Back to Basics: How Fundamental Material Testing Affects Plant-Produced Asphalt Mixes

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Abstract

The primary objective of developing laboratory-produced asphalt mix designs is to establish conditions that as best as practicable replicate plant production, field operations, and quality processes. The ability to replicate these conditions provides confidence that the asphalt mixture will demonstrate similar material qualities in both the laboratory and field and will provide the selected performance characteristics. Recent experience suggests current asphalt mix design processes do not always provide material characteristics correlating to those produced in the field. This paper presents the findings of a study investigating laboratory testing variability of key asphalt mix properties and how this variability could influence quality, performance, and overall cost of asphalt production.

A study was undertaken in 11 laboratories across Canada to compare the potential variability of 5 key metrics employed in asphalt mix design: 1) fine aggregate relative density; 2) coarse aggregate relative density; 3) maximum relative density of uncompacted asphalt; 4) bulk relative density of compacted asphalt; and 5) addition of dust or baghouse fines in the lab to replicate the inadvertent creation of dust by the plant.

Outcomes from the study were compiled and reviewed and a summary is presented with commentary on the potential biases that may exist. The study concluded that there are variables in the basic materials testing we do that can have dramatic effects on asphalt mix design results and by better understanding and controlling those variables, asphalt mix designs can produce more repeatable results.

Résumé

L'utilisation de ce modèle est obligatoire. Des instructions détaillées pour les auteurs sont fournies séparément avec quelques conseils fournis ici. Si vous copiez du texte d'un ou plusieurs autres documents dans ce modèle, utilisez la fonction "Collage spécial" dans le menu Edition et sélectionnez "Texte non formaté". Cela appliquera automatiquement le formatage de texte approprié. Si un ajustement manuel est nécessaire, profitez du menu déroulant Style et sélectionnez le "Texte abstrait CTAA". Il n'est pas nécessaire de fournir une ligne blanche entre les paragraphes car l'interligne approprié vous a été fourni.

En utilisant un maximum de 200 mots, transmettez l'essence de l'article de l'article afin que les lecteurs occasionnels soient persuadés de lire l'article en entier. Pour être efficaces, les résumés doivent fournir une brève introduction des problèmes et un aperçu de l'approche de recherche, ainsi que les principales conclusions et recommandations pour les travaux futurs. Ne sous-estimez pas l'importance du résumé – c'est généralement le seul texte fourni aux moteurs de recherche en ligne et aux bases de données des bibliothèques.

Les résumés fournis en anglais seront traduits en français et vice versa.

1.0 Introduction

The elemental purpose of an asphalt mix design is to find the best blend of aggregate and asphalt cement that provides the desired properties for the intended application. If that laboratory developed blend can be replicated at the asphalt plant, constructed in the field, and lasts a long time, that is even better. However, as an industry, we have moved far past the basics into advanced chemistry of asphalt binders and sophisticated performance testing that attempts to predict long-term performance and prevent asphalt deficiency challenges.

As technological advancements in the asphalt and pavement industries continue to evolve, it is important to understand the material fundamentals that are used to produce the mixture long before performance testing can even be considered. Foundational lab testing of asphalt materials and asphalt mixtures is a topic often glossed over or is considered “well-known” information in the industry; however, similar to structures, if the foundation is flawed, failures are inevitable.

This study’s objective was to bring the fundamental parts of asphalt mix design back to the forefront. We reviewed the basic tests and materials that form the foundation of a mix design by looking at the certainties we think exist in asphalt mix design. We determined what we considered to be the five (arguably) most impactful metrics in mix design development:

1. Fine Aggregate Relative Density.
2. Coarse Aggregate Relative Density.
3. Maximum Relative Density of Asphalt Mixtures (MRD).
4. Bulk Relative Density of Compacted Asphalt (BRD).
5. Magic Dust (Baghouse Fines).

These five items form the basis of any asphalt mix design. As these (top 4) are the commonly conducted tests in any materials testing laboratory, it is expected that most of the laboratories would have mastered the test procedures and the results would be very similar. However, in our experience, it was observed that the inter-lab and inter-technician variations were significant in some instances.

2.0 Background

The idea for this paper started with a single client who was concerned with the rising cost of asphalt binder and was seeking assistance in trying to find ways to lower the asphalt cement content of their mixes to lower the mix prices so that they could be cost competitive. We had the benefit of working with this client for many years, so we had access to a large amount of historical data.

As we compiled all the data and started to compare the mix designs from the last 10+ years, we were drawn to the differences and variations in the most basic and fundamental test results. Many of the differences from one year to the next were so minimal that they were barely perceptible; however, by reviewing historical data spread over years, we noticed significant changes over longer time frames despite the supplier using the same material sources. Throughout the process of working with this client and trying to help them lower their asphalt cement content, it became clear that small changes in some of the most fundamental test properties, that could be perceived as minor test variability, were having a larger impact over an extended period of time on asphalt production.

This led us to question the impact of small variations in the fundamental test properties in the lab on the asphalt mix. Inevitably, every laboratory and operator will have their own precision and bias limitations, so by reviewing data from numerous labs, the results can be expected to be more variable. Moreover, many jurisdictions across Canada have different specifications and different sieve nest configurations. With so many variables in play, the basic tests are no longer as simple as they appear.

So, what happens when you give 11 labs across Canada the same products, sampled and prepared by a single individual, with the same test instructions? In theory, you would hope that the results would be the same or at least similar. The results of this study showed us a different picture.

3.0 Disclaimer

A bit of a disclaimer before we get into the study: the purpose of pointing out the variabilities in the testing is not to create lack of confidence in laboratory testing and test results, but rather to reinforce the importance of experience and expertise. Many of the labs performing testing commented that the source material was nothing like the material they were used to. Test labs were given only one sample to test. In a real-world scenario, the lab would typically have historical local data available to use as a reference, such as a mix design, available quality assurance (QA)/quality control (QC) data, aggregate source, and test information.

An experienced lab technician knows when and where to check their data when something seems amiss, but in this case the labs were given none of that, giving them no opportunity for redemption if a result seemed to be erroneous.

4.0 Why Do We Care? Laboratory Produced Mix Design Versus Plant Production

An asphalt mix design is the recipe for the optimum blend of aggregate and asphalt binder. The aggregate and asphalt binder design blend provide the asphalt mixture meeting the target volumetric properties resulting in the desired performance in the field. The results of the field QC or QA testing are compared to the mix design. If it matches, it is good; if it does not, that is bad. This seems simple.

When developing mix designs, our overall goal in the lab is to accurately predict field conditions and plant production of asphalt. Every test in the lab is performed with the assumption that the asphalt mix properties achieved during the mix design in the lab are achieved during the plant production and the QC/QA test results are similar to those from the mix design. Over the long term, it is also assumed that the asphalt mix will meet the performance expectations over the desired life of the pavement. Any observed variations caused during design, production, and construction highlight the importance of matching lab designs and field test results to prevent rework and lost productivity.

The subjective nature of aspects of testing means that too much inconsistency between the lab and field mix properties can amplify small differences into bigger physical and financial problems down the road. To minimize associated costs with mix -related issues and performance deficiencies, it is crucial to carry out accurate field and laboratory testing, as well as to monitor changes to any materials used for production that can have an impact on the mix properties.

Correct aggregate relative densities (specific gravities) are important because of their use in Voids in Mineral Aggregate (VMA) calculations. Similarly, MRD and BRD are used in determining proper compaction. Similarly, dust or baghouse fines are often added or at least considered in various ways to account for the aggregate breakdown that happens during plant production but not during lab mixing. Combined, these values are used in determining optimal binder content and asphalt absorption resulting in an asphalt mix that will perform as desired and meet the serviceability expectations during the expected lifespan of the pavement.

Accurate testing can result in a more cost-effective mix design. It can help optimize the asphalt binder content, which is a major cost component of the asphalt mix. Optimal binder content and VMA ensures that there is sufficient binder to coat the aggregate particles but not an excess amount resulting in higher costs and adversely affecting the mix performance. Additionally, an ideal VMA allows for better control of other volumetric mix properties and can maintain good stability and high durability. Since proper design VMA can lower material costs and increase efficiency, there is also a direct impact on sustainability through the reduction of waste and total energy used in production.

