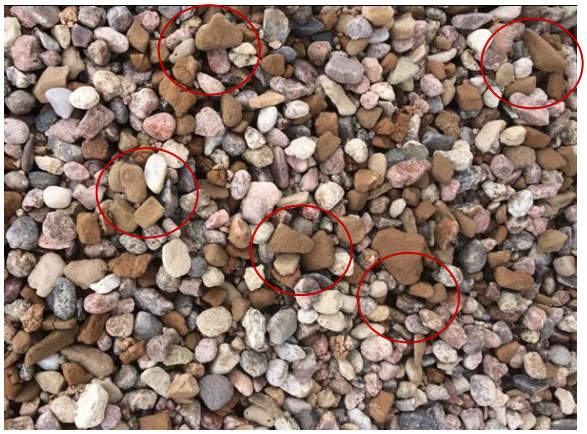


Figure 6. Old Stockpile

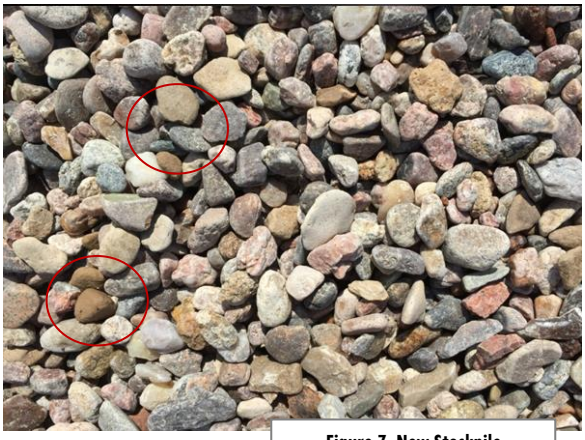


Figure 7. New Stockpile

Table 1 shows results for AASHTO T-113, NDR Visual Test, and NDR T 504 , the results are in percent lightweight particle by mass weight.

Table 1- Percent Lightweight Pieces by Mass

Sample Identification	Lightweight Pieces AASHTO T113 %	Not Standard Visual Test %	Soft Particles NDR T504 %
Old Stockpile #1	1.60	2.7	1.51
Old Stockpile #2	1.70	5.0	2.22
Old Stockpile #3	1.40	1.9	0.83
New Stockpile #1	0.78	2.2	0.62
New Stockpile #2	1.10	3.0	0.55
Project Sample CA-307	1.10	NA	1.20

Observations:

- The comparison of the results between test methods showed that T 113 consistently had lower values than the Visual test and slightly greater values than NDR T 504. As expected, T 113 was more consistent than the other two tests, as the test has less subjectivity.
- The deviation of the Visual Test was expected, as the test is highly subjective with results depending on technician's visual examination.
- The deviations of NDR T 504 may be attributed to the absorptivity of the soft particles, which may vary depending on the type of soft particles that are found in the sample.

Standard Test Method Modification

The observations from Table 1, suggested that the percent composition of lightweight pieces was higher than the test results suggested. Since the density of the lightweight pieces is lower than the density of the aggregate; mathematically, the percent by mass would appear low compared to field observations. It was concluded that percent by mass was not an accurate method of calculating the percent of lightweight pieces.

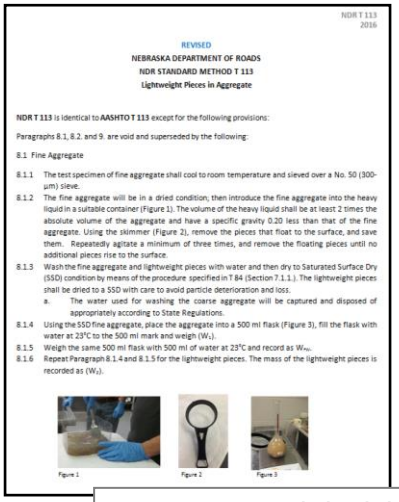
The principal investigator suggested that describing the composition of soft pieces as a percent by volume would be an accurate way to calculate the percent composition, and would correlate with field observations. Therefore, the test was performed by volume, as shown in Table 2.

