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Sensitivity of the Flow Number to Mix Factors of Hot-Mix Asphalt

Md Rashadul Islam *, Sylvester A. Kalevela and Shelby K. Nesselhauf

Department of Engineering Technology, Colorado State University, Pueblo, CO 81001, USA; sylvester.kalevela@csupueblo.edu (S.A.K.); sk.nesselhauf@pack.csupueblo.edu (S.K.N.)
* Correspondence: md.islam@csupueblo.edu; Tel.: +1-719-549-2612

Received: 25 April 2019; Accepted: 4 June 2019; Published: 7 June 2019

Abstract: In the design of pavement infrastructure, the flow number is used to determine the suitability of a hot-mix asphalt mixture (HMA) to resist permanent deformation when used in flexible pavement. This study investigates the sensitivity of the flow numbers to the mix factors of eleven categories of HMAs used in flexible pavements. A total of 105 specimens were studied for these eleven categories of HMAs. For each category of asphalt mixture, the variations in flow number for different contractors, binder types, effective binder contents, air voids, voids in mineral aggregates, voids filled with asphalt, and asphalt contents were assessed statistically. The results show that the flow numbers for different types of HMA used in Colorado vary from 47 to 2272. The same mix may have statistically different flow numbers, regardless of the contractor. The flow number increases with increasing effective binder content, air voids, voids in mineral aggregates, voids filled with asphalt, and asphalt content in the study range of these parameters.

Keywords: hot-mix asphalt; flow number; effective binder content; air voids; voids in mineral aggregates; voids filled with asphalt; asphalt content

1. Introduction

The flow number (N) is an empirical way of characterizing a hot-mix asphalt (HMA) mixture's rutting potential. To determine the flow number, a cyclic load in haversine form is applied on a cylindrical specimen axially as shown in Figure 1. The duration of the load pulse is 0.1 s, followed by a rest period of 0.9 s. The permanent axial deformation measured at the end of the rest period is monitored during repeated loading, and the strain is calculated by dividing by the initial gauge length. The test may be conducted with or without confining pressure. However, if confining pressure is used, it is kept constant while the flow number is tested. If confining pressure is used, it remains constant during the test.

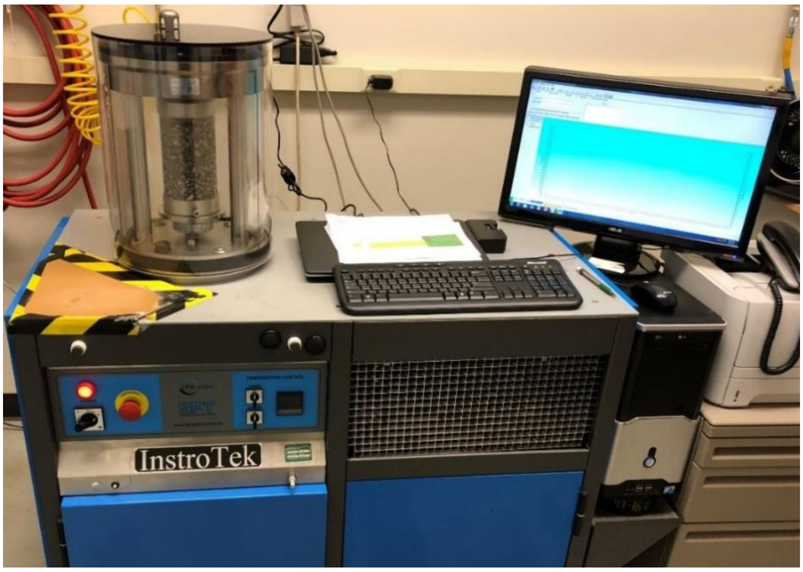

Figure 1. Flow number test setup.

In the flow number test, the permanent strain at each cycle is measured while constant deviator stress is applied at each load cycle on the test sample. Permanent deformation of asphalt pavements has three stages [1]: (i) primary or initial consolidation; (ii) secondary; and (iii) tertiary or shear deformation.

Figure 2 shows the three stages of permanent deformation. The first stage of deformation is due to the initial filling of voids, particle rearrangement, etc. The second region is the actual deformation of the aggregates, asphalt film, etc. The tertiary region is the zone where drastic shear failure of the mix occurs. The *N*-value is the number of load cycles at which tertiary flow begins, i.e., where permanent deformation occurs non-linearly. Tertiary flow can be differentiated from secondary flow by a marked departure from the linear relationship between cumulative strain and number of cycles in the secondary zone, as shown in Figure 2. It is assumed that in tertiary flow, the specimen's volume remains constant. The *N*-value can be correlated with rutting potential. The higher the flow number, the better the mix is in terms of its rutting resistance.