This paper aims to assess results of fundamental laboratory tests and discuss the implications of any variability, which inevitably will have some financial implications.

5.0 Five Metrics – Why These Five?

5.1 Fine Aggregate Relative Density

Relative density, also known as specific gravity, is the ratio of the weight of material to the weight of water (at 23°C) of the same volume. In an asphalt mix design, this value is used in the calculation of air voids, VMA, and water absorption. In Asphalt Institute's MS-2 Asphalt Mix Design Methods[1], there is a note regarding the accuracy of specific gravity measurements and its importance - "Unless specific gravities are determined to four significant figures (three decimal places), an error in air voids value of as much as 0.8 percent can occur." This test also calculates the water absorption of the aggregate, which is very important in the determination of the quality of the aggregate and how much binder may be required in the mix. A more porous or absorptive aggregate will ultimately require more asphalt binder.

5.2 Coarse Aggregate Relative Density

Coarse aggregate relative density (or specific gravity) is important for all the same reasons noted above. However, we kept the two separate because of the different test methods required to test fine and coarse aggregates. Each comes with their own challenges for testing, so it was important that these were analyzed separately.

5.3 Maximum (Theoretical) Relative Density of Asphalt Mixtures

This is another relative density or specific gravity test comparing a unit mass of water to the same mass of asphalt mixture. This value is called theoretical because it would be the maximum value if all the air was removed from the mix; however, there is no way to confirm that the test truly produces zero air voids. Regardless, this test number provides the maximum value or the highest density the asphalt mixture can be, and this value is used in the calculation of air voids and asphalt absorption. For brevity, the word theoretical had been omitted from the remainder of the study except when referencing the title of the test standard.

5.4 Bulk Relative Density of Compacted Asphalt

This test refers to the density of briquettes formed in the laboratory. For this study, the Marshall method of mix design was used so all the briquette references are a Marshall specimen. While the actual test method compares the unit mass of the briquette to the same mass of water of the same volume at 25°C± 1°C like the previously mentioned tests, this test result is highly dependent on the forming of the briquette, so we also included that as part of the analysis of this metric. The BRD is used to determine air voids of the mixture as well as the stability and flow of a Marshall mixture.

5.5 Magic Dust

While the magic dust does not have a test procedure, its presence, absence, or proportion in the mix can be an important factor in the asphalt mix design. Various jurisdictions in Canada do not require dust to be tested even though it is used as a component in the mix design. Some mix designs in Canada do not report dust in the design, but it is assumed it exists or is created by plant operations. SuperPave mix designs and volumetric test reports usually require the dust to binder ratio to be reported, but this is not typical of Marshall mixes. Dust content in a mixture can affect density, workability, binder content, and air voids among other things.

6.0 The Study

Eleven labs participated in the study across Canada. The following sections detail what each lab was provided to perform the requested testing.

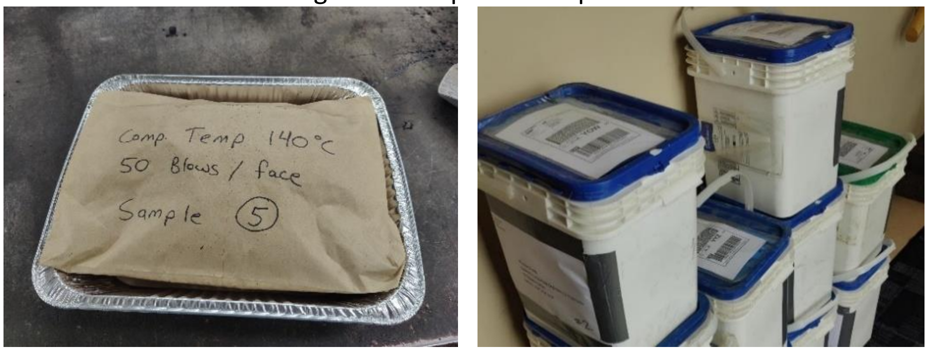
6.1 Sample Preparation

Samples were sent to the 11 labs included in the study. To minimize any variations in sample preparation, all aggregates were sampled from the same pit, the same asphalt binder was used, and one technician sampled and prepared all the samples and put the packages together for testing. The same instructions were issued to all 11 participating labs.

Each sample package contained:

- One 2000 g sample of 12.5 mm Nominal Maximum Size (NMS) coarse aggregate.
- One 1000 g sample of manufactured fines (MF).
- One 1000 g sample of washed sand (WS).
- 5000 g of mixed 12.5 mm asphalt with a target asphalt content of 6.30% by mass of mix.

Figure 1. Prepared Samples



The larger aggregate sample was preblended before splitting to account for any segregation that might have occurred during collection from the stockpile, and all aggregates were split and bagged simultaneously to minimize any variations in moisture levels. The same technician batched the asphalt over the course of two consecutive days using the exact same split aggregates, binder, tools, and temperatures. To account for any variations that could result from the necessary tests, the masses of the aggregate and binder in the asphalt mix were measured to the nearest tenth of a gram. Any given sample never deviated from the intended binder content by more than 0.01%.

6.2 Instructions to Participants

The following instructions were sent to all participating labs.

6.2.1 Aggregate Testing

Two (2) kilograms (minimum) of NMS 12.5 mm coarse aggregate and one (1) kilogram (minimum) of each MF and sand have been supplied in your test sample package. Split the sample accordingly, per American Society for Testing and Materials (ASTM) C702, "Standard Practice for Reducing Samples of Aggregate to Testing Size"[2].

Coarse aggregates shall be tested according to ASTM C127, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate"[3], and fine aggregates shall be tested according to ASTM C128, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate, Gravimetric Procedure"[4].

Additional program requirements are as follows:

- One determination of coarse aggregate relative density and two determinations of each fine aggregate relative density are required.
- Coarse aggregate has been sieved over the 5 mm sieve (to reduce sample size for shipping), but material has not been oven dried or washed and further sieving may be required.

6.2.2 Reporting and Extras

- Please use the reporting sheet provided to report all results. Excel formulas for calculations are acceptable. Report all aggregate relative density data (oven dry, saturated surface dry [SSD], apparent) to the nearest 0.001 and absorption results to the nearest 0.01.
- Please report water temperature used at time of testing for both coarse and fine aggregates.

- Use and report typical sieve size used for washing (75 µm or 80 µm) in your jurisdiction.
- Please provide a picture of the scale, bath setup, and towel used before testing. These pictures will not be shared as part of the paper or presentation but are being used to help identify variability.
- Please provide a picture or video of your sand and MF at SSD condition (upon lifting the cone during cone test).

6.3 Asphalt Testing

A sample box containing approximately 5000 g of 12.5 mm mixed asphalt has been supplied and is ready for testing. BRD and MRD samples shall be tested according to ASTM D6926, "Standard Practice for Preparation of Asphalt Mixture Specimens Using Marshall Apparatus"[5], ASTM D2726, "Bulk Specific Gravity and Density of Non-Absorptive Compacted Asphalt Mixtures"[6], and ASTM D2041, "Standard Test Method for Theoretical Maximum Specific Gravity & Density of Asphalt Mixtures"[7]. The asphalt testing program requirements are as follows:

- Using the material provided, prepare two briquettes and one MRD sample.
- Test two briquettes for BRD.
- Loose mix asphalt has a design compaction temperature of 140°C and is a 50-blow Marshall mix.
- Mixture has been dried and preconditioned. Moisture content determination is not required for the purpose of this testing program.

6.3.1 Reporting and Extras

- Report the data and calculations on the data sheet provided. Excel formulas are acceptable.
- Report the BRD and MRD to the nearest 0.001.
- Report MRD residual pressure manometer (mm of Hg).
- Report MRD water temperature in the bowl and bath (if applicable).
- Report BRD bath water temperature.
- Provide a picture of the bath setup.
- Provide a picture of the MRD/vacuum setup.