Table 2 Percent Lightweight Pieces by Volume

Lab Identification	% Lightweight Pieces T 113	% Soft Particles NDR T 504
Old Stockpile #1	4.57%	2.3%
Old Stockpile #2	10.20%	NA
Old Stockpile #3	NA*	NA
Old Stockpile #4	NA	NA
New Stockpile #1	0.85%	1.0%
New Stockpile #2	NA	NA
CA-307	NA	NA

** (NA) not enough split sample to re-run the test.*

It was found the percent of lightweight pieces by volume was higher than corresponding percent lightweight pieces by mass. These results correlated with the field observations. In order to test the samples by volume, AASHTO T 113 was modified. The test procedure describing the modification by volume can be found on the Material and Research website as a Modified Nebraska (NDR) Standard Test Method of AASTHO T 113 Lightweight Pieces in Aggregate, as shown in Figure 8 and Figure 9.



NDR T 113
2016

REVISED

NEBRASKA DEPARTMENT OF ROADS
NDR STANDARD METHOD T 113
Lightweight Pieces in Aggregate

NDR T 113 is identical to **AASHTO T 113** except for the following provisions:

Paragraphs 8.1, 8.2, and 9. are void and superseded by the following:

8.1 Fine Aggregate

8.1.1 The test specimen of fine aggregate shall cool to room temperature and sieved over a No. 50 (300-µm) sieve.

8.1.2 The fine aggregate will be in a dried condition, then introduce the fine aggregate into the heavy liquid in a suitable container (Figure 1). The volume of the heavy liquid shall be at least 2 times the absolute volume of the aggregate and have a specific gravity 0.20 less than that of the fine aggregate. Using the skimmer (Figure 2), remove the pieces that float to the surface, and save them. Repeatedly agitate a minimum of three times, and remove the floating pieces until no additional pieces rise to the surface.

8.1.3 Wash the fine aggregate and lightweight pieces with water and then dry to Saturated Surface Dry (SSD) condition by means of the procedure specified in T 84 (Section 7.1.1.). The lightweight pieces shall be dried to a SSD with care to avoid particle deterioration and loss.

a. The water used for washing the coarse aggregate will be captured and disposed of appropriately according to State Regulations.

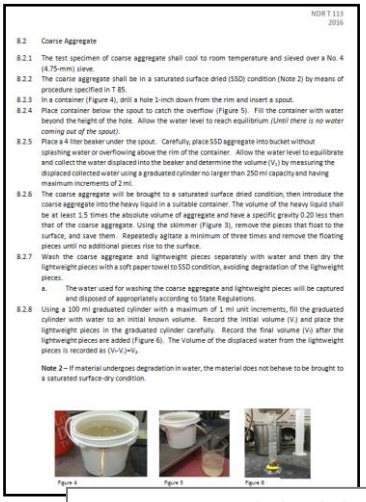
8.1.4 Using the SSD fine aggregate, place the aggregate into a 500 ml flask (Figure 3), fill the flask with water at 23°C to the 500 ml mark and weigh (W_1).

8.1.5 Weigh the same 500 ml flask with 500 ml of water at 23°C and record as W_{500}.

8.1.6 Repeat Paragraph 8.1.4 and 8.1.5 for the lightweight pieces. The mass of the lightweight pieces is recorded as (W_2).

Figure 1 Figure 2 Figure 3

Figure 8. NDR Standard Method T 113



NDR T 113
2016

8.2 Coarse Aggregate

8.2.1 The test specimen of coarse aggregate shall cool to room temperature and sieved over a No. 4 (4.75-mm) sieve.

8.2.2 The coarse aggregate shall be in a saturated surface dried (SSD) condition (Note 2) by means of procedure specified in T 85.

8.2.3 In a container (Figure 4), drill a hole 1-inch down from the rim and insert a spout.

8.2.4 Place container below the spout to catch the overflow (Figure 5). Fill the container with water beyond the height of the hole. Allow the water level to reach equilibrium *(Until there is no water coming out of the spout)*.

8.2.5 Place a 4 liter beaker under the spout. Carefully, place SSD aggregate into bucket without splashing water or overflowing above the rim of the container. Allow the water level to equilibrate and collect the water displaced into the beaker and determine the volume (V_1) by measuring the displaced collected water using a graduated cylinder no larger than 250 ml capacity and having maximum increments of 2 ml.

8.2.6 The coarse aggregate will be brought to a saturated surface dried condition, then introduce the coarse aggregate into the heavy liquid in a suitable container. The volume of the heavy liquid shall be at least 1.5 times the absolute volume of aggregate and have a specific gravity 0.20 less than that of the coarse aggregate. Using the skimmer (Figure 3), remove the pieces that float to the surface, and save them. Repeatedly agitate a minimum of three times and remove the floating pieces until no additional pieces rise to the surface.