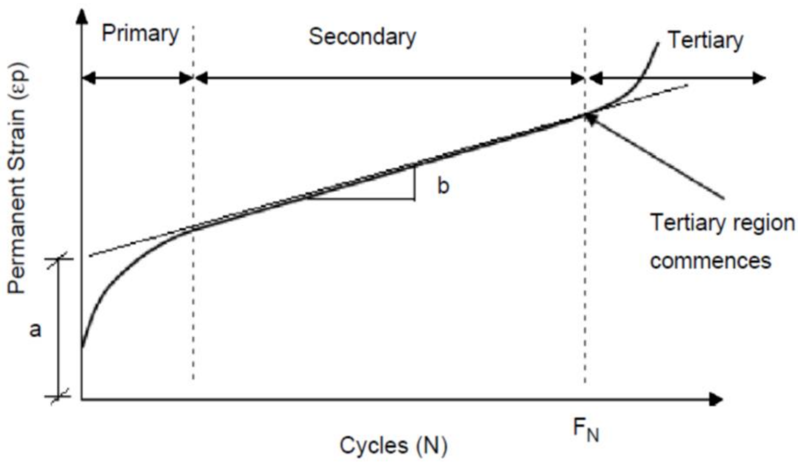

Figure 2. Relationship between permanent strain and number of load cycles [1].

Mathematically, the *N*-value can be determined using the Francken model.

The Francken model is currently built into the Asphalt Mixture Performance Tester (AMPT) software (Federal Highway Administration, Washington DC, USA). At the beginning, the entire permanent strain curve is fitted using nonlinear least squares optimization, as shown in Equation (1).

The flow number is then determined from the second derivative of the best fitted curve. The flow number is the number of cycles where the second derivative, Equation (2), changes from negative to positive.

$$\varepsilon_p = A\left(n^B\right) + C\left(e^{Dn} - 1\right), \quad (1)$$

where ε_p is the permanent strain (%); n is the number of cycles; and A, B, C, and D are fitting parameters.

$$\frac{d^2\varepsilon_p}{dn^2} = AB(B-1)n^{B-2} + CD^2e^{Dn}, \quad (2)$$

where $\frac{d^2\varepsilon_p}{dn^2}$ is the second derivative of permanent strain with respect to the number of loading cycles.

The final evaluation is an evaluation of the rutting resistance of the mixture using the flow number test defined by the American Association of State Highway and Transportation Officials (AASHTO) TP 79 [2] using the AMPT. The test is conducted at the "high" pavement temperature calculated by the long-term pavement performance (LTPP) Bind 3.1 software program (Federal Highway Administration, Washington DC, USA) for a specific project location. An unconfined flow number test with a repeated deviatoric stress of 600 kPa (87 psi) and a contact deviatoric stress of 30 kPa (4.4 psi) was used in this study. The test was conducted on specimens that were short-term conditioned for two hours at the compaction temperature to simulate the binder absorption and stiffening that occurs during construction. The flow number criteria for HMA as a function of the traffic level are summarized in Table 1.

Table 1. Flow number criteria for hot-mix asphalt (HMA) [2].

Traffic Level, Million Equivalent Single Axle Load (ESAL, 80 kN (18 kips))	Flow Number
Less than 3.0	NA
3.0 to less than 10	50
10 to less than 30	190
More than 30	740

The effects of different mix factors on the flow number have also been studied by different researchers [3–6]. Kaloush [3] determined that the flow number increases with the viscosity of binder and decreases with the test temperature, effective binder content, and air voids. Kvasnak et al. [4] determined that the flow number increases with gyrations and the viscosity of the binder and decreases with voids in mineral aggregates (VMA) when using Wisconsin dense graded mixtures. Both researchers determined that aggregate gradation also affects the flow number. Christensen [5] applied various statistical techniques to relate the flow number with the applied stress level and observed that the flow number decreases with increasing applied deviator stress. Rodezno et al. [6] determined that the flow number increases with the viscosity of the binder; however, it decreases with the test temperature and air voids and is affected by aggregate gradation. The current study was not intended to investigate the viscosity of the binder or the test temperature. Other factors such as the VMA, voids filled with asphalt (VFA), effective binder content, contractors, testing time, mix gradation, and binder types were investigated. There are some other researches on flow number. For example, Irfan et al. [7] evaluated the flow numbers for static and dynamic creep tests and then correlated it with the rutting. Ogundipe [8] studied the flow numbers of lime-modified asphalt concrete. Irfan et al. [9] investigated the flow numbers of fiber-added stone mastic asphalt concrete mixtures. Leiva-Villacorta et al. [10] evaluated the flow numbers for High-modulus asphalt concrete (HMAC) mixtures for use as base course. Tripathi [11] studied the economic benefits of fiber-reinforced asphalt mixtures by flow number including some other tests. Ziari and Divandari [12] developed a flow number prediction model using artificial neural network. Siswanto et al. [13] investigated the flow numbers of Asphalt Concrete Using Crumb Rubber Modified of Motorcycle Tire Waste. All these studies investigated the flow number under different conditions. However, none of the studies investigated the sensitivity of different mix factors such as such as VMA, void-filled with asphalt (VFA), effective binder content, contractors, testing time, mix gradation, and binder types on the flow number of asphalt concrete.