Labs were instructed to include any possible errors or variability in test results. As stated above, all results are presented anonymously, and it is in the study's interest to account for all scenarios.

7.0 The Results of The Study

In addition to the material testing results, additional information was requested from the labs including soak times, water temperatures, agitation methods and times, and other details. While we could not make any large correlations using the extra data, the information served to prove that all participants were familiar and competent in following ASTM guidelines and were using appropriate equipment for testing, leading to no conclusions of error through faulty equipment or laboratory knowledge of test methods.

Each of this study's focus test methods (except for dust) were graded. Scores were based on using the average taken from the 11 submissions and rated based on how many were within 1 standard deviation (SD) of that average. Values that strayed more than 2 SD and 3 SD were also recorded. Any results greater than 3 SD from the average and any results suspected of reporting error were excluded from averages. Multi-laboratory precision SD values were used from each ASTM in the precision, reporting, and bias sections of each test method.

7.1 Coarse and Fine Aggregate Relative Densities

Aggregate relative densities are one of the first tests done when beginning an asphalt mix design and are one of the first places where errors in mix design and test results could begin due to its subjective nature and use in further calculations.

Table 1. Summary of Aggregate Testing

Summary of Aggregate Testing (ASTM C127, C128)													Of 11 Samples:				ASTM Standard Deviation for multilaboratory precision	Accuracy % (Based on < 1 SD of Avg)
													< 1 SD from Avg	1 SD < Avg < 2 SD	2 SD < Avg < 3 SD	> 3 SD from Avg (excluded)		
Coarse Aggregate	**Relative Density (OD)**	2.620	2.619	2.615	~~2.689~~	2.619	2.610	2.612	2.614	2.622	2.640	2.608	9	1	0	1	0.013	82%
	Absorption (%)	1.00	1.16	1.21	1.11	1.09	1.02	1.09	1.10	1.01	0.72	1.10	-	-	-	-	-	-
Manufactured Fines	**Relative Density (OD)**	2.560	2.620	2.555	2.619	2.588	2.560	2.599	2.589	2.555	2.641	2.547	3	7	1	0	0.023	27%
	Absorption (%)	2.10	1.36	2.29	1.05	1.41	2.30	2.10	1.34	1.95	~~0.60~~	2.00	2	5	3	1	0.23	18%
Washed Sand	**Relative Density (OD)**	2.580	2.594	2.606	2.590	2.566	2.540	2.570	2.593	2.610	2.591	2.557	7	4	0	0	0.023	64%
	Absorption (%)	1.70	1.36	1.29	1.38	1.54	2.10	1.70	1.10	0.88	1.11	1.70	4	5	2	0	0.23	36%
Blended Aggregate	**Relative Density**	2.593	2.618	2.596	2.642	2.600	2.581	2.602	2.604	2.599	2.632	2.579	-		-	-	-	-
Regional Sieve	**80µm, 75µm, 0 = unwashed**	0	75	75	75	75	0	75	80	0	75	80						

Standard Deviations according to ASTM C127, C128 for multilaboratory precision.
Values with a strikethrough were excluded from averages due to extreme deviation or possible reporting error.

Each lab was asked to follow ASTM guidelines as much as possible, but also to follow the regional test procedures such as the sieve size that the aggregate would be washed on, if washed. Specific to the sieve size, no correlation could be determined as the other results showed too much variability to isolate this as a cause if it did make a difference.

Across all aggregate testing, the coarse aggregate relative densities were the most consistent, with 9 of 11 results within 1 SD of the mean value (82%) and no samples greater than 2 SD from the average were used in the analysis. One value was excluded from the average due to extreme deviation. The WS also fared well, with 7 submissions within 1 SD of the average (64%), and 4 results within 2 SD. MF had the most variability, with only 3 results within 1 SD (27%) 7 within 2 SD, and 1 SD greater than 2 SD from the average. This is shown in the data summarized in Table 1, above, and is concerning since fine aggregate consists of 70% of the target blend of aggregate in the mix used for this study.

The fine aggregate absorptions were inconsistent, with MF ranging from 1.05 to 2.30 (scoring 18%) and 1 result being excluded due to extreme deviation, and WS ranging from 0.88 to 2.10 (36%).

The relative densities of blended aggregates from each laboratory were also variable, ranging from 2.579 to 2.642, and at each extreme would need selecting vastly different target asphalt contents for the asphalt mix. Further, relative density values did not show any relationship with the absorption (from the same lab), adding extra noise to the variability. This would certainly have implications for a target asphalt content in any mix design.