8.2.7 Wash the coarse aggregate and lightweight pieces separately with water and then dry the lightweight pieces with a soft paper towel to SSD condition, avoiding degradation of the lighweight pieces.

a. The water used for washing the coarse aggregate and lightweight pieces will be captured and disposed of appropriately according to State Regulations.

8.2.8 Using a 100 ml graduated cylinder with a maximum of 1 ml unit increments, fill the graduated cylinder with water to an initial known volume. Record the initial volume (V_i) and place the lightweight pieces in the graduated cylinder carefully. Record the final volume (V_f) after the lightweight pieces are added (Figure 6). The Volume of the displaced water from the lightweight pieces is recorded as $(V_f - V_i) = V_2$.

Note 2 – If material undergoes degradation in water, the material does not behave to be brought to a saturated surface-dry condition.

Figure 4 Figure 5 Figure 6

Figure 9. NDR Standard Method T 113

The test method NDR T 113 calculation is expressed as a percentage of volume of pieces that float, to the total volume of the fine or coarse aggregate sample. Therefore, all plus #4 material is classified as coarse aggregate and all minus #4 to plus #50

is classified as fine aggregate. The following calculations of lightweight pieces are for the fine and coarse aggregate respectability;

Calculation of Lightweight Pieces in Fine Aggregate as follows:

$$V_1 = (W_1 - W_{FW}) \qquad V_2 = (W_2 - W_{FW})$$

$$V_t = V_1 + V_2 \qquad L = \frac{V_2}{V_t}\ x\ 100$$

where:

W_{FW} = Weight of flask and water filled to 500 ml mark at 23°C
W_1 = Weight of flask, aggregate only and water filled to 500 ml mark at 23°C
W_2 = Weight of flask, lightweight pieces and water filled to 500 ml mark at 23°C
L = Percentage of lightweight pieces,
V_1 = Saturated surface dry volume of fine aggregate,
V_2 = Saturated surface dry volume of lightweight pieces,
V_t = Volume saturated surface fine aggregate.

Calculation of Lightweight Pieces in Coarse Aggregate as follows:

$$L = \frac{V_2}{V_1}\ \text{x}\ 100$$

where:

L = *Percentage of lightweight pieces,*
V_1 = *Intial volume of saturated surface dry coarse aggregate with lightweight pieces,*
V_2 = *Final saturated surface dry volume of lightweight pieces.*

Since there was such a large amount of lightweight pieces found on one project and the Department's current specification did not touch on this matter, the Department changed the Nebraska Standard Specifications for aggregates in Section 1033, Paragraph 3.b (2) and (3), to address lightweight pieces in aggregates. Section 1033.02, Paragraph 3. b. (2) was replaced by the following:

(2) The percent of clay lumps, shale, or soft particles shall not exceed the following amounts:

(3) Any combination of clay lumps, shale and soft particles (all percent by weight values) plus the lightweight pieces (a percent by volume value) shall not exceed 3.5%.

Clay Lumps	0.5%
Shale	1.0%
Soft Particles	3.5%
Lightweight Pieces	3.5%

The quality aggregate testing results will be reported separately for the fine and coarse aggregate and there shall be no more than 3.5% lightweight pieces in accordance to NDR T 113 by volume. The cumulative percentage of clay, shale, soft particles in accordance to NDR T 504 and NDR T 113 lightweight pieces shall not exceed 3.5%. Coarse aggregate test results will be reported/calculated, as shown in Table 3.

The research done prior to the change in Specification (Table 2) shows the percent cumulative total for the plus #4 materials.

Table 3. Coarse Aggregate Percent Cumulative Total

NDR T504*			NDR T113	
% Clay Lumps (0.5% Max) A	% Shale (1.0% Max) B	% Soft Particles (3.5% Max) C	% Lightweight Pieces (3.5% Max) D	**% Cumulative Total** of A,B,C, & D **(3.5% Max)**

* In order to prevent double counting of lightweight pieces, material collected from the NDR T 504 shall be placed in the High Density Solution to check for possibility of Lightweight pieces.

Table 4 shows the report for minus #4 to plus #50 material expressed in percentage, where there shall be no more than 3.5% lightweight pieces per the Departments specification for the test method NDR T 113 which is done by volume.

