DOT/FAA/TC-18/25

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

Laboratory Performance Testing of Polymer-Modified Asphalt Mixtures for Airfields

August 2018

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient=s Catalog No.
DOT/FAA/TC-18/25		

4. Title and Subtitle	5. Report Date
LABORATORY PERFORMANCE TESTING OF POLYMER-MODIFIED ASPHALT MIXTURES FOR AIRFIELDS	August 2018
	6. Performing Organization Code
7. Author(s) John F. Rushing	8. Performing Organization Report No.
9. Performing Organization Name and Address U.S. Army Engineer Research and Development Center Geotechnical and Structures Laboratory 3909 Halls Ferry Road Vicksburg, MS 39180-6199	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Airport Engineering Division 800 Independence Ave., SW Washington, DC 20591	13. Type of Report and Period Covered 14. Sponsoring Agency Code AAS-100

15. Supplementary Notes

The Federal Aviation Administration COR was Navneet Garg.

16. Abstract

Asphalt concrete pavements on commercial airports in the United States are constructed according to the Federal Aviation Administration Advisory Circular (AC) 150/5370-10G, Part 5 – Flexible Surface Courses, Item P-401 Hot Mix Asphalt (HMA) Pavements. The most recent version of Item P-401 includes an optional mixture design procedure based on the Superpave gyratory compactor. Selection of the design mix by this optional method is based solely on volumetric properties of the asphalt concrete. In this study, four laboratory performance tests were investigated for their ability to detect whether mixtures designed by this new method may be prone to rutting. These tests included repeated load, static creep, indirect tensile strength, and asphalt pavement analyzer tests. The objective was to evaluate acceptance criteria for the laboratory tests for asphalt mixtures prepared using unmodified and polymer-modified binders. Six aggregate combinations, each with six different binders, comprised the mixtures studied here. The binders included two different base performance grades, each with two levels of modification. Based on the results, the asphalt pavement analyzer test is recommended as a rutting performance test for airport hot-mix asphalt mixture design. The test was selected for recommendation based on its ability to differentiate between and rank mixture performance measures and to identify significant improvement when polymer-modified binders are used in the design mix.

17. Key Words	18. Distribution Statement
Hot-mix asphalt, Asphalt mixtures, Laboratory performance tests, Asphalt pavement analyzer, Flow number, Flow time, Polymer-modified	This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	108	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

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LIST OF SYMBOLS AND ACRONYMS

π	Pi
ε	Plastic strain
AC	Advisory Circular
ANOVA	Analysis of variance
APA	Asphalt pavement analyzer
ASTM	American Society of Testing and Materials
C	Celsius
d	Diameter
D/B	Dust-to-binder ratio
FAA	Federal Aviation Administration
FN	Flow number
FT	Flow time
G_{mb}	Bulk specific gravity of asphalt mixture
G_{mm}	Maximum theoretical specific gravity of asphalt mixture
G_{se}	Effective specific gravity of asphalt mixture
h	Height
HMA	Hot-mix asphalt
IDT	Indirect tensile
JMF	Job-mix formula
kN	Kilonewton
kPa	Kilopascal
MMPT	Mean monthly pavement temperature
n	Number of load cycles
P	Peak load at failure
P_b	Percent binder
P_{ba}	Percent absorbed binder
P_{be}	Percent effective binder
PG	Performance grade
SGC	Superpave gyratory compactor
t	Time
V_a	Air voids
VFA	Voids filled with asphalt
VMA	Voids in mineral aggregate

EXECUTIVE SUMMARY

Asphalt concrete pavements on commercial airports in the United States are constructed according to the Federal Aviation Administration Advisory Circular (AC) 150/5370-10G, Part 5 – Flexible Surface Courses, Item P-401 Hot Mix Asphalt (HMA) Pavements. The most recent version of Item P-401 includes an optional mixture design procedure based on the Superpave gyratory compactor. Selection of the design mix by this optional method is based solely on volumetric properties of the asphalt concrete. In this study, four laboratory performance tests were investigated for their ability to detect mixtures designed by this new method that may be prone to rutting. These tests included repeated load, static creep, indirect tensile strength, and asphalt pavement analyzer tests. The objective was to evaluate acceptance criteria for the laboratory tests for asphalt mixtures prepared using unmodified and polymer-modified binders. Six aggregate combinations, each with six different binders, comprised the mixtures studied here. The binders included two different base performance grades, each with two levels of modification. Based on the results, the asphalt pavement analyzer is recommended as a rutting performance test for airport hot-mix asphalt mixture design. The test was selected for recommendation based on its ability to differentiate between and rank mixture performance measures and to identify significant improvement when polymer-modified binders are used in the design mix.

1. INTRODUCTION.

Rut minimization on airport hot-mix asphalt (HMA) pavements is an important consideration in mixture design and selection. The Federal Aviation Administration (FAA) has stringent material requirements that are intended to result in quality HMA mixtures. Tests for aggregate angularity, soundness, durability, and shape are required in FAA Advisory Circular (AC) 150/5370-10G, Part 5 – Flexible Surface Courses, Item P-401 Hot Mix Asphalt (HMA) Pavements [1]. In addition to the aggregate, the selected asphalt binder significantly influences the rutting performance of HMA. Binder stiffness can influence aggregate particle mobility during traffic loadings.

Next-generation aircraft are expected to have heavier wheel loads and higher tire pressures. These heavier loads and higher tire pressures are more likely to cause rutting to occur in HMA airfield pavements. Using polymer-modified asphalt binders in HMA mixtures is one technique employed to mitigate the effects of greater loading encountered with these aircraft.

The FAA AC 150/5370-10G recommends increasing the high-temperature binder performance grade (PG) by 6°Celsius (C) for aircraft with gross weights less than 890 kilonewton (kN) or tire pressures less than 1380 kilopascal (kPa) if the average number of annual departures and arrivals is greater than 60,000. If the gross weight is greater than 890 kN or the tire pressure is higher than 1380 kPa, a 6°C increase is recommended if the average number of annual departures and arrivals is less than 60,000; a 12°C increase is recommended if the average number of annual departures and arrivals is greater than 60,000.

Rushing, Little, and Garg [2] recommended including a laboratory performance test to assess rutting performance as a companion to the mixture design process for HMA mixtures. The repeated load, static creep, indirect tensile strength, and asphalt pavement analyzer (APA) tests were studied as potential candidates for the needed performance test. Results from their study indicated that using a polymer-modified binder could greatly improve rutting performance, but they recommended additional study of the binder effect on rutting. To support that additional study, this report quantifies the effect of binder modification on laboratory rutting performance.