Air void (V_a) is the total volume of the small pockets of air between the coated aggregate particles expressed as a percentage of the bulk volume of the compacted mixture. The volume of the void space among aggregate particles of a mixture that includes the air voids and the effective asphalt content is known as VMA. The portion of the voids in the mineral aggregate that contain asphalt binder is known as VFA. The total asphalt binder content of the mix less the portion of asphalt binder that is lost by absorption into the aggregate is called the effective asphalt content (V_{be}). This portion of binder is coated on the aggregate surface and takes part in binding aggregates. The total asphalt binder used in a mix is called the asphalt content (AC).

The flow number (N) test procedure recommended in the National Cooperative Highway Research Program (NCHRP) project 9-19 is a simple performance test for rutting evaluation of asphalt mixtures. The test showed good correlation with the rutting performance of mixtures at WesTrack, MnROAD, and the Federal Highway Administration's (FHWA's) accelerated loading facility. Subsequent NCHRP studies allowed the development of a provisional standard. AASHTO TP 79 [2] includes test parameters for stress, temperature, specimen conditioning, and minimum flow number criteria that were established for HMA and for warm-mix asphalt (WMA) based on the traffic level.

The current study used the testing conditions and criteria for N testing described in AASHTO TP 79 [2] for unconfined tests. The recommended test temperature, determined by LTPP Bind Version 3.1 software, was the average design high pavement temperature at 50% reliability for cities in Colorado. Tests were conducted at a temperature of 55 °C with an average deviator stress of 600 kPa (87 psi) and a minimum (contact) axial stress of 30 kPa (4.4 psi). For conditioning, samples were kept in a conditioning chamber at the testing temperature for 12 h prior to testing.

To confirm again, the objectives of this study were to study the effects of mix factors such as VMA, VFA, effective binder content (V_{be}), contractors, testing time, mix gradation, and binder types on the flow number of asphalt concrete.

2. Materials

The eleven types of mixtures studied are listed in Table 2 along with their basic information such as nominal maximum aggregate size (NMAS), performance grade (PG) binder type, and number of gyrations used while designing the mixes. Superpave performance grading is reported using two numbers: the first being the average seven-day maximum pavement temperature (°C) and the second being the minimum pavement design temperature likely to be experienced (°C). Thus, a PG 64-22 is intended for use where the average seven-day maximum pavement temperature is 64°C and the expected minimum pavement temperature is −22°C. The letter "S" denotes an NMAS of 0.75 in. (19 mm). The letters "SX" denote an NMAS of 0.5 in. (12.5 mm). SMA is the abbreviated form of the stone mix asphalt mixture. The numbers in parentheses are the numbers of gyrations used in the mix design. All the mixes were designed following the Superpave requirements for all parameters. Every group of mixes had identical aggregate gradations.

Table 2. A list of the eleven mixtures used in this study

Mix ID	NMAS, in. (mm)	Binder	Number of Gyrations	Number of Specimens
S(100) PG 64-22	0.75 (19)	PG 64-22	100	6
S(100) PG 76-28	0.75 (19)	PG 76-28	100	5
SMA PG 76-28	0.50 (12.5)	PG 76-28	100	12
SX(75) PG 58-28	0.50 (12.5)	PG 58-28	75	8
SX(75) PG 58-34	0.50 (12.5)	PG 58-34	75	4
SX(75) PG 64-22	0.50 (12.5)	PG 64-22	75	8
SX(75) PG 64-28	0.50 (12.5)	PG 64-28	75	4
SX(100) PG 58-28	0.50 (12.5)	PG 58-28	100	2
SX(100) PG 64-22	0.50 (12.5)	PG 64-22	100	15
SX(100) PG 64-28	0.50 (12.5)	PG 64-28	100	10
SX(100) PG 76-28	0.50 (12.5)	PG 76-28	100	31

S = NMAS of 0.75 in. (19 mm); SX = NMAS of 0.5 in. (12.5 mm); SMA = stone mix asphalt mixture.