Table 4. Fine Aggregate Percent Cumulative Total

NDR T113
% Lightweight Pieces (3.5% Max) D

On the project in question, the testing continued as the producer changed the method of washing the coarse aggregate in order to minimize the amount of lightweight pieces (Figure 10). The coarse aggregate was originally identified containing the majority of the lightweight pieces. Table 5 shows a reduction of lightweight pieces from the new washed coarse aggregate stockpile. The producer started using a log washer to reduce the amount of lightweight pieces in the coarse aggregate.

Table 5 also shows the test results of the fine aggregate of lightweight pieces in accordance of NDR T 113.

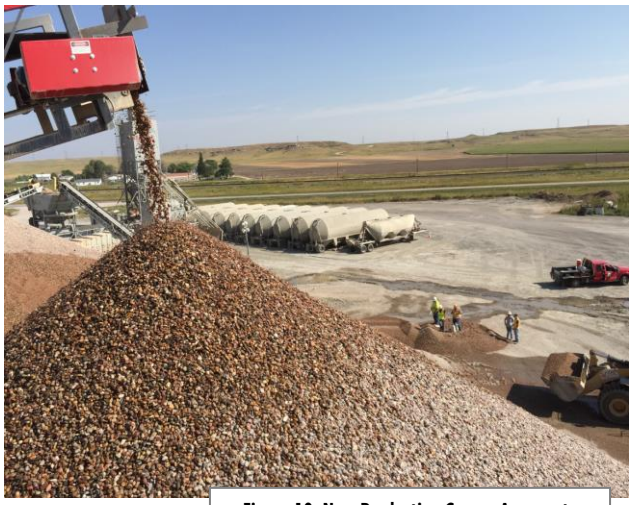


Figure 10. New Production Coarse Aggregate

Table 5. Lightweight Pieces by NDR T 113 by Volume of Fine Aggregate and Course Aggregate

Fine Aggregate					
Sample Number	Aggregate Volume (mL)	Lightweight Pieces Volume (mL)	Total Volume (mL)	Lightweight Pieces By Volume	Solution Specify Gravity
#4	119.18	1.93	121.11	1.59%	2.40
#5	127.75	1.84	159.59	1.42%	2.40
Coarse Aggregate (New Production)					
Sample Number	Beginning of Sample Volume (mL)	Soft Particle Volume (mL)	Aggregate Volume (mL)	Lightweight Pieces By Volume	Solution Specify Gravity
#1	1506	16	1490	1.06%	2.40
#2	1511	24	1535	1.58%	2.39
#3	1550	35	1515	2.25%	2.40

Since the mix design for this specific project was using 100% local aggregate, samples of both fine and coarse aggregate were combined at the mix design ratio and split over the #4 sieve and tested according to NDR T 113 and NDR T 504. The results are provided in Table 6. Note that NDR T 504 was not performed on the all plus #4 material for the fine (A1 & A2) due to the small particle size and inability to accurately perform the test.

Table 6. The cumulative percentage of clay, shale, soft particles in accordance to NDR T 504 and NDR T 113 lightweight pieces

Material	NDR T 504 % Soft Particles	NDR T 113 % Lightweight Pieces	% Cumulative Total (3.5% Max)
All Plus #4 from Fine A1	NA	0.8	0.8+0.6+0.91= 2.31
All Plus #4 Sample A1	0.6	0.91	
All Plus #4 from Fine A2	NA	0.8	0.8+0.8+1.11= 2.71
All plus #4 Sample A2	0.8	1.11	

Based on these test results, the samples tested meet the requirement for both lightweight pieces and the total combined percent of clay, shale, soft particles, and lightweight pieces.

In August 2015, the research team performed a field evaluation on the concrete for the eastbound paving operation where some of the high percentage of lightweight pieces was used (Figure 11). The test results of the field evaluation and laboratory testing are shown in Table 7.

Figure 11. Paving Operation

The work to evaluate the performance of lightweight pieces on concrete properties was based on the following;

Field Sampling & Testing:

1. Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method (ASTM C 231).