The indirect tensile (IDT) strength test is a simple performance test that has been shown to correlate very well to asphalt mixture cohesion [3] and has potential application for screening asphalt mixtures during the design phase. As a rutting indicator, the test is performed at 40°C. The minimum acceptable test result is based on the grade of binder used in the mixture [4]. Separate requirements exist for light- and heavy-duty pavements.

1.1 PROBLEM STATEMENT.

The PG of binder used in an HMA mixture has a significant influence on asphalt mixture performance in the field. A laboratory performance test is needed to quantify the influence of binder grade on mixture rutting performance and establish criteria that will indicate acceptable mixtures. Several tests procedures were evaluated and criteria were considered in assessing the suitability of the tests as potential indicators of HMA rutting performance. The applicability of these criteria across a broad range of binder grades is unknown, but the study presents recommendations for using laboratory tests to select the most desirable asphalt mixtures for airfield pavements.

1.2 OBJECTIVE AND SCOPE.

The objective of this study was to validate previously developed acceptance criteria for potential mixture design performance tests, including the repeated load, static creep, APA, and IDT strength tests. The objective was accomplished by laboratory preparation and testing of 36 asphalt mixtures comprised of various aggregate structures and binder grades.

2. MATERIALS.

This section provides properties of all materials tested as part of this study. Thirty-six binder and aggregate mixtures were designed and tested. The materials and the nomenclature system used to identify each mixture are described in sections 2.1 through 2.4.

2.1 ASPHALT BINDER.

Six asphalt binders were used in this study. Five binders were obtained from Axeon Specialty Products, LLC in Paulsboro, New Jersey. The five Axeon binders included a neat PG 58-28 and polymer-modified PG 70-28 binder as well as a neat PG 64-22 and polymer-modified PG 76-22 and PG 82-22 binders. The three Axeon polymer-modified binders were produced from the neat asphalt grades. Distributor tests indicated both neat binders had a specific gravity of 1.038. The PG 76-28 polymer-modified binder was obtained from the Valero refinery in Ardmore, Oklahoma. Mixing and compaction temperatures used for each binder are included in table 1.

Table 1. Binder Mixing and Compaction Temperatures

Binder	Type	Supplier	Mixing Temperature (^{o}C)	Compaction Temperature (^{o}C)
PG 58-28	Neat	Axeon	150	139
PG 70-28	Polymer modified	Axeon	159	148
PG 76-28	Polymer modified	Valero	165	155
PG 64-22	Neat	Axeon	154	144
PG 76-22	Polymer modified	Axeon	165	155
PG 82-22	Polymer modified	Axeon	169	160

2.2 AGGREGATE.

Aggregates used in this study were obtained from suppliers in Arkansas, Massachusetts, Mississippi, and New Jersey. The Arkansas aggregate was from Granite Mountain Quarries in Little Rock, Arkansas. The Massachusetts aggregate was from an Aggregate Industries quarry in Swampscott, Massachusetts. The Mississippi aggregate included chert gravel from the Hamilton quarry as well as limestone from a Vulcan Materials quarry in Calera, Alabama. The New Jersey specification aggregate was from the Glasgow Catanach Quarry in Frazer, Pennsylvania.

Additionally, some mixtures were blended with selected percentages of natural sand obtained from Mississippi Materials Corporation in Vicksburg, Mississippi. Aggregates were blended to meet requirements for the 19-mm maximum aggregate size gradation in FAA AC 150/5370-10G [1]. The stockpile gradations, percent used, and job mix formula (JMF) blends for the study are provided in tables 2 through 7, where G_{sb} is the bulk specific gravity of the aggregate, G_{sa} is the apparent specific gravity, and Abs is the absorption.

Table 2. Arkansas Aggregate Blend Gradation

Stockpile	S-1 Granite	S-2 Granite	S-3 Granite	Sand	P-401 Specification Limits		
Percent Used	13%	35%	41%	10%			
Sieve Size (mm)	% Passing	% Passing	% Passing	% Passing	Minimum	Maximum	JMF
25	100	100	100	100	100	100	100
19	100	100	100	100	100	100	100
12.5	45	93	100	100	79	99	90
9.5	19	84	96	100	68	88	82
4.75	1	61	72	97	48	68	62
2.36	1	42	46	87	33	53	43
1.18	0	29	30	79	20	40	31
0.6	0	20	20	62	14	30	23
0.3	0	13	13	9	9	21	12
0.15	0	8	8	1	6	16	7
0.075	0.2	4.8	4.5	0.4	3	6	4.6
G_{sb}	2.615	2.606	2.612	2.600			2.605
G_{sa}	2.647	2.643	2.642	2.653			2.640
Abs %	0.47	0.55	0.45	0.78			0.52

Note: 1% hydrated lime was added to this mixture.

Table 3. Massachusetts Aggregate Blend Gradation

Stockpile	12.5-mm	#4	Screenings	S-4	Sand	P-401 Specification Limits		
Percent Used	22%	15%	19%	34%	9%			
Sieve Size (mm)	% Passing	% Passing	% Passing	% Passing	% Passing	Minimum	Maximum	JMF
25	100	100	100	100	100	100	100	100
19	100	100	100	100	100	100	100	100
12.5	83	100	100	100	100	79	99	96
9.5	16	97	100	100	100	68	88	81
4.75	1	32	100	98	97	48	68	67
2.36	1	3	62	67	87	33	53	44
1.18	1	2	31	41	79	20	40	29
0.6	1	2	18	29	62	14	30	20
0.3	1	2	10	21	9	9	21	11
0.15	1	1	6	12	1	6	16	7
0.075	0.9	1.3	2.3	5.7	0.4	3	6	3.8
G_{sb}	2.922	2.899	2.860	2.803	2.600			2.827
G_{sa}	2.959	2.956	2.933	2.860	2.653			2.882
Abs %	0.43	0.62	0.87	0.72	0.78			0.67

Note: 1% hydrated lime was added to this mixture.