3. Effects on the Flow Number

3.1. Same Mix by the Same Contractor

To investigate the variation in the flow number within the work of a single contractor for the same mix, the following mixes were selected randomly. The information regarding the paving contractor, binder supplier, and aggregate pits is kept confidential. The mixes were manufactured in 2014.

The N-values vary from 120 to 531 with an average value of 261 and standard deviation of 125, as shown in Figure 3. The values shown are for each individual specimen. To determine whether these data are statistically significant or not, a one-sample t-test was conducted. The t-test requires the data to be normally distributed. The t-test showed the 95% Confidence Interval (CI) boundaries to be 150 and 372 with a mean value of 261. This means that all the mixes, except for 19655 P21 14 and 19655 P87 14, are statistically the same. Therefore, a conclusion can be made that the same mix may have statistically different flow numbers for the same contractor. Note that Colorado Department of Transportation (CDOT) uses a 10-digit format to express the mix identity, such as 19655 P21 14. The first five numbers denote the project and the last five digits denote the site and specimen number.

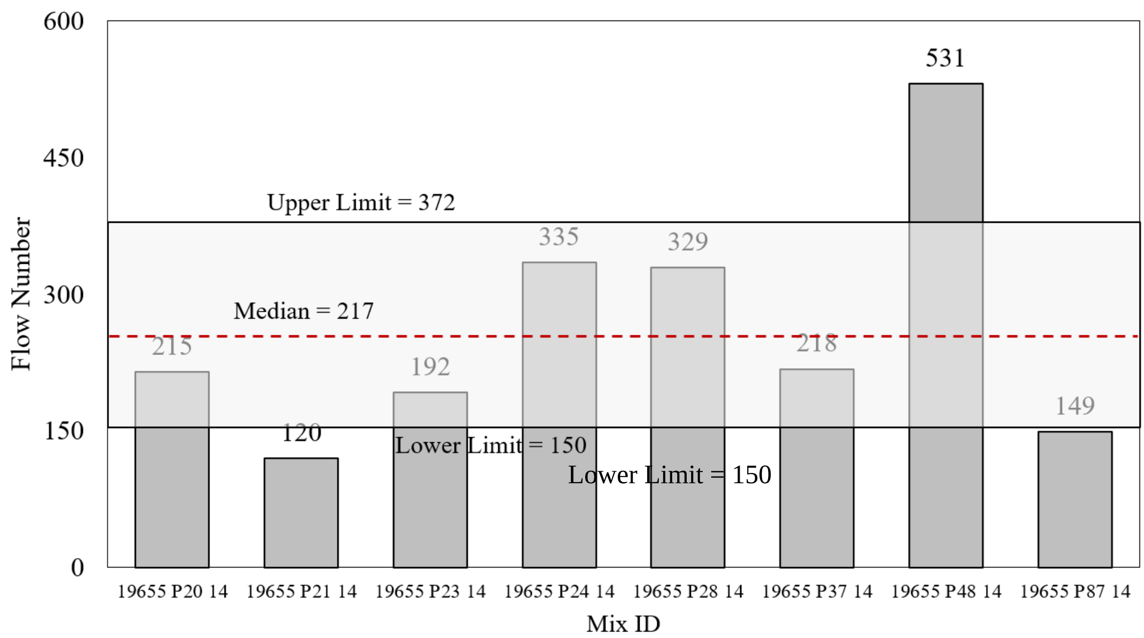

Figure 3. Flow numbers of eight specimens of SX(100) PG 64-28 mix.

3.2. Same Mix by Different Contractors

To investigate the differences in flow number for the same mix prepared by different contractors, SX(100) PG 76-28 mix was selected. The average flow numbers from four contractors, 19128, 18842, 19458, and 19677, are presented in Figure 4.