Testing Conducted in the Laboratory:

1. Standard Test Method for Microscopical Determination Parameters of the Air Void Analysis in Hardened Concrete (ASTM C 457 – Method B)
2. Standard Test Method for Rapid Chloride Ion Penetration (AASHTO TP 65)
3. Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing (ASTM C 666)
4. Mechanical Properties:
    i. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTM C39)
    ii. Standard Test Method for Compressive Strength of Core Concrete Specimens (ASTM C42)

Table 7. Mix Design and Test Results

Performed	Mix Design	W/CM ratio	7 Days Compressive Strength (psi) Cylinder	28 days Compressive Strength (PSI) Core	Air Content Front Paver	Air Content Behind Paver	NDOR Wet & Dry 18 Months Performance Test	Freeze & Thaw (Percentage)	Total Hardened Air Count	Permeability
NDOR's Requirements →		Max 0.48	-	3500 min.psi	6.5%-9.0%	-	-	Durability >70% 300 cycles	-	-
08/13/15	100% Sand & Gravel Aggregate S ½ Sec 13, T 13N, R-51 W	0.41	3500	4150	8.0%	5.2%	Showed cracking after 5 months	26% (Average of 3 samples)	4.71%	Very Low
08/28/2015		0.40	4920	6710	8.7%	5.3%	Showed cracking after 5 months	30% (Average of 2 samples)	5.78%	Very Low

Table 7 shows the majority of properties tested met the specification required with the exception of the NDOR Wet and Dry test and the Freeze and Thaw test. The tests completed correlates quite well with the amounts of lightweight pieces found at the beginning of the project (Old Stockpile) as shown in Tables 1 and 2. The initial testing showed that the amount of lightweight pieces were higher than 3.5% which was found to be detrimental to the quality of concrete. Figure 12 shows a core taken from the section of pavement that had used the higher percentage of lightweight pieces. Figure 13 shows the pavement surface after the grinding of bumps with a significant amount of lightweight pieces at the surface.

Figure 12. Old Production of Coarse Aggregate

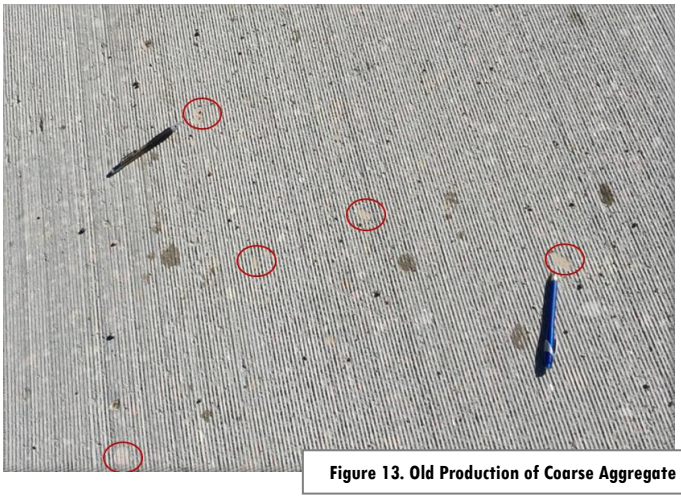


Figure 13. Old Production of Coarse Aggregate

Summary:

Samples were collected from the field and evaluated from a project which started out with large amounts of lightweight particles. The Department found the initial stockpile had an excess of 3.5% of lightweight particles which impacted the performance of the concrete pavement in Phase I of the project. Therefore, the Department judged the coarse aggregate stockpile to be non-compliant due to injurious quantities of deleterious materials. After the supplier had made changes to the production of the coarse aggregate, the Department showed a reduction of the lightweight particles to a level that the Department considered acceptable. The pavement construction continued as planned for the 2015 construction season. In an effort to determine a quantitative quality control method to evaluate the effectiveness of lightweight particles and to develop quantitative acceptance criteria for the second phase of the project, the Department developed the NDR T 113 "Lightweight Pieces in Aggregate" test method and modified the specifications of the current aggregate acceptance criteria. The Department will continue the evaluation of the concrete placed during Phase I of the project which had high amounts of lightweight particles and verify the long term performance of the pavement with Department's new specification for

aggregate acceptance criteria allowing the following as acceptable material: Clay Lumps 0.5%, Shale 1.0%, Soft Particles 3.5% and Lightweight Pieces 3.5% not exceeding accumulative value of 3.5% for quality testing of coarse aggregate. As well as, the quality of lightweight particles in the fine aggregate not exceeding 3.5%.

References

1. AASTHO, 2015. Lightweight Pieces in Aggregate, T 113.
2. North Dakota Department of Transportation, 2015. ND T 113 Lightweight Pieces in Aggregate Standard Test Method.