Table 4. Mississippi With 7% Sand Aggregate Blend Gradation

Stockpile	19-mm Gravel	12.5-mm Gravel	78 Limestone	892 Limestone	Sand	P-401 Specification Limits		
Percent Used	19%	23%	17%	33%	7%			
Sieve Size (mm)	% Passing	% Passing	% Passing	% Passing	% Passing	Minimum	Maximum	JMF
25	100	100	100	100	100	100	100	100
19	100	100	100	100	100	100	100	100
12.5	91	100	70	100	100	79	99	93
9.5	78	90	37	100	100	68	88	83
4.75	47	55	9	99	97	48	68	63
2.36	25	31	3	75	87	33	53	44
1.18	14	18	2	44	79	20	40	28
0.6	9	12	2	27	62	14	30	19
0.3	7	8	2	16	9	9	21	10
0.15	5	6	2	8	1	6	16	6
0.075	3.9	4.3	1.8	4.1	0.4	3	6	4.4
G_{sb}	2.373	2.342	2.728	2.689	2.600			2.534
G_{sa}	2.621	2.652	2.766	2.747	2.653			2.691
Abs %	4.00	4.90	0.49	0.80	0.78			2.29

Note: 1% hydrated lime was added to this mixture.

Table 5. Mississippi With 15% Sand Aggregate Blend Gradation

Stockpile	19-mm Gravel	12.5-mm Gravel	78 Limestone	892 Limestone	Sand	P-401 Specification Limits		
Percent Used	17%	29%	12%	26%	15%			
Sieve Size (mm)	% Passing	% Passing	% Passing	% Passing	% Passing	Minimum	Maximum	JMF
25	100	100	100	100	100	100	100	100
19	100	100	100	100	100	100	100	100
12.5	91	100	70	100	100	79	99	95
9.5	78	90	37	100	100	68	88	86
4.75	47	55	9	99	97	48	68	66
2.36	25	31	3	75	87	33	53	47
1.18	14	18	2	44	79	20	40	32
0.6	9	12	2	27	62	14	30	23
0.3	7	8	2	16	9	9	21	10
0.15	5	6	2	8	1	6	16	6
0.075	3.9	4.3	1.8	4.1	0.4	3	6	4.3
G_{sb}	2.373	2.342	2.728	2.689	2.600			2.511
G_{sa}	2.621	2.652	2.766	2.747	2.653			2.680
Abs %	4.00	4.90	0.49	0.80	0.78			2.48

Note: 1% hydrated lime was added to this mixture.

Table 6. New Jersey Aggregate Blend Gradation

Stockpile	19-mm S-1	12.5-mm S-2	S-3	S-4	Sand	P-401 Specification Limits		
Percent Used	9%	30%	10%	51%	0%			
Sieve Size (mm)	% Passing	% Passing	% Passing	% Passing	% Passing	Minimum	Maximum	JMF
25	100	100	100	100	100	100	100	100
19	100	100	100	100	100	100	100	100
12.5	38	100	100	100	100	79	99	94
9.5	8	80	100	100	100	68	88	86
4.75	3	9	83	99	97	48	68	62
2.36	3	2	13	67	87	33	53	36
1.18	2	2	3	41	79	20	40	22
0.6	2	2	2	29	62	14	30	16
0.3	2	2	1	21	9	9	21	11
0.15	2	2	1	12	1	6	16	7
0.075	2	1.7	1	5.7	0.4	3	6	3.7
G_{sb}	2.829	2.828	2.815	2.803	2.600			2.814
G_{sa}	2.863	2.866	2.864	2.860	2.653			2.862
Abs %	0.41	0.47	0.60	0.72	0.78			0.60

Note: 1% hydrated lime was added to this mixture.

Table 7. New Jersey With 15% Sand Aggregate Blend Gradation

Stockpile	19-mm S-1	12.5-mm S-2	S-3	S-4	Sand	P-401 Specification Limits		
Percent Used	11%	22%	15%	36%	15%			
Sieve Size (mm)	% Passing	% Passing	% Passing	% Passing	% Passing	Minimum	Maximum	JMF
25	100	100	100	100	100	100	100	100
19	100	100	100	100	100	100	100	100
12.5	38	100	100	100	100	79	99	93
9.5	8	80	100	100	100	68	88	85
4.75	3	9	83	99	97	48	68	66
2.36	3	2	13	67	87	33	53	41
1.18	2	2	3	41	79	20	40	29
0.6	2	2	2	29	62	14	30	21
0.3	2	2	1	21	9	9	21	11
0.15	2	2	1	12	1	6	16	6
0.075	2	1.7	1	5.7	0.4	3	6	3.8
G_{sb}	2.829	2.828	2.815	2.803	2.600			2.774
G_{sa}	2.863	2.866	2.864	2.860	2.653			2.822
Abs %	0.41	0.47	0.60	0.72	0.78			0.61

Note: 1% hydrated lime was added to this mixture.

Each aggregate mixture was a composite of materials from multiple stockpiles proportioned to meet the target gradations. Blends were adjusted to produce asphalt concrete specimens with 3.5% air voids and voids in mineral aggregate (VMA) near the minimum requirement of 15%. The representative aggregate gradations and specification limits are given in figure 1.

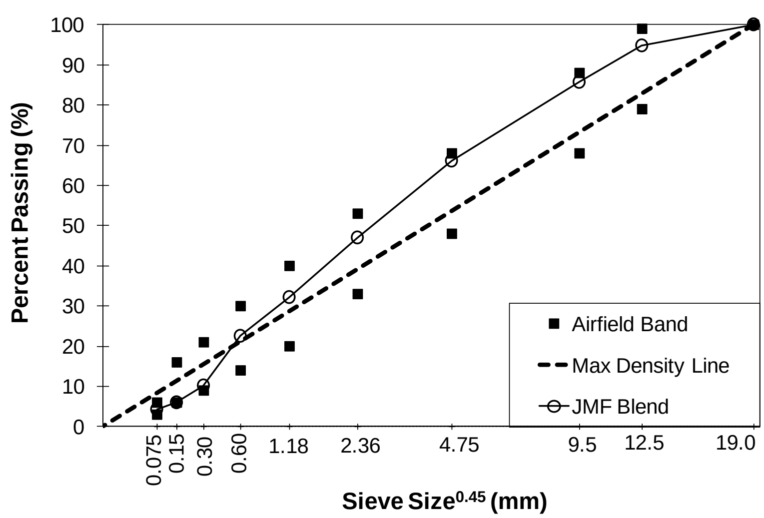

Figure 1. Representative Aggregate Gradation

2.3 MIXTURE NOMENCLATURE SYSTEM.

A nomenclature system was established to identify each mixture according to the variables identified in sections 2.1 and 2.2. The mixture identifier begins with the state postal abbreviation from where the aggregates were obtained, followed by two numbers representing the percentage of natural sand in the mixture, and ends with four numbers representing the binder grade used in the mixture. The aggregate source of the mixture is identified as either

- AR Arkansas, or
- MA Massachusetts, or
- MS Mississippi, or
- NJ New Jersey.