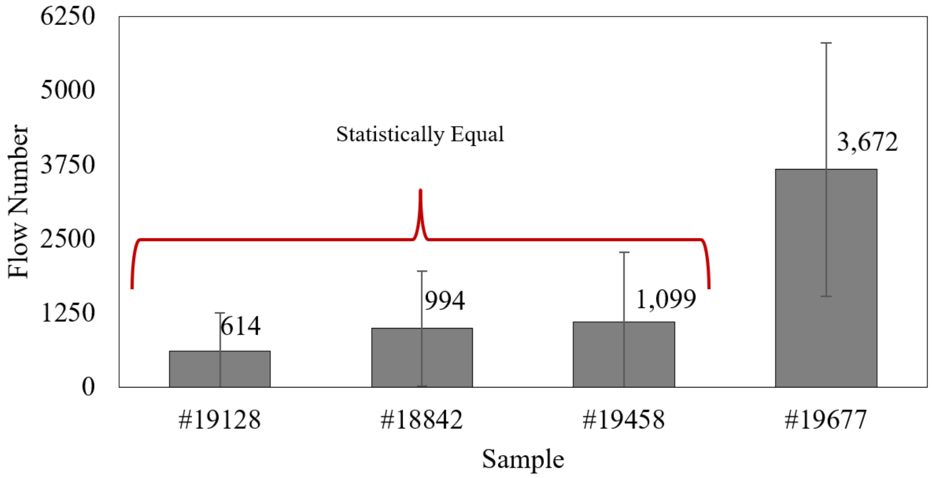

Figure 4. Flow numbers of a mix by different contractors.

The pairwise comparison test result shows that the mixes by 19128, 18842, and 19458 are statistically the same (Table 3). Therefore, a conclusion can be made that the same mix may have statistically different flow numbers for different contractors. This is due to variations in the aggregate structures, shapes, orientation, smoothness, etc.

Table 3. Pairwise comparisons using *t*-tests to determine statistical difference.

	19128	**18842**	**19458**
18842	Equal	-	-
19458	Equal	Equal	-
19677	Different	Different	Different

3.3. Groupwise Comparison

The flow number variation for each group of mix is described in this section. An effort was made to examine whether all specimens' flow numbers were statistically equal or not. A 95% Confidence Interval (CI) was used to indicate reliability. Next a statistical regression analysis was conducted to find the effects of different mix factors.

3.3.1. S(100) PG 64-22

The flow numbers for the S(100) PG 64-22 mix varied from 110 to 252, with an average number of 155, median of 130, and standard deviation of 59. As per AASHTO [2], a mix is good for 3 to 10 million equivalent single axle loads (ESALs) if it has a flow number greater than 50. The current mix had an average flow number of 103; however, about one-third of the test results indicated flow numbers less than 50. Despite this, the S(100) PG 64-22 mix would be considered good for pavement designs with traffic between 3 and 10 million ESALs. The *t*-test showed the 95% CI boundaries to be 47 and 262. Four mixes, 18695 P9 15, 18695 P13 14, 18695 P25 14, and 18465 P9 14, were found to be statistically the same, although the paving contractors, binder supplier, and production dates differed. The 18465 P9 14 mix, for example, had a much lower VFA compared to the others. Thus, definitive conclusions cannot be made from this mix.

3.3.2. S(100) PG 76-28

The flow numbers for the S(100) PG 76-28 mix varied from 626 to 2065 with an average number of 1223, median of 1101, and standard deviation of 528. As per AASHTO [2], a mix is good for more than 30 million ESALs if it has a flow number greater than 740. The current mix had an average flow number of 1223. All the test results showed flow numbers greater than 740. Therefore, this mix is considered good for traffic greater than 30 million ESALs. The *t*-test showed the 95% CI boundaries to be 253 and 2193. All the values were within the 95% CI boundaries; thus, they are statistically equal. The generic information shows that the mix factors of all mixes were very close to each other. Comparing the above two mixtures, S(100) PG 64-22 and S(100) PG 76-28, both have the same aggregate size; the only difference is the binder type. With an increase in binder grade, the flow number increased. The mix parameters show that all four mixes (17800 P17 14, 17800 P26 14, 17800 P38 14, and 17800 P53 14) had similar properties, and their flow numbers are statistically equal.

3.3.3. SMA PG 76-28

The flow numbers for the SMA PG 76-28 mix varied from 426 to 4311, with an average number of 2272, median of 2219, and a standard deviation of 1182. All the test results, with the exception of one outlier judged by visual inspection, showed the flow numbers to be greater than 740. Therefore, this mix is considered to be good for traffic greater than 30 million ESALs. The *t*-test showed the 95% CI boundaries to be 1487 and 3057. Comparing the two mixtures S(100) PG 76-28 and SMA PG 76-28, both have the same binder, but they have different aggregate sizes. An increase in aggregate size increased the flow number as observed from these two mixtures. The coarser aggregate shows better resistance to deformation due to its aggregate-to-aggregate interlocking. The mix parameters dictatethat mixes with similar properties (such as V_{be}, V_a, VMA, VFA, AC) can have statistically different flow numbers.