Figure 2. Manufactured Fines Relative Density Results from Different Labs

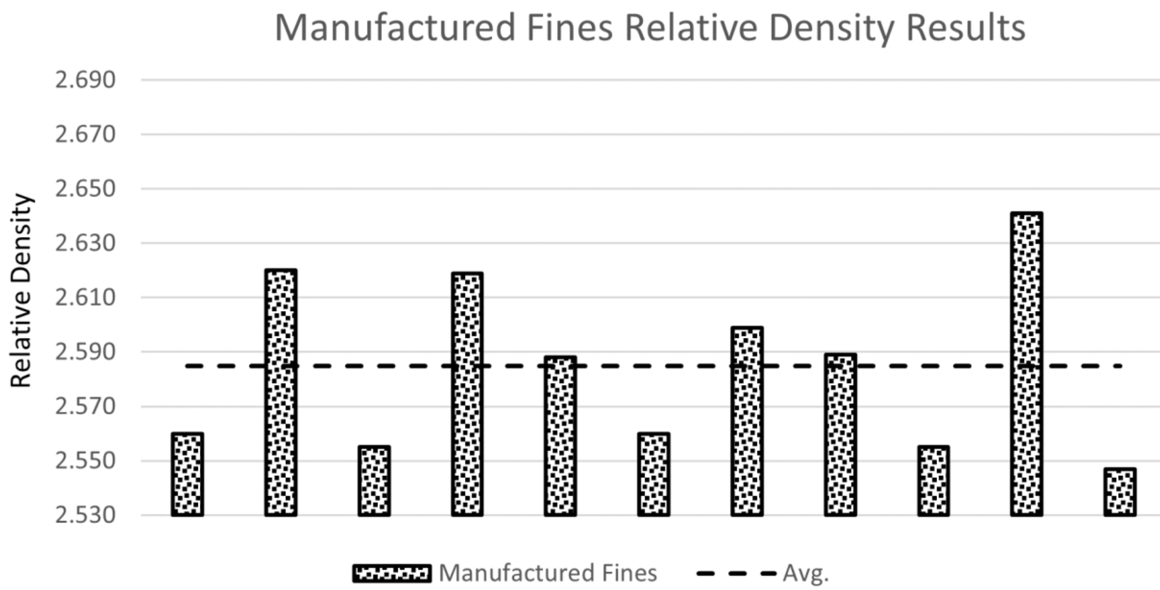


Figure 3. Washed Sand Relative Density Results from Different Labs

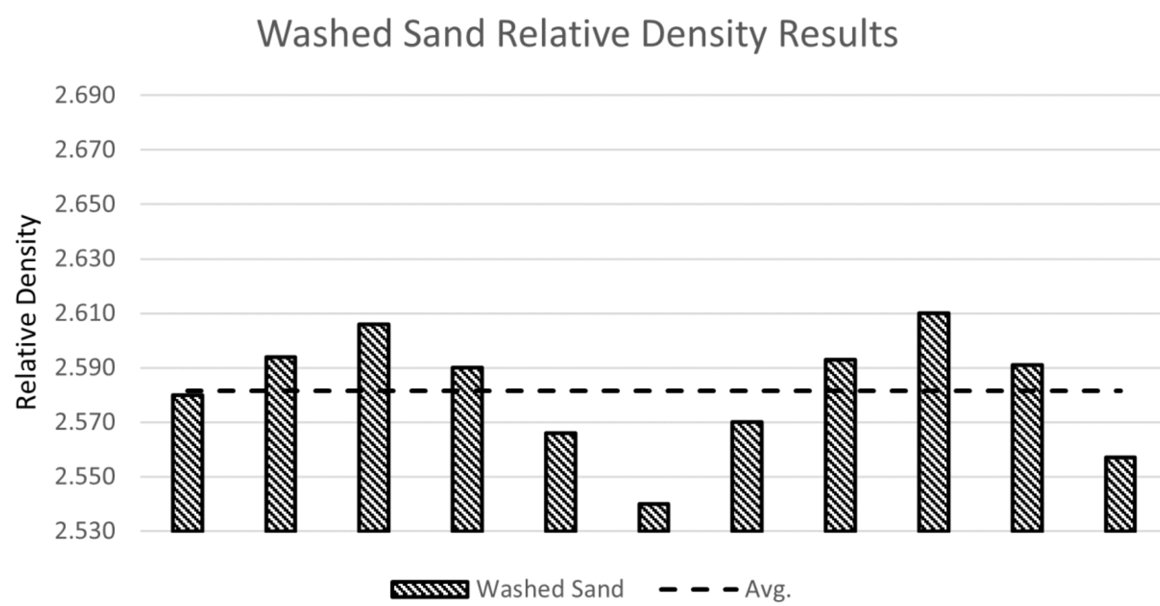


Figure 4. Coarse Aggregate Relative Density Results from Different Labs

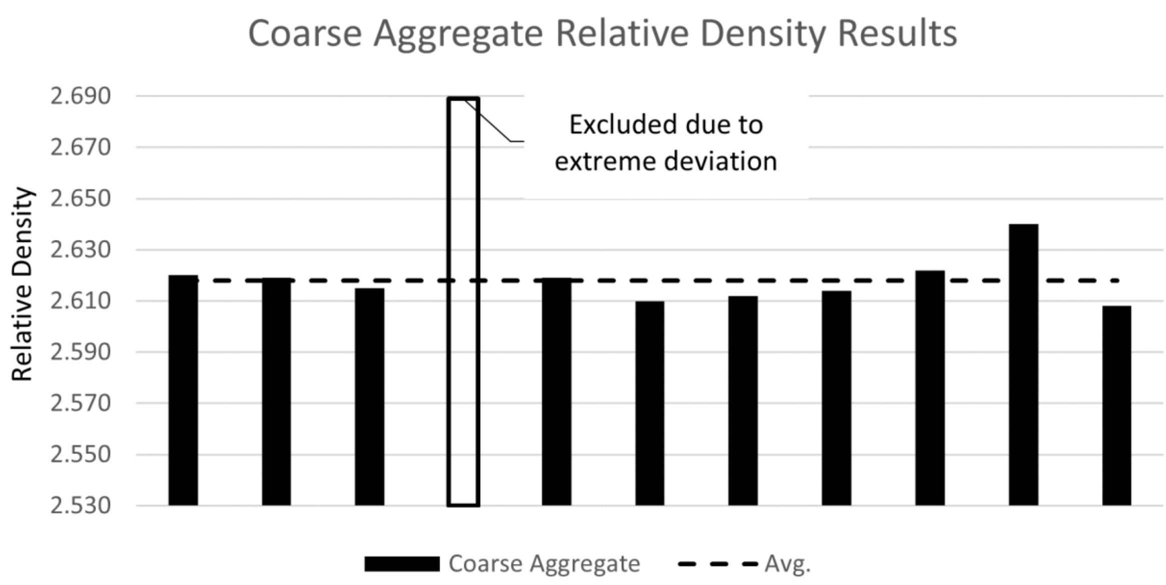
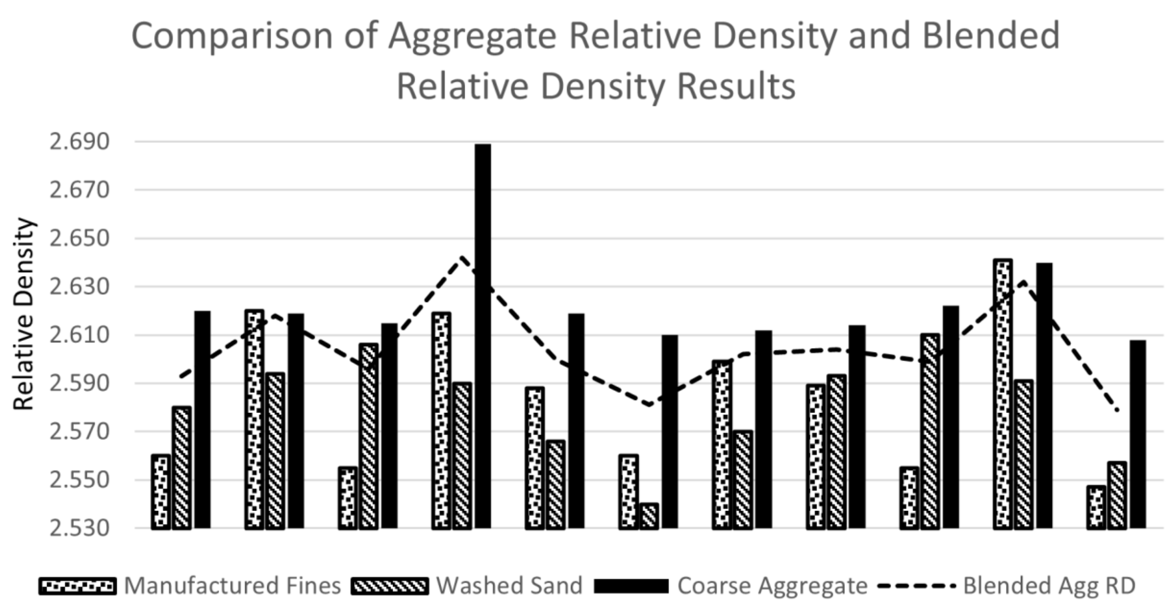


Figure 5. Comparison of Aggregate Relative Density and Blended Relative Density Results from Different Labs



<u>7.2 Bulk Relative Densities and Maximum Relative Densities</u>

Once relative density testing is completed and deemed accurate, MRD and BRD test results then become two important values that determine VMA and air voids. For this study, these results were scored the same manner as the aggregate relative densities, using multi-laboratory precision values from the ASTMs as standard deviations.

Table 2. Summary of Asphalt Testing

Summary of Asphalt Testing (ASTM D2041, D2726)													Of 11 Samples: < 1 SD from Avg	1 SD < Avg < 2 SD	2 SD < Avg < 3 SD	> 3 SD from Avg (excluded)	ASTM Standard Deviation for multilaboratory precision	Accuracy % (Based on < 1 SD of Avg)
12.5mm Asphalt Mix	**Bulk Relative Density**	2.332	2.348	2.364	2.348	2.371	2.334	2.346	2.366	2.333	2.354	2.344	6	0	5	0	0.015	55%
	Maximum Relative Density	2.420	2.420	2.411	2.417	2.415	2.433	2.417	2.422	2.426	2.420	2.425	11	0	0	0	0.016	100%
Calculations	**Air Voids (%)**	3.6	3.0	1.9	2.9	1.8	4.1	2.9	2.3	3.8	2.7	3.3	-	-	-	-	-	-
	VMA (%)	15.7	16.0	14.7	16.7	14.6	15.3	15.5	14.9	15.9	16.2	14.8	-	-	-	-	-	-

Standard Deviations according to ASTM D2041, D2726 for multilaboratory precision.
Air Void and VMA calculated using each submissions blended aggregate relative density to simulate what each lab would have produced individually.

MRD tests were the most consistent test values, and all 11 samples showcased this by reporting within 1 SD of the average (100%). However, the BRD results scored much lower, with only 6 samples within 1 SD (55%), which combined with even small variability in MRD values, resulted in larger variability in calculated air voids as displayed in Figures 6 to 8 below.