The number in the middle of the mixture identifier indicates the percentage of natural sand used in the mixture. For this study, possible values are

- 00 No natural sand; the aggregate is 100 percent crushed, or
- 07 The mixture contains 7 percent natural sand by mass of aggregate, or
- 10 The mixture contains 10 percent natural sand by mass of aggregate, or
- 15 The mixture contains 15 percent natural sand by mass of aggregate.

The last four numbers represent the binder grade used in the mixture. For this study, possible values are

- 5828 PG 58-28 neat binder, or
- 7028 PG 70-28 polymer-modified binder, or
- 7628 PG 76-28 polymer-modified binder, or
- 6422 PG 64-22 neat binder, or
- 7622 PG 76-22 polymer-modified binder, or
- 8222 PG 82-22 polymer modified binder.

For example, NJ-15-5828 identifies a mixture with aggregate from the New Jersey plant that contains 15 percent natural sand and is prepared using a PG 58-28 binder. Table 8 provides designations for all mixtures used in this study. Mixtures of each aggregate blend were prepared using the same design binder content with six different binders to measure the change in performance achieved by using a premium binder.

Table 8. Aggregate Mixture Designations and Design Binder Content

Aggregate Identifier	Design Binder Content (%)	Binder	Mixture Designation
Arkansas	5.3	PG 58-28	AR-10-5828
		PG 70-28	AR-10-7028
		PG 76-28	AR-10-7628
		PG 64-22	AR-10-6422
		PG 76-22	AR-10-7622
		PG 82-22	AR-10-8222
Massachusetts	5.3	PG 58-28	MA-00-5828
		PG 70-28	MA-00-7028
		PG 76-28	MA-00-7628
		PG 64-22	MA-00-6422
		PG 76-22	MA-00-7622
		PG 82-22	MA-00-8222
Mississippi (7% sand)	6.9	PG 58-28	MS-07-5828
		PG 70-28	MS-07-7028
		PG 76-28	MS-07-7628
		PG 64-22	MS-07-6422
		PG 76-22	MS-07-7622
		PG 82-22	MS-07-8222
Mississippi (15% sand)	6.5	PG 58-28	MS-15-5828
		PG 70-28	MS-15-7028
		PG 76-28	MS-15-7628
		PG 64-22	MS-15-6422
		PG 76-22	MS-15-7622
		PG 82-22	MS-15-8222
New Jersey (0% sand)	5.0	PG 58-28	NJ-00-5828
		PG 70-28	NJ-00-7028
		PG 76-28	NJ-00-7628
		PG 64-22	NJ-00-6422
		PG 76-22	NJ-00-7622
		PG 82-22	NJ-00-8222
New Jersey (15% sand)	4.6	PG 58-28	NJ-15-5828
		PG 70-28	NJ-15-7028
		PG 76-28	NJ-15-7628
		PG 64-22	NJ-15-6422
		PG 76-22	NJ-15-7622
		PG 82-22	NJ-15-8222

2.4 MIXTURE DESIGN.

For mixture designs, individual batches for each mixture were prepared by weighing the target batch weight of aggregate from the appropriate stockpiles into a shallow mixing pan. Aggregate batches were placed in an oven overnight at the mixing temperature of the binder prior to performing mixture designs. To perform the mixture design, the binder was heated to the mixing temperature of the asphalt cement. The aggregate was weighed into a mixing bowl, and binder was added to achieve the target binder content for the mixture. The sample was mixed using a bucket mixer until the aggregate was thoroughly coated with binder. The mixture was then placed into a shallow pan and stored in the oven at the compaction temperature for two hours before placing it into the preheated compaction molds. A Pine Instruments Company model AFGC125X gyratory compactor was used in the mixture designs during this study to compact cylindrical asphalt concrete specimens with a diameter of 150 mm at a target height of 115 mm. Compaction was performed using a ram pressure of 600 kPa and an internal angle of gyration of 1.16 ±0.02. Asphalt mixtures were compacted to 70 gyrations at a rate of 30 revolutions per minute. Seventy gyrations are recommended for N_{design} for HMA mixtures designed for high tire pressure aircraft [5].

The optimum binder content for each mixture was determined by compacting specimens using at least three different binder contents. The theoretical maximum density was measured for each mixture in accordance with American Society of Testing and Materials (ASTM) D2041 [6]. The bulk-specific gravity was determined in accordance with ASTM D2726 [7]. The percentage of air voids in the specimen was determined in accordance with ASTM D3203 [8]. The percentage of air voids was plotted versus the percentage of binder in the mixture to determine the percentage of binder required to compact the mixture to 3.5% air voids (V_a) at the design compactive effort. The air void content of 3.5% was selected because it is the center of the allowable design range in FAA specifications. This percentage of binder was considered the design binder content. Specimens for further testing were prepared using this design binder content. Mixture volumetric properties were determined in accordance with the Asphalt Institute MS-02 manual [9] and are listed in table 9, where G_{mm} is the maximum specific gravity of the mixture, G_{se} is the effective specific gravity, G_{mb} is the bulk specific gravity, P_b is the percent binder, P_{ba} is the percent absorbed asphalt, P_{be} is the percent effective binder, VFA are the voids filled with asphalt, and D/B is the dust to binder ratio.

Material handling and mixing procedures used to prepare specimens for performance tests were the same as noted above for mixture design. The test methods required specimens with different heights. Compaction of performance test specimens was performed by setting the SGC to compact to a given height to match test requirements. The weight of mixture was adjusted to result in a compacted specimen having a target average of 3.5% air voids.