3.3.4. SX(75) PG 58-28

The flow numbers for the SX(75) PG 58-28 mix varied from 29 to 220, with an average number of 91, median of 81, and standard deviation of 55. All the test results, apart from one outlier, showed a flow number greater than 50. The current mix had an average flow number of 91; therefore, per AASHTO, this mix is considered good for traffic of 3 to 10 million ESALs. The *t*-test showed the 95% CI boundaries to be 42 and 140. All mixes except 19489 P51 14 and 19879 P113 14 did not have statistically similar flow numbers. One mix (19489 P51 14) had a unique aggregate source (Chambers), and another mix (19879 P113 14) had a unique contractor and aggregate source (Ralston, Firestone). All the other properties were similar to those of the mixes whose flow numbers were statistically the same. Therefore, contractor or aggregate source may be a factor in the variation of the flow number.

3.3.5. SX(75) PG 58-34

The flow numbers for the SX(75) PG 58-34 mix varied from 19 to 75, with an average flow number of 47 and standard deviation of 28. As per AASHTO, a mix is considered good for traffic of less than 3 million ESALs if it has a flow number less than 50. The current mix had an average flow number of 47; therefore, this mix is good for traffic of less than 3 million ESALs. However, we had data for only two mixes from the current mix. Therefore, no sensitivity analysis was conducted on this mix.

3.3.6. SX(75) PG 64-22

The flow numbers for the SX(75) PG 64-22 mix varied from 19 to 123, with an average number of 59, median of 49, and standard deviation of 34. As per AASHTO, a mix is considered good for traffic between 3 and 10 million ESALs if it has a flow number greater than 50. The current mix had an average flow number of 59; therefore, this mix is considered good for traffic between 3 and 10 million ESALs. The *t*-test showed the 95% CI boundaries to be 28 and 90. The mix parameters show that mixes with similar properties have statistically different flow numbers. For example, mixes with the prefix

19935 have the same binder supplier, aggregate source, region, and volumetric properties, though they have statistically different flow numbers.

3.3.7. SX(75) PG 64-28

The flow numbers for the SX(75) PG 64-28 mix varied from 32 to 311, with an average number of 106, median of 41, and standard deviation of 118. As per AASHTO, a mix is considered good for traffic between 3 and 10 million ESALs if it has a flow number greater than 50. The current mix had an average flow number of 99; therefore, this mix is considered good for traffic between 3 and 10 million ESALs. The same observations were noted for binders SX(75) PG 58-28 and SX(75) PG 58-34.

3.3.8. SX(100) PG 58-28

Only a single sample with a flow number of 128 was tested for this mix. No statistical test or sensitivity analysis was conducted on this mix due to insufficient data.

3.3.9. SX(100) PG 64-22

The flow numbers for the SX(75) PG 64-22 mix varied from 23 to 388, with an average number of 112, median of 97, and standard deviation of 92. As per AASHTO, a mix is considered good for traffic between 3 and 10 million ESALs if it has a flow number greater than 50. The current mix had an average flow number of 112; therefore, this mix is considered good for traffic between 3 and 10 million ESALs. Nonetheless, a *t*-test was conducted, and the results showed the 95% CI boundaries to be 59 and 164. The mix parameters show that mixes with different properties had statistically similar flow numbers. On the other hand, mixes by the same contractor with the same aggregate source had statistically different flow numbers.

3.3.10. SX(100) PG 64-28

The flow numbers for the SX(100) PG 64-28 mix varied from 77 to 531, with an average of 241, median of 215, and standard deviation of 131. As per AASHTO, a mix is considered good for traffic between 10 and 30 million ESALs if it has a flow number greater than 190. The current mix had an average flow number of 240; therefore, this mix is considered good for traffic between 10 and 30 million ESALs. The *t*-test showed the 95% CI boundaries to be 134 and 347. Three mixes were not statistically the same; however, two mixes had similar properties to the statistically similar mixes. Therefore, flow numbers can be statistically different for the same mix by the same contractor.

3.3.11. SX(100) PG 76-28

The flow numbers for the SX(100) PG 76-28 mix varied from 82 to 6343, with an average number of 1578, median of 810, and a standard deviation of 1837. As per AASHTO, a mix is considered good for traffic greater than 30 million ESALs if it has a flow number greater than 740. Although the average flow number was 1482, nearly half of the samples had a flow number less than 740. Therefore, it is very difficult to conclude whether this mix is considered good for traffic greater than 30 million ESALs. Comparing this result with those for the previous binders, the flow number increased with an increase in the high-temperature grade of the binder. Similar observations were noted for the SX(75) mix. The *t*-test showed the 95% CI boundaries to be 893 and 2262. Out of 33 specimens, only 7 specimens were within the 95% CI boundaries.