Figure 6. Reported Bulk Relative Density Results by Different Labs

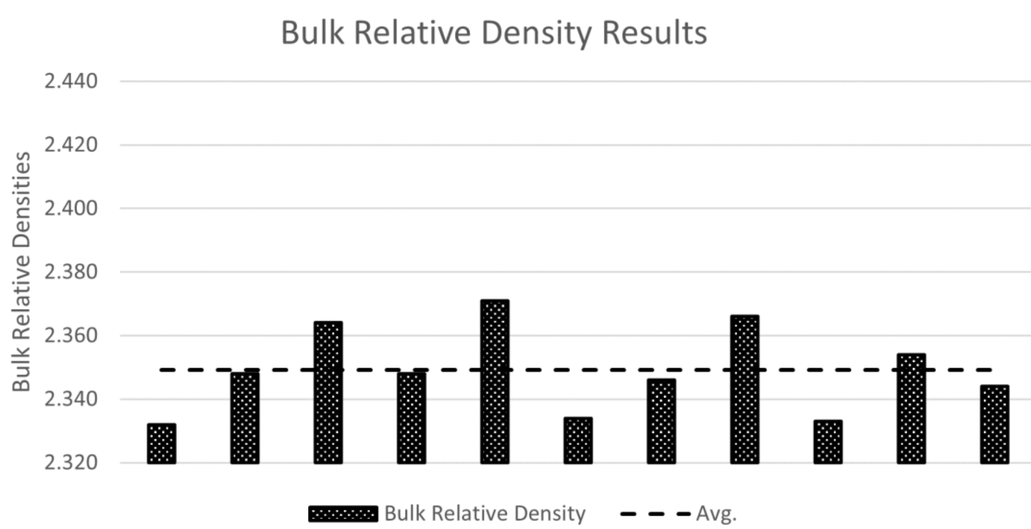


Figure 7. Reported Maximum Relative Density Results by Different Labs

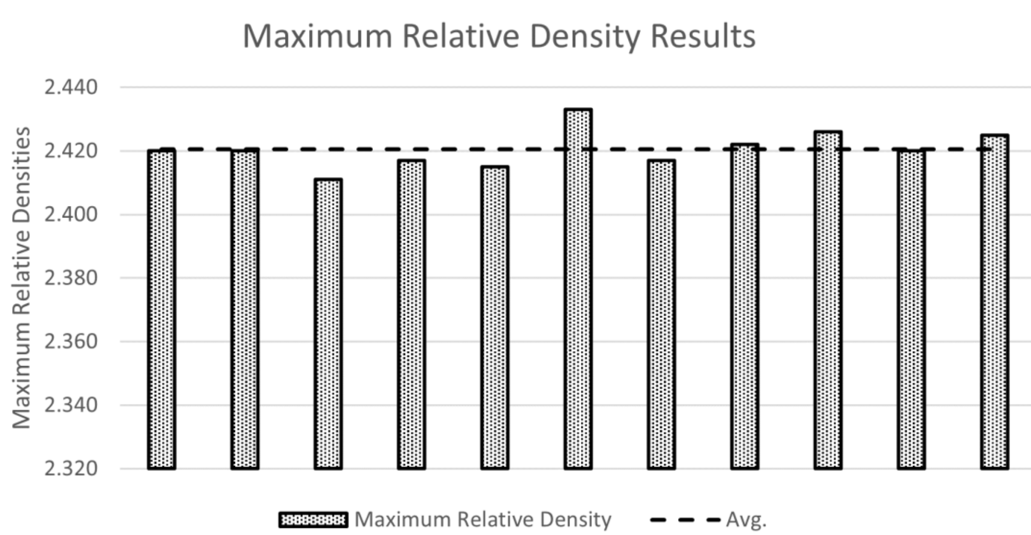
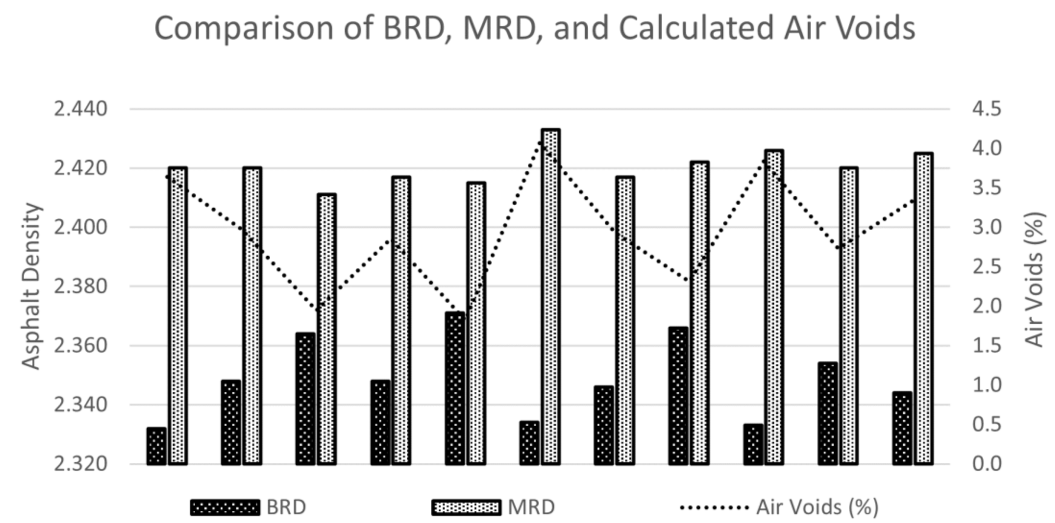


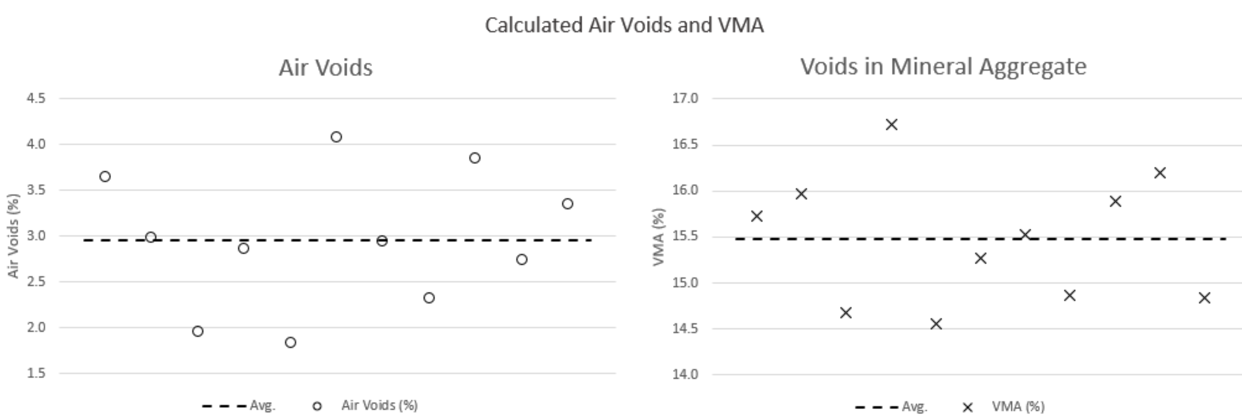
Figure 8. Comparison of Bulk Relative Density, Maximum Relative Density, and Calculated Air Voids



7.3 Calculations and Observations

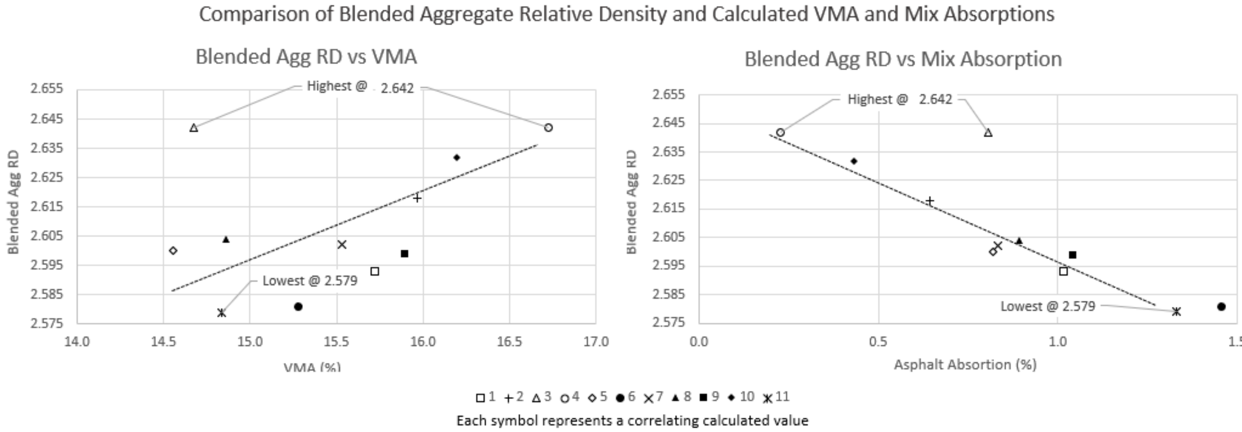
Though ASTMs are assumed to have been followed during the study, there were a number of results with no common trend and consequently large variability, which affected the asphalt mix volumetric property calculations.