Table 9. Mixture Volumetric Properties

Mix	G_{mm}	G_{se}	G_{mb}	P_b	P_{ba}	P_{be}	V_a (%)	VMA	VFA (%)	D/B
Arkansas with 10% sand	2.427	2.626	2.341	5.3	0.59	4.74	3.5	14.6	76	0.97
Massachusetts	2.628	2.862	2.536	5.3	0.45	4.68	3.5	15.1	77	0.81
Mississippi with 7% sand	2.368	2.612	2.284	6.9	1.21	5.77	3.5	15.2	77	0.76
Mississippi with 15% sand	2.362	2.595	2.280	6.5	1.33	5.26	3.5	15.1	77	0.82
New Jersey	2.620	2.857	2.528	5.0	0.55	4.48	3.5	14.4	76	0.83
New Jersey with 15% sand	2.604	2.831	2.512	4.6	0.57	4.05	3.5	13.7	74	0.94

3. PERFORMANCE TESTS FOR PERMANENT DEFORMATION OF ASPHALT CONCRETE.

For this study, four laboratory performance tests were conducted on compacted mixtures. The tests were:

- Repeated Load Test
- Static Creep Test
- IDT Strength Test
- APA Test

The performance tests selected for this study were among those most recommended by previous research [2, 3, 10, 11, 12, and 13]. Sections 3.1 through 3.4 describe the details of these four performance tests. Also, performance criteria from Rushing, Little, and Garg [2] were applied to the repeated load, static creep, and APA tests. Criteria from Advanced Asphalt Technologies [4] were used for the indirect tensile strength test. These criteria provided a reasonable assessment of the rutting performance of the different asphalt mixtures compared to those reported in the available literature.

3.1 REPEATED LOAD TEST.

The repeated load triaxial test measured permanent deformation as axial load cycles were applied to cylindrical HMA specimens. Cumulative permanent deformation was reported as a function of number of load cycles. Figure 2 shows the general shape of the curve from typical data in terms of accumulated permanent axial strain as a function of number of load cycles.

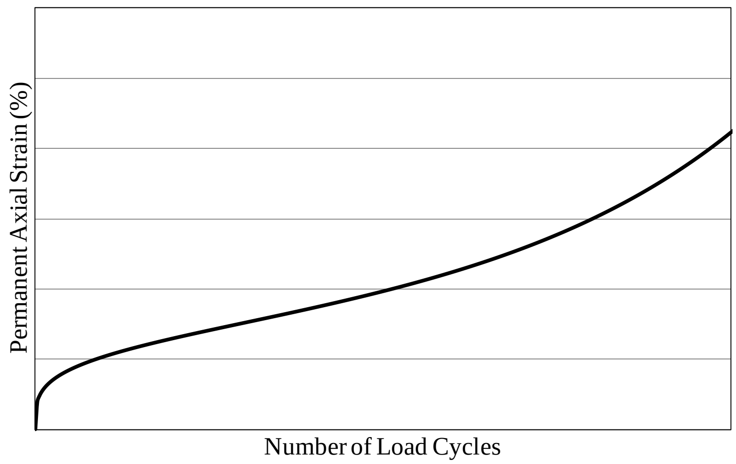

Figure 2. Typical Permanent Deformation Behavior of Asphalt Mixtures

The repeated load test was performed on cylindrical specimens that were 100 mm in diameter by 150-mm high and cored from gyratory compacted mixtures. A confining stress of 276 kPa and deviator stress of 1380 kPa were selected for testing. The load pulse consisted of a 0.1-second load followed by 0.9-second dwell time. The test temperature was selected to be the mean monthly pavement temperature (MMPT) and was defined by Witczak [14]. The MMPT was 43°C in Vicksburg, Mississippi, the selected climate for the PG 64-22, PG 76-22, and PG 82-22 binders. The MMPT was 37°C in Hartford, Connecticut, the selected climate for the PG 58-28, PG 70-28, and PG 76-28 binders.

The repeated load test was used to determine the flow number (FN). The FN was defined as the number of cycles corresponding to the minimal rate of change of permanent axial strain during the repeated load test. The FN for each specimen was determined by fitting the Francken model (equation 1) to the repeated load test data by a least sum of squares method. The Francken model fit the permanent strain data by using a combination of a power law and an exponential model. Four fitting coefficients were used to fit the model to experimental data (figure 3). The FN was defined as the number of cycles when the second derivative of the model (equation 2) changed from negative to positive. Rushing, Little, and Garg [2] recommend a FN greater than 200 for airfield paving mixtures.

$$\varepsilon_p = An^B + C(e^{Dn} - 1) \quad (1)$$

where

ε_p = plastic strain
n = number of load cycles
A, B, C, and D = fitting coefficients

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

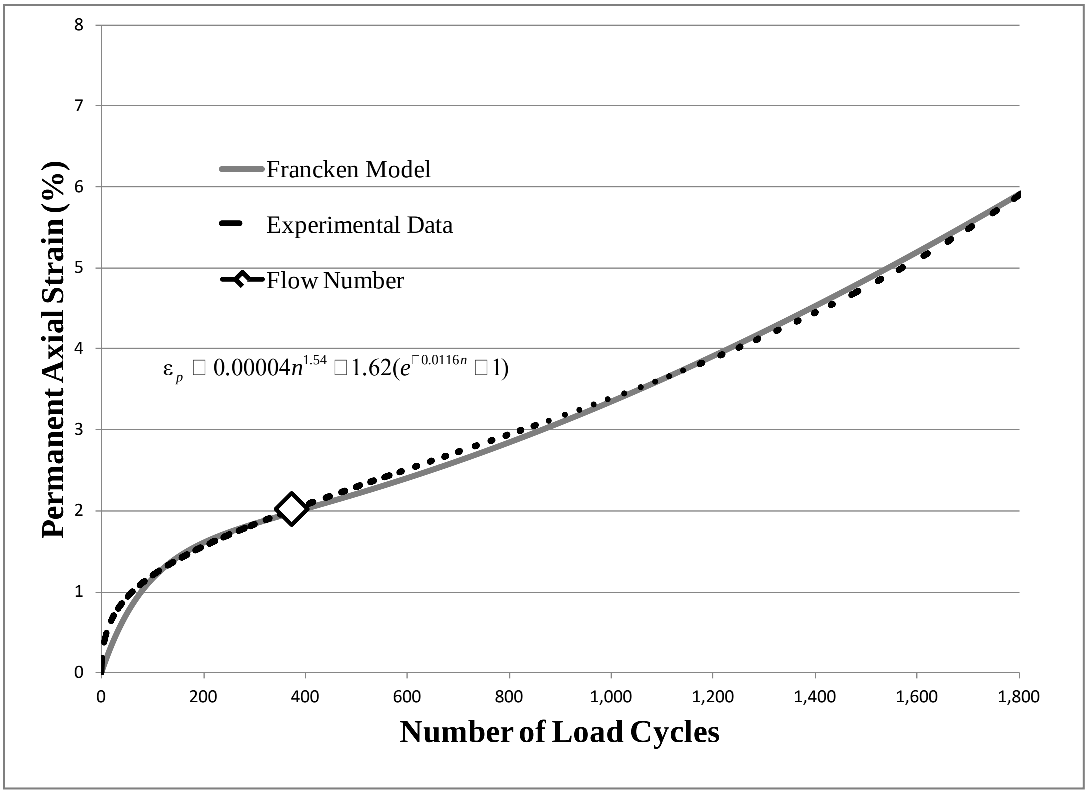

Figure 3. Determining FN

3.2 STATIC CREEP TEST.

The static creep triaxial test measured permanent deformation as a function of time when a constant load was applied to cylindrical HMA specimens. Cumulative permanent deformation was reported as a function of time during loading.