3.4. Analysis Summary

The flow numbers for each group and their variations, 95% CI boundaries, etc., are presented in Table 4 and Figure 5. They show that SX(75) PG 58-34 had the lowest flow number and SMA PG 76-28 had the highest flow number. Comparing the average flow numbers with the above-listed values, the following may be concluded:

- Only two types of mixtures, SX(100) PG 76-28 and SMA PG 76-28, had flow numbers greater than 740. Thus, only these mixtures are considered good for traffic greater than 30 million ESALs.
- S(100) PG 76-28 had an average flow number of more than 190; thus, it is considered good for traffic between 10 and 30 million ESALs.
- SX(100) PG 64-22, SX(100) PG 64-28, and SX(100) PG 58-28 are considered good for traffic between 3 and 10 million ESALs.
- The other five mixtures—S(100) PG 64-22, SX(75) PG 58-28, SX(75) PG 58-34, SX(75) PG 64-22, and SX(75) PG 64-28—had flow numbers less than 50; thus, they are considered good for traffic of less than 3 million ESALs.
- Comparing SX(100) PG 64-28 and SX(100) PG 76-28, the flow number of HMA increases with an increase in the high-temperature grade of the binder.
- Variable results were observed as to whether the flow number increases or decreases with an increase in the low-temperature grade of the binder. For example, when comparing SX(75) PG 64-22 and SX(75) PG 64-28, the flow number increases with an increase in the low-temperature grade of the binder; however, when comparing SX(75) PG 58-34 and SX(75) PG 58-28, the flow number decreases with an increase in the low-temperature grade of the binder.
- An SX mix has 0.5 in. (12.5 mm) nominal aggregate size, and an S mix has 0.75 in. (19 mm) nominal aggregate size. SX mixes have larger flow numbers, i.e., smaller aggregate size produces a larger flow number, from the comparisons of the flow numbers of SX(100) PG 64-22 with S(100) PG 64-22, and SX(100) PG 76-28 with that of S(100) PG 76-28. However, the differences between these pairs are not statistically significant.
- The (75) and (100) refer to the number of gyrations during design. Greater number of gyrations produce greater flow numbers, as shown from the comparisons of SX(75) PG 58-28 with SX(100) PG 58-28, SX(75) PG 64-22 with SX(100) PG 64-22, and SX(75) PG 64-28 with SX(100) PG 64-28. However, the differences between these pairs were not statistically significant.

Table 4. Groupwise average flow numbers with 95% boundaries.

Mixes	Lowest Value	Highest Value	95% CI Lower Limit	95% CI Upper Limit	Average
S(100) PG 64-22	110	252	47	262	155
S(100) PG 76-28	626	2065	253	2193	1223
SMA PG 76-28	426	4311	1487	3057	2272
SX(75) PG 58-28	29	220	42	140	91
SX(75) PG 58-34	19	75	0	403	47
SX(75) PG 64-22	19	123	28	90	112
SX(75) PG 64-28	32	311	0	323	106
SX(100) PG 58-28	-	-	-	-	128
SX(100) PG 64-22	23	388	59	164	112
SX(100) PG 64-28	77	531	134	347	241
SX(100) PG 76-28	82	6343	893	2263	1578

The sensitivity analysis summary presented in Table 5 shows that the effects of V_{be}, V_a, VMA, VFA, and AC on the flow number are inconsistent. For example, six mixes show that the flow number increases with V_{be}, two mixes show the opposite, and one mix shows it is insensitive to V_{be}. This inconsistency is true for V_a, VMA, VFA, and AC as well. The reason behind this may be the effects of the paving contractor, manufacture date, and/or aggregate source. Using most scores, the flow number increases with an increase in V_{be}, V_a, VMA, VFA, and AC for the range studied in this study. The study by Kaloush [3] showed that the flow number decreases with an increase in air voids, which is contradictory to the results of the current study. This is due to the study range of air voids. The current study only investigated air void proportions between 3% and 6%.