Figure 9. Calculated Air Voids and Voids in Mineral Aggregate



There was notable scattering of calculated air voids and VMA percentages. Variability in the aggregate relative densities and asphalt BRD results amplified widening ranges with air voids ranging from 1.8% to 4.1% and VMA from 14.6% to 16.7%.

Figure 10. Comparison of Blended Aggregate Relative Density and Calculated Voids in Mineral Aggregate and Mix Absorptions



There was some correlation between values such as the blended aggregate relative densities and VMA and blended aggregate relative densities and mix absorption, though both values are calculated using each participating lab's submitted results. Given the spread of VMA results in the figures above, these correlations highlight the importance of consistent and correct aggregate densities to be able to calculate and report correct volumetric properties of a mix.

7.4 Reporting Extras

The labs were asked to provide additional information on their testing beyond the standard results, including lab setups and photographs from testing. They were also asked to respond to seven optional survey questions; however, only a small number of labs chose to answer these questions. Some of the information obtained from this extra data is presented in the following section.

7.4.1 Coarse Aggregate Relative Density

- One out of eleven labs soaked aggregate for less than 20 hours; all other labs reported soaking the aggregates between 20 hours and 24 hours.

7.4.2 Fine Aggregate Relative Density

- Eight labs reported that they washed their aggregate for aggregate relative density testing; three did not wash their aggregate.
- All labs reported using a fan to dry their aggregates.
- Only one lab reported using a mechanical shaker for air bubble removal.
- One lab soaked aggregate for less than 20 hours; all other labs reported soaking material between 20 hours and 24 hours.

7.4.3 Bulk Relative Density and Maximum Relative Density

- Two labs reported using a mechanical hammer to form Marshall briquettes.
- Two labs reported immersing briquette samples for more than five minutes. Nine labs reported immersion times between three minutes and five minutes.

- Of the responses received on reheating methods, all labs reported using an oven. Reheat times and possible aging times of the asphalt mix were not recorded.
- All labs reported a 15-minute “shake time” and 10-minute soak time.

7.5 Miscellaneous

- Experience level of technicians ranged from 1 year to 35 years.
- The number of technicians involved with the testing at each of the labs varied. Of the labs that reported on technician involvement with the testing, there was an even spread between one technician who did it all and having multiple technicians tackle each different testing section. It was not verified if multiple technicians were involved due to area of expertise or busy schedules.

8.0 American Society for Testing and Materials Versus American Association of State Highway and Transportation Officials’ Literature Review

The ASTM procedures used in the testing and referenced in the study are:

1. ASTM D6926 “Standard Practice for Preparation of Asphalt Mixture Specimens Using Marshall Apparatus”[5] vs. American Association of State Highway and Transportation Officials (AASHTO) R 68 “Standard Practice for Preparation of Asphalt Mixtures by Means of the Marshall Apparatus.”[8]
2. ASTM D2726/D2726M “Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Asphalt Mixtures”[6] vs. AASHTO T 166 “Standard Method of Test for Bulk Specific Gravity (G_{mb}) of Compacted Asphalt Mixtures Using Saturated Surface-Dry Specimens.”[9]
3. ASTM C128 “Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate”[4] vs. AASHTO T 84 “Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate.”[10]
4. ASTM C127 “Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate”[3] vs. AASHTO T 85 “Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate.”[11]
5. ASTM D2041/D2041M “Standard Test Method for Theoretical Maximum Specific Gravity and Density of Asphalt Mixtures”[7] vs. AASHTO T 209 “Standard Method of Test for Theoretical Maximum Specific Gravity (Gmm) and Density of Asphalt Mixtures.”[12]
6. ASTM C188 “Standard Test Method for Density of Hydraulic Cement”[13] vs. AASHTO T 133 “Standard Method of Test for Density of Hydraulic Cement.”[14]

For this study, we focused on the ASTM methods for all testing. However, differences between AASHTO and ASTM procedures were reviewed. Test standards for aggregates are also available through the Canadian Standards Association (CSA) but were not reviewed for this study. Both ASTM and AASHTO reference the other in their standards making it accepted that the test procedures are generally interchangeable. However, this is not always the case, and several noted differences between the two for our key metrics are discussed below.

8.1 Fine Aggregate Relative Density

Upon reviewing the testing standards, both test methods were found to have similarities regarding the methodologies provided. However, there was one metric that differed between the two, where one is required to soak the sample for a period before progressing to the next step of the test. While the AASHTO standard specifies a soak time of 15 hours to 19 hours, ASTM states a soak time of 24 hours ± 4 hours. Both test methods have considered it to be a negligible difference despite the nine -hour difference between both test procedures.

8.2 Coarse Aggregate Relative Density

A varying finding was the water bath overflow outlet, as mentioned in AASHTO. While the ASTM mentions the displacement of water, there was no specification of an overflow outlet in the test standard.

While the AASHTO standard specifies a soak time of 15 hours to 19 hours, ASTM states a soak time of 24 hours + 4 hours. Both test methods have considered it to be a negligible difference despite the nine-hour difference between both test procedures.

8.3 Maximum Relative Density of Asphalt Mixtures

Given that the MRD test is known to be reliable in the asphalt testing world, both standards left room for subjectivity, including things like sample testing portions, time of maintaining vacuum pressure, and methods permitted to agitate a sample.

AASHTO stated that it may be tested in portions if the sample is larger than container capacity. As per ASTM, “Sample sizes greater than about two thirds of the volume of the container shall be tested in portions, with none of the test portions being less than 1250 g.”

ASTM specifies 15 minutes ± 1 minute time for maintaining vacuum pressure and AASHTO specifies 15 ± 2 minutes time for maintaining vacuum pressure, indicating an allowable difference in tolerance of 1 minute.

Another difference that was discovered was the option to manually agitate the sample in the AASHTO test standard versus the ASTM, which did not include that option. The manual agitation method proceeded to specify agitation intervals of two minutes while maintaining the required vacuum pressure.

8.4 Bulk Relative Density of Compacted Asphalt

The ASTM method only indicated the method a sample is immersed, indicating operators should utilize a water bath setup under a scale. This method is also included in the AASHTO test standard, so there appeared to be no differences to consider for this test.

There is one additional method provided in AASHTO (AASHTO T 166[9]) to determine a specimen BRD, which includes the use of a calibrated volumeter.

Before we can address the test standards related to the BRD testing mentioned above, we must consider the procedures associated with making the briquettes used for the BRD testing ASTM D6926 ("Standard Practice for Preparation of Asphalt Mixture Specimens Using Marshall Apparatus"[5]) and AASHTO R 68 ("Preparation of Asphalt Mixtures by Means of the Marshall Apparatus"[8]). Upon review, there were two metrics between both testing standards that had differing specifications, and those included Marshall mould dimensions and temperatures to heat the Marshall moulds to prior to compacting the specimens.

Mould dimensions found in both testing standards generally aligned, but the difference lay in the measuring tolerances of the mould. The ASTM standard provide a range of dimensions, while AASHTO has no tolerances except for the inside diameter of the compaction mould. Comparing both tolerances, the range difference equates to 0.17 mm.