The static creep test was performed on cylindrical specimens, 100 mm in diameter by 150 mm high, cored from gyratory compacted mixtures. A confining stress of 276 kPa and deviator stress of 1380 kPa were selected for testing. The test temperature was selected to be the MMPT. The MMPT was 43°C in Vicksburg, Mississippi, the selected climate for the PG 64-22, PG 76-22, and PG 82-22 binders. The test temperature was 37°C in Hartford, Connecticut, the selected climate for the PG 58-28, PG 70-28, and PG 76-28 binders.

The static creep test was used to determine the flow time (FT). The FT was defined as the time corresponding to the minimal rate of change of permanent axial strain during the static creep test. The FT for each specimen was determined by fitting the Francken model (equation 3) to the repeated load test data by a least sum of squares method. Four fitting coefficients were used to fit the model to experimental data (figure 4). The FT was defined as the time when the second derivative of the model (equation 4) changed from negative to positive. Rushing, Little, and Garg [2] recommend a FT greater than 30 for airfield paving mixtures.

$$\varepsilon_p = Wt^x + Y(e^{Zt} - 1) \quad (3)$$

where

ε_p = plastic strain
t = time (seconds)
W, X, Y, and Z = fitting coefficients

$$\frac{d^2\varepsilon_p}{dt^2} = WX(X-1)\mathrm{t}^{(X-2)} + YZ^2e^Z \quad (4)$$

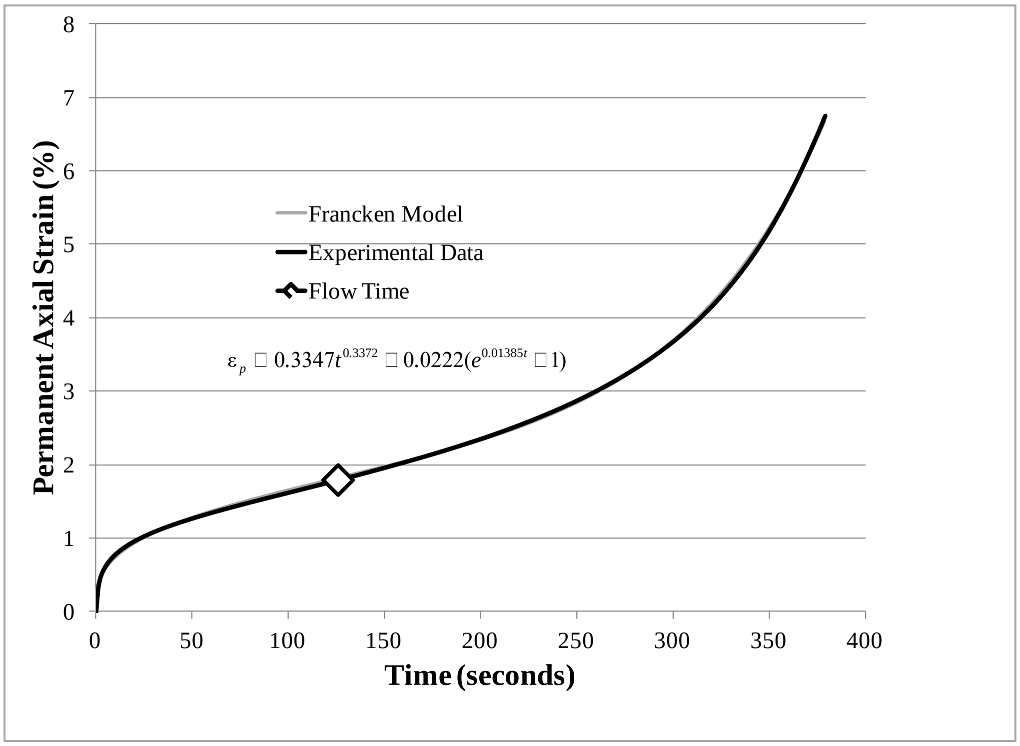

Figure 4. Determining FT From Static Creep Data

3.3 INDIRECT TENSILE STRENGTH TEST.

The IDT strength test was used to measure the cohesive properties of each mixture. The test applies a compressive load to the diametral axis of a cylindrical specimen. A specimen diameter of 150 mm and target height of 100 mm was used for testing. Specimens were compacted in the SGC to the target height of 100 mm using appropriate mass of asphalt mixture to result in a target air void content of 3.5%. Specimens were submerged in a water bath at the test temperature of 40°C for at least 2 hours prior to testing. The load was applied in a Humboldt load frame at a rate of 50 mm/min. The peak load was recorded from a dial gage and used to calculate indirect tensile strength according to equation 5. The results from three specimens were averaged and reported.

$$IDT = (2000 \times P) \div (\pi \times d \times h) \quad (5)$$

where

IDT = indirect tensile strength (kPa)
P = peak load at failure (N)
π = Pi
d = specimen diameter (mm)
h = specimen height (mm)

Advanced Asphalt Technologies, LLC [4] prepared recommendations for the FAA's gyratory compaction-based specification. These recommendations include requirements for IDT strength test results. The requirements are based on the binder grade used in the mixture. Since testing is performed at 40°C, increasing high binder grade temperatures are expected to result in higher IDT strength. Two sets of requirements exist: those for normal-duty HMA designs and those for heavy-duty HMA designs. Heavy-duty HMA designs are defined as those intended for runways or taxiways with a total of more than 60,000 annual arrivals and departures and handling a design aircraft with gross weight exceeding 890 kN or with tire pressure exceeding 1380 kPa. Table 10 lists the requirements for mixtures prepared with common airfield binder PG.