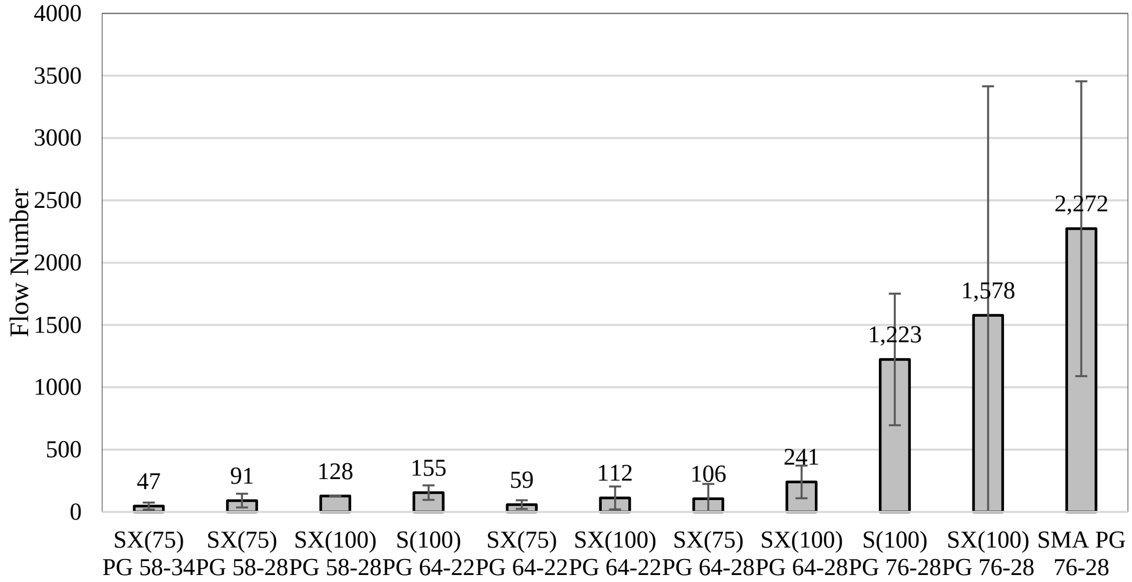

Figure 5. Groupwise average flow numbers.

Table 5. Summary of the effect of mix factors on the flow number of HMA.

	V_{be} (%)	V_a (%)	VMA (%)	VFA (%)	AC (%)
S(100) PG 64-22	Decreases	Increases	Increases	Increases	Decreases
S(100) PG 76-28	-	Decreases	Increases	Decreases	-
SMA PG 76-28	Decreases	Increases	Increases	Increases	Decreases
SX(75) PG 58-28	Increases	Decreases	Decreases	Increases	Increases
SX(75) PG 58-34	NA	NA	NA	NA	NA
SX(75) PG 64-22	Increases	Decreases	Increases	Decreases	Increases
SX(75) PG 64-28	Increases	Decreases	-	Increases	-
SX(100) PG 58-28	NA	NA	NA	NA	NA
SX(100) PG 64-22	Increases	Increases	Decreases	Decreases	Increases
SX(100) PG 64-28	Increases	Increases	Decreases	Decreases	Increases
SX(100) PG 76-28	Increases	Increases	Decreases	Increases	Increases
Summary	6 Increases 2 Decreases 1 Insensitive	5 Increases 4 Decreases 2 N/A	5 Increases 4 Decreases 1 Insensitive	5 Increases 4 Decreases 2 N/A	5 Increases 2 Decreases 2 Insensitive

4. Conclusions

This study evaluates the effects of mix factors such as VMA, void-filled with asphalt, effective binder content, etc. on the flow number of asphalt concrete. Laboratory testing was performed, and test results were analyzed using the statistical tools. The following conclusions can be made from this study:

1. The same mix may have statistically different flow numbers, and this is independent of the contractor.
2. The flow number increased with increasing Vbe, Va, VMA, VFA, and AC for the range studied in this study.
3. Only two types of mixtures, SX(100) PG 76-28 and SMA PG 76-28, had flow numbers greater than 740. Thus, only these mixtures are considered good for traffic greater than 30 million ESALs.
4. S(100) PG 76-28 had an average flow number of more than 190; thus, it is considered good for traffic between 10 and 30 million ESALs.
5. SX(100) PG 64-22, SX(100) PG 64-28, and SX(100) PG 58-28 are considered good for traffic between 3 and 10 million ESALs.

6. The other five mixtures—S(100) PG 64-22, SX(75) PG 58-28, SX(75) PG 58-34, SX(75) PG 64-22, and SX(75) PG 64-28—had flow numbers less than 50; thus, they are considered good for traffic of less than 3 million ESALs.

Our recommendation for future research is that a flow number predictive model should be developed to determine the flow number of a new mix with more laboratory testing on a pre-planned test matrix.

Author Contributions: M.R.I. is the primary investigator of this research article. He is the lead researcher with collecting the research ideas, pursuing funding, execution, delivery and publication. S.A.K. supervised all aspects of this research including editing and proofreading. S.K.N. helped in data collection, analysis, and helped the team finally publish it.

Funding: This research is funded by the Colorado Department of Transportation (CDOT), Grant No. CDOT 417.01.

Acknowledgments: The Colorado State University—Pueblo (CSU-Pueblo) research team appreciates the research funding by the Colorado Department of Transportation (CDOT). It would like to express its sincere gratitude and appreciation to Jay Goldbaum, Michael Stanford, Aziz Khan, Melody Perkins, Keith Uren, Vincent Battista, Skip Outcalt, Bill Schiebel, and Roberto E. DeDios from the CDOT.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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