As for the heating requirements of the mould assembly, AASHTO specifies temperatures ranging between 93.3°C to 148.9°C. ASTM, however, provided two temperature requirements, one ranging from 90°C to 150°C and the other to be "within 5°F (3°C) of the required mixing and compaction temperatures."

8.5 Magic Dust

There is no specific test procedure commonly used for the testing of relative density of baghouse fines. ASTM C188 test method "Standard Test Method for Density of Hydraulic Cement"[13] and AASHTO T 133 "Standard Method of Test for Density of Hydraulic Cement"[14] test methods are often considered the most relevant test methods for these ultrafine aggregate particles but are rarely specified for use in mix design development. If these test methods were to be utilized, there are minimal differences between the two test standards. Even though the variations were found to be minimal, the differences observed were in the temperature required when immersing the flask and its contents in a water bath. ASTM specifies maintaining temperatures of 23°C±2°C and AASHTO specifies a tolerance of 23°C±4°C.

9.0 Discussion and Test Procedures

9.1 Fine Aggregate Relative Density

To wash or not to wash and what sieve do we use to wash? Our study showed that 6 of the 11 labs washed their aggregate on the 75 µm sieve, 2 used an 80 µm sieve, and 3 did not wash at all. Neither the AASHTO nor the ASTM procedure for this test specified which sieve size to use because the procedure does not specify washing at all. So, while all labs were told to follow the ASTM procedure, why did so many wash?

Although there is no information available to validate this, it appears that washing of the aggregates has become a standard practice that may have been passed down as part of training procedures from experienced technicians to new technicians.

During the literature review, we came across a paper that was published in the 1993 Canadian Technical Asphalt Association Proceedings and was titled "The Canadian Asphalt Mix Exchange Program 1992-1993 Summary," by R. Daryl Nixon[15]. In the paper, the instructions to the exchange were provided, and those instructions included the following:

**The following interpretive revisions to ASTM C128-84 were agreed to at the 1989 Canadian Asphalt Mix Exchange meeting. All participants should incorporate the following into their procedures:*

- *For the fine aggregate should again be washed after the 24-hour immersion period*.*

This comment was reported with the Canadian Asphalt Mix Exchange Program (CAMEP) summary in almost every CTAA Proceedings up to and including 2015. Its possible that this excerpt from the CTAA proceedings became part of a standard of practice for many labs.

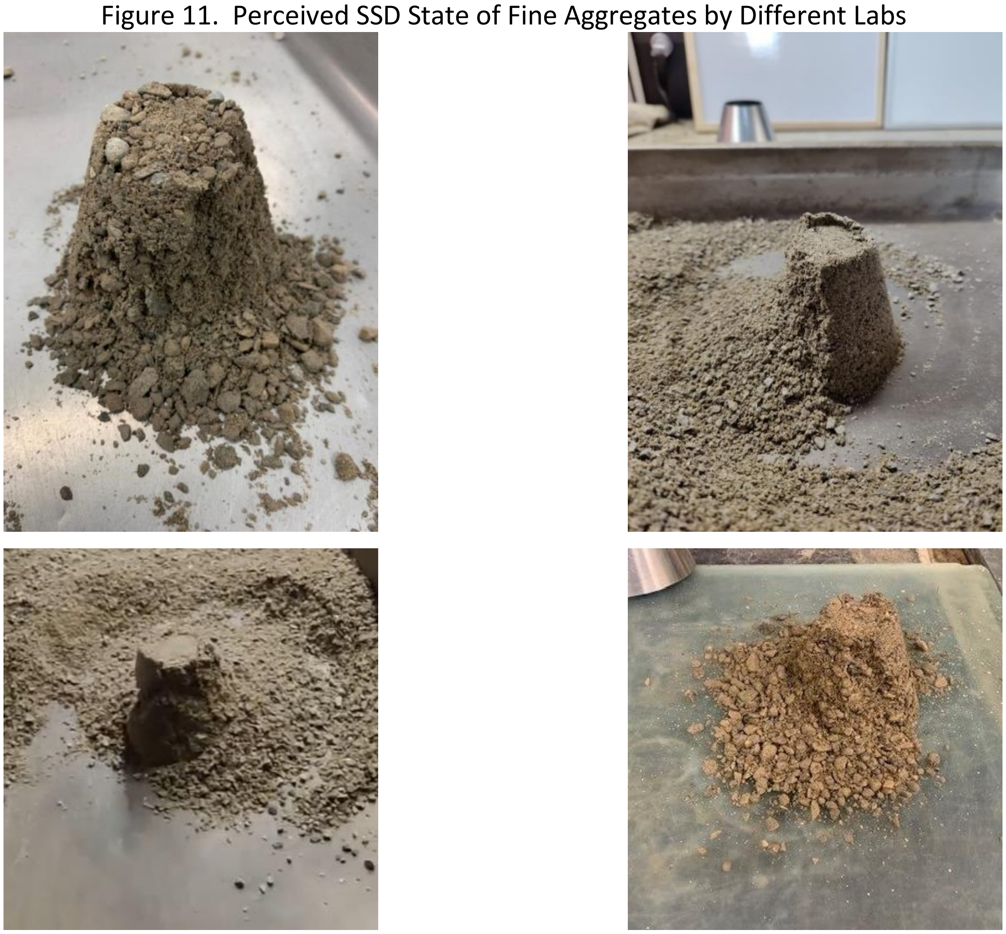
9.1.1 Saturated Surface Dry

The SSD part of this test is always a challenge and discussion topic especially for those of us who were trained to do the test before YouTube. It often depended on who trained you as to what you considered SSD to be because the test standard has a description of the SSD condition but with no image or picture.

If you look up this test online today, you continue to get varying information on what your aggregate should look like if it is at SSD. Simply do a search of “fine aggregate relative density SSD” and see what you get. There will be examples of perfect volcanoes of sand and examples of dry piles of sand both claiming to be at SSD. The test standard simply says to look for “slight slumping” but there is no example or picture to describe what this is, so this is left to the operator’s discretion.

Here are some pictures of the material at SSD from the labs included in the study:

Figure 11. Perceived SSD State of Fine Aggregates by Different Labs



The two aggregates used in the study were very different. The MF material was very coarse, and the sand was a typical uniform natural sand. One major variability exists in this test because there is variability in aggregates, the MF will behave much differently than the sand. It was reported by the testing labs that the MF material was much harder to achieve SSD than the natural sand and it was much harder to work with overall. From the pictures above, you can see that the SSD in the sand looks much different than the SSD condition of the MF.

9.2 Coarse Aggregate Relative Density

SSD is always subjective and could be very different depending on the type and luster of the aggregate. Some types of coarse aggregate will appear dull, and it will be harder to see moisture on the surface compared to others that may appear shiny with even a slight amount of moisture. The test itself is very basic as it involves drying of the aggregates with a towel. Drying the aggregates uniformly also poses a challenge, especially if the towel is dirty or if the towel is wet (because that single towel has been used a few times that day).

Below are a few select photos illustrating the test material at SSD as well as a towel used for testing.

Figure 12. Laboratory Testing of Coarse Aggregates for Specific Gravity

Aggregates produced from different parts of a single quarry or pit can also have variations in specific gravity and absorption. One section in a pit may produce a softer material that will affect the overall absorption value, which could result in high asphalt cement contents in the asphalt mixes. Minor fluctuations may be considered inconsequential, but when the asphalt cement is the major component of asphalt mix cost, this could have significant impact on the overall project cost.

9.3 Maximum Relative Density of Asphalt Mixtures

The MRD test is considered by many asphalt lab practitioners to be one of the most consistent and reliable tests that is performed as part of the asphalt mix testing. Once an operator is trained and has successfully performed the test a few times, we see consistent results. The test is not without its issues though. Vacuum pump pressure, water temperature, mix type, agitation method, and other factors can cause variations in this test. These are especially challenging in a field lab where air and water temperatures are more difficult to control. However, this test does reliably provide an air void value that is representative of the mixture in the field. This again proves the importance of using an experienced operator who has access to historical representative test results or numerous samples to be able to set a baseline for data to be able to quickly identify an erroneous sample.