Table 10. Minimum IDT Strength Requirements

Specified Minimum High Temperature Binder PG	Minimum Design IDT Strength (kPa)	
	Normal-Duty HMA Designs	Heavy-Duty HMA Designs
PG 52-XX	138	207
PG 58-XX	207	276
PG 64-XX	310	414
PG 67-XX	345	483
PG 70-XX	414	552
PG 76-XX	552	758
PG 82-XX	758	965

3.4 ASPHALT PAVEMENT ANALYZER TEST.

The APA used in this study was designed specifically to simulate high tire pressures associated with aircraft. An APA tube or hose pressure of 1724 kPa under a wheel load of 1113 kN was used for testing. The test temperature was 64°C for mixtures prepared using the PG 64-22, PG 76-22, and PG 82-22 binders and 58°C for mixtures prepared using the PG 58-28, PG 70-28, and PG 76-28 binders. Mixtures containing polymer-modified binder were tested at the same temperature as the parent binder to quantify the benefit obtained from using premium binders in a given climatic region. Figure 5 shows the APA test configuration. Cylindrical asphalt concrete specimens with a target air void content of 3.5% were prepared and tested. The air void content was selected as the midpoint of the allowable range in the FAA mix design procedure. Six replicate specimens were tested for each mix. The APA reports the average rut depth of two specimens along each test path. The APA rut depth reported for each mixture was the overall average rut depth for the three test positions.

Figure 5. The APA Test Configuration

The APA applied cyclic loads at a rate of one cycle per second. The terminal rut depth of the specimens was set at 12 mm after 8000 cycles; however, the test was terminated when the 12-mm rut depth was achieved if this occurred before 8000 cycles. Once one of the two specimens at each test position reached terminal rut depth, the test was stopped. However, since the APA reports the average rut depth for the two specimens at each test position, some average rut depths were less than 12 mm. Figure 6 shows two specimens in one test position after the test was complete.

Figure 6. The HMA Specimens After Testing in the APA

4. PERFORMANCE TEST RESULTS.

4.1 REPEATED LOAD TEST RESULTS.

As described in section 3.1, repeated load testing was performed, and the permanent deformation was recorded after each load cycle. The Francken model was fit to the data to provide a mathematical equation for calculating the FN. Plots of the permanent deformation curves are provided in appendix A. The fitting coefficients and calculated FN for each specimen are in tables 11 through 16, and a summary of average FN values for each mixture is in table 17.

Test temperatures were adjusted such that mixtures prepared using PG XX-28 binders were expected to produce similar results to mixtures prepared using PG XX-22 binders. In general, this expectation was met. The exception was that the mixtures prepared using the PG 76-28 binder experienced tertiary flow before 10,000 cycles in all but one case, and all but one mixture prepared using the PG 82-22 binder did not.

Rushing, Little, and Garg [2] recommended a FN greater than 200 for airfield paving mixtures. Of the mixtures prepared with the unmodified binders, only two met this criterion (NJ-00-5828 and NJ-15-5828). These results were unexpected because all mixtures were designed according to standards for heavy-duty aircraft pavements. For both the PG 58-28 and PG 64-22 binders, the MA-00-, NJ-00-, and NJ-15- mixtures performed better than the AR-10-, MS-07-, and MS-15-mixtures. All mixtures prepared using polymer-modified binders easily surpassed the FN criterion. The FN improved by a factor of around 6 when bumping the binder grade twice, and by a factor of around 12 when using three grade bumps. This test performed well in differentiating performance when using a premium binder.

Table 18 provides the mixture ranking for each binder grade according to greatest FN. For the mixtures with PG 82-22 binder, the ranking is by the lowest permanent strain after 10,000 load cycles since tertiary flow only occurred in the AR-10-8222 mixture. In four of six cases, the MA-00-, NJ-00-, and NJ-15- mixtures outperform the AR-10-, MS-07-, and MS-15- mixtures. The MA-00- or NJ-00- mixture was the best performer in every case, and the AR-10- or MS-15-mixture was the poorest performer in every case. Overall, the FN results were fairly consistently in ranking mixture performance.

Table 11. Repeated Load Test Results for AR-10 Mixtures

Mixture Designation	Specimen	FN	Regression Coefficients			
			A	B	C	D
AR-10-5828	1	103	0.2135	0.3391	1.5441	0.0032
	2	98	0.1905	0.4510	0.3705	0.0072
	3	101	0.2319	0.3376	1.9496	0.0031
	Average	101	0.2120	0.3759	1.2881	0.0045
AR-10-7028	1	968	0.0459	0.7385	22.0646	-0.0003
	2	452	0.0813	0.7105	15.7634	-0.0007
	3	496	0.0623	0.7456	18.6552	-0.0006
	Average	639	0.0632	0.7316	18.8277	-0.0005
AR-10-7628	1	1,831	0.0311	0.7138	19.3918	-0.0002
	2	1,056	0.1108	0.5702	9.5438	-0.0005
	3	1,328	0.1398	0.5131	7.1570	-0.0005
	Average	1,405	0.0939	0.5990	12.0309	-0.0004
AR-10-6422	1	112	0.1689	0.4474	0.2862	0.0067
	2	99	0.1713	0.4070	0.8943	0.0044
	3	135	0.2250	0.3210	3.0970	0.0018
	Average	115	0.1884	0.3918	1.4259	0.0043
AR-10-7622	1	478	0.0636	0.7541	22.1140	-0.0006
	2	258	0.0000	1.6834	-0.9801	-0.0182
	3	436	0.0720	0.7491	22.5185	-0.0006
	Average	391	0.0452	1.0622	14.5508	-0.0065
AR-10-8222	1	>10,000	0.0018	0.7076	-0.5891	-0.0497
	2	3,759	0.1915	0.2299	0.1250	0.0002
	3	3,224	0.1430	0.2700	0.1380	0.0003
	Average	3,492	0.1672	0.2500	0.1315	0.0003