An issue with the MRD test is the vacuum pressure. It can be assumed that if we are trying to achieve the maximum density, we would want to remove the maximum amount of air by applying the maximum vacuum pressure. However, the test procedure identifies that the vacuum pressure should be set to maintain 30 mm of Hg ± 2.5 mm of Hg. This value can be more challenging to maintain than a full vacuum without an automatic controller. We can assume that the value is set to less than full vacuum to allow for less-efficient pumps to be used, but in our experience achieving full vacuum is easily possible and could possibly eliminate some test variability. If all operators were applying full vacuum for the test period or until no additional air is being pulled from the sample, it could provide a better multi operator and multi lab precision.

Another step in the MRD test procedure that can provide variability is fine aggregate particle size, which states that fine aggregate and asphalt binder ‘clumps’ shall not be larger than 6 mm. Large clumps of fine aggregate can hold excess air, and without sufficient agitation and enough vacuum, that air could remain trapped in the sample. Some asphalt mix types with polymers can have larger clumps of mastic and fine aggregate, which could stick together during the test and impact the final result.

The ambient air temperature is not specified for this test, but the water temperature is specified at 25°C±1°C. This temperature can influence the density of water and therefore the test result. Having dirty water with excess sediment can also have an impact on the density of the water and the result. Many labs use their water bath for multiple tests, and those tests may require the bath water to be maintained at different temperatures. For example, the bath for testing BRD and MRD is required to be maintained at 25°C±1°C, but the water temperature specified for aggregate relative density is 23°C±2°C. This leaves a window of only 1°C in which the bath can be used for both sets of tests, which is a very small temperature range to maintain, especially during extreme seasonal variations.

9.4 Bulk Relative Density of Compacted Asphalt

Prior to testing for BRD, the briquette needs to be prepared. Our samples were prepared using the Marshall method of laboratory compaction. The impact method of compaction inherent to the Marshall method is generally not considered a good representation of field compaction, however, the method is still widely used in Canada likely due to the low cost and portability of the test equipment.

The basic steps once the mixture is in the mould include keeping the hammer perfectly perpendicular to the pedestal surface (without leaning on it) and letting the mould weight fall freely. The test standards do not have any more details on the process once the asphalt mix is in the mould. Thus, this part of the test is subjective and can be highly variable from lab to lab and operator to operator.

The Canadian Council of Independent Laboratories (CCIL) methodology calls for allowing the weight to bounce before picking it up and lifting it to the top of the hammer shaft, creating a slower rhythm to the series of blows. This is because the CCIL Asphalt Correlation Testing instructions[16] include the following note:

- “Note 4. With the manual hammer, the following should be noted: (a) compaction pedestal must be secured; (b) the timing of blows should be 60+ 5 blows per minute; and (c) the hammer should be allowed to rebound between successive blows.”

The ASTM and AASHTO test methods have no requirements regarding hammer rebound and specify 64±4 blows per minute for the mechanical hammer. Sometimes technicians try to rush the test and do not allow the weight to drop freely or lift the weight all the way resulting in operator variability.

The varying methods of compaction can be expected to alter the BRD result, especially when multiple labs and multiple operators are involved. This again reflects the importance of historical data and qualified operators providing consistent results.

The actual BRD test is very basic and simple, requiring a 3 to 5 minute soaking time and determining weight in water, weight in air, and weight at SSD state. The bath temperature for this test should be 25°C ± 1°C and the operator should attempt to make sure each Marshall briquette is in water for the same amount of time. Some variability can be expected from dirty bath water, dirty drying towel, and the subjectivity of determining SSD. An experienced operator will generally have developed a routine for the test and the repeatability will be excellent, but more junior staff will likely show variability specifically in the SSD determination.

9.5 Magic Dust a.k.a. Baghouse Fines – the "Dirty White Elephant" of Mix Design

We are referring to baghouse fines as the magic dust because like a magician's trick, these fines seem to be the secret of the practitioner. The use of baghouse fines is relatively common in mix design, but no one seems to know enough to create a standard for its use. Each operator is doing something different, but experience is key in this design metric.

As mentioned in the previous section discussing the fine aggregate relative density, in 1989, asphalt professionals managing CAMEP decided to start washing aggregates before testing for relative density to limit multiple operator variability as observed during the CAMEP. By washing the aggregates and removing the fine dust, we are getting test results for clean aggregates, which is not a good representation of reality as the asphalt aggregates used during production of asphalt mix are typically not washed. Therefore, the dust is added back to the mix and how it is added back is part of the magic:

- One method seems to be to directly add the dust back in at the time of mixing as if it were another fine material similar to WS or MF, or even to add a percentage of the dust to the bottom sieve replacing another material to simulate the aggregate breakdown.
- Another method used is to add an amount of dust left in the pan after an MF sieve that feels right. Conversely, a lab could attempt to reverse engineer plant production data to add the correct proportion of material back into the mix.

Once and if the dust has been added, the notion of who needs to know and what to do with that information seems just as varied:

- Among labs who do physically add dust back into the mix, that is the end of the story, with no report or detail being included in the mix design.
- Some labs report an assumed relative density and absorption value for the dust and may or may not report this in the final mix design but may use it in the calculations for mix density.
- Other labs will provide a disclaimer with the mix design noting that dust was considered but attach no specific details on amounts or calculations.

The handling of baghouse fines is completely dependent on the experience and knowledge of the asphalt mix designer. It comes from historical field data and knowing the compacted density typical to the source material being used. The purpose of a mix design is to predict field conditions, and experienced operators know that to replicate field density in the lab, the addition of baghouse fines may be needed.

When asphalt mix designs are done from the same source for years and the design density from the lab is not being achieved in the field, designers know that something in the lab needs to change to replicate field conditions. Mix designers have learned that additional filler (magic dust / baghouse fines) needs to be added to represent field conditions and plant operations.

10.0 Conclusion

The labs included in the study spanned across the Canada with technician experience ranging from 1 to 35 years. Despite all these variations and differences in regional practices, procedures, and experience, following conclusions could be drawn from the study:

- Coarse Relative Densities were the most consistent across all labs, and the MF was the most variable. This is considered as a concern since MF can often make up to 50% of the aggregate blend in an asphalt mixture.
- MRD testing proved to be extremely reliable, while BRD results proved otherwise.
- As expected, there was a correlation between aggregate densities and calculated absorption. Since higher absorption would require higher asphalt cement content to meet the same volumetric properties, variability in density values can be expected to affect the calculated target binder content.
- If certain combinations of aggregate relative density and absorption values were used without proper analysis and caution, these differences are enough to cause significant variations in volumetric properties in the asphalt mix during production.
- In a theoretical mix design scenario, if the submitted range of values were inserted into mix calculations, combinations of them are enough to move a target binder content by 0.5% or more. This could cause incorrect and potentially unnecessary binder being used in asphalt mix production.
- In extreme circumstances, incorrect densities and calculated volumetrics also have the potential to produce further inaccurate results, causing the produced asphalt mix to be rejected. Project cost overruns, increased costs, appeals and investigations, and decreased productivity due to increased testing are all real threats if erroneous values are not corrected. Even if the test results seem correct in the lab, care still needs to be taken that those values can be accurately replicated during plant production.
- Variability in reported results had significant effect on calculated values and offered few correlations between tests among each participating lab. That is to say, we could not predict a high or low value of any lab based on any other test result from the same lab (for example, a lab that reported a high WS relative density did not necessarily also have a high MF relative density even though it is the same test).

This underlines the importance of knowledgeable technicians who have experience with materials and access to historical data for reference. With some guidance from ASTM Standards combined with real world knowledge and experience, any of the reported variabilities reported in this study might be identified through analysis and recognized as a red flag. Retesting would likely have occurred before any submissions. But small changes can creep up and cause larger problems over time that may not be immediately noticed.

In conclusion, we need to be vigilant with basic testing methods to avoid unnecessary variability to minimize variation that can result in increased costs.

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