Table 12. Repeated Load Test Results for MA-00 Mixtures

Mixture Designation	Specimen	FN	Regression Coefficients			
			A	B	C	D
MA-00-5828	1	175	0.0009	1.2590	-1.3519	-0.0301
	2	111	0.2030	0.4313	0.2448	0.0075
	3	162	0.2776	0.3754	0.6889	0.0037
	Average	149	0.1605	0.6886	-0.1394	-0.0063
MA-00-7028	1	949	0.0431	0.7367	18.8375	-0.0003
	2	692	0.0749	0.6984	17.2932	-0.0005
	3	772	0.0549	0.7098	14.8972	-0.0004
	Average	804	0.0576	0.7150	17.0093	-0.0004
MA-00-7628	1	Specimen Not Available				
	2	Specimen Not Available				
	3	Specimen Not Available				
MA-00-6422	1	209	0.2260	0.3696	0.1383	0.0048
	2	188	0.1953	0.3758	0.3052	0.0040
	3	162	0.0000	1.8534	-1.7148	-0.0286
	Average	186	0.1404	0.8663	-0.4237	-0.0066
MA-00-7622	1	787	0.1625	0.3453	0.0856	0.0015
	2	985	0.2340	0.3085	0.1204	0.0011
	3	777	0.0626	0.4761	0.1055	0.0014
	Average	850	0.1530	0.3766	0.1038	0.0013
MA-00-8222	1	>10,000	0.0079	0.5359	-0.6083	-0.0178
	2	>10,000	0.0125	0.4970	-0.6365	-0.0176
	3	>10,000	0.0297	0.3792	-0.4372	-0.0186
	Average	>10,000	0.0167	0.4707	-0.5607	-0.0180

Table 13. Repeated Load Test Results for MS-07 Mixtures

Mixture Designation	Specimen	FN	Regression Coefficients			
			A	B	C	D
MS-07-5828	1	94	0.2446	0.4867	0.4418	0.0082
	2	93	0.2432	0.4900	0.5890	0.0074
	3	106	0.2361	0.4567	0.8616	0.0054
	Average	98	0.2413	0.4778	0.6308	0.0070
MS-07-7028	1	842	0.1195	0.5808	6.7866	-0.0008
	2	523	0.0733	0.7240	14.6055	-0.0007
	3	627	0.1137	0.6368	10.0105	-0.0008
	Average	664	0.1022	0.6472	10.4675	-0.0008
MS-07-7628	1	1,414	0.1102	0.5776	10.4719	-0.0004
	2	1,380	0.1338	0.5548	10.1291	-0.0004
	3	1,478	0.6110	0.2327	0.2967	0.0006
	Average	1,424	0.2850	0.4550	6.9659	-0.0001
MS-07-6422	1	146	0.2816	0.4036	0.5821	0.0046
	2	132	0.2588	0.3994	0.9627	0.0040
	3	142	0.2824	0.3921	2.3247	0.0026
	Average	140	0.2743	0.3984	1.2898	0.0037
MS-07-7622	1	371	0.0000	1.7730	-1.4587	-0.0140
	2	625	0.1089	0.6617	14.6260	-0.0007
	3	353	0.0000	1.5463	-1.6204	-0.0133
	Average	450	0.0363	1.3270	3.8489	-0.0093
MS-07-8222	1	>10,000	0.0049	0.6487	-0.8850	-0.0113
	2	>10,000	0.0012	0.8285	-1.1191	-0.0072
	3	>10,000	0.0004	0.9492	-1.0794	-0.0067
	Average	>10,000	0.0021	0.8088	-1.0279	-0.0084

Table 14. Repeated Load Test Results for MS-15 Mixtures

Mixture Designation	Specimen	FN	Regression Coefficients			
			A	B	C	D
MS-15-5828	1	115	0.1989	0.4659	0.5151	0.0059
	2	73	0.2184	0.4702	0.5160	0.0088
	3	74	0.2578	0.4284	0.7610	0.0074
	Average	87	0.2250	0.4548	0.5973	0.0074
MS-15-7028	1	534	0.0674	0.7446	21.5869	-0.0005
	2	579	0.0704	0.6947	12.4391	-0.0007
	3	591	0.0738	0.6898	13.0276	-0.0006
	Average	568	0.0706	0.7097	15.6845	-0.0006
MS-15-7628	1	1,273	0.0936	0.6423	19.5088	-0.0003
	2	915	0.0984	0.6449	17.1582	-0.0004
	3	1,124	0.1030	0.6153	14.3987	-0.0004
	Average	1,104	0.0984	0.6342	17.0219	-0.0004
MS-15-6422	1	99	0.3084	0.3804	0.9857	0.0052
	2	80	0.2426	0.4334	0.9186	0.0064
	3	84	0.2398	0.4197	1.0313	0.0057
	Average	88	0.2636	0.4112	0.9785	0.0057
MS-15-7622	1	810	0.0672	0.6834	15.0179	-0.0005
	2	807	0.0661	0.6951	17.2064	-0.0004
	3	687	0.0559	0.7421	21.9765	-0.0004
	Average	768	0.0631	0.7069	18.0669	-0.0004
MS-15-8222	1	>10,000	0.0012	0.7737	-0.7183	-0.0094
	2	>10,000	0.0002	0.9623	-0.9132	-0.0083
	3	>10,000	0.0004	0.8849	-0.7741	-0.0074
	Average	>10,000	0.0006	0.8736	-0.8019	-0.0084

Table 15. Repeated Load Test Results for NJ-00 Mixtures

Mixture Designation	Specimen	FN	Regression Coefficients			
			A	B	C	D
NJ-00-5828	1	206	0.2948	0.3754	0.2114	0.0048
	2	261	0.2370	0.4013	0.1919	0.0039
	3	295	0.2817	0.3842	0.2484	0.0033
	Average	254	0.2712	0.3870	0.2173	0.0040
NJ-00-7028	1	1,328	0.0927	0.6090	11.6579	-0.0004
	2	1,179	0.0687	0.6635	16.0405	-0.0003
	3	898	0.0618	0.6896	14.4555	-0.0004
	Average	1,135	0.0744	0.6540	14.0513	-0.0004
NJ-00-7628	1	>10,000	0.0073	0.5893	-0.8431	-0.0113
	2	>10,000	0.0036	0.6673	-0.9089	-0.0110
	3	>10,000	0.0087	0.5510	-0.6999	-0.0125
	Average	>10,000	0.0065	0.6025	-0.8173	-0.0116
NJ-00-6422	1	131	0.0004	1.4092	-1.4516	-0.0402
	2	180	0.0001	1.6782	-1.5931	-0.0229
	3	228	0.2131	0.4096	0.3775	0.0033
	Average	180	0.0712	1.1657	-0.8891	-0.0199
NJ-00-7622	1	1,265	0.0686	0.6478	13.2168	-0.0003
	2	909	0.0629	0.6926	15.1620	-0.0004
	3	1,084	0.0633	0.6824	17.1661	-0.0003
	Average	1,086	0.0649	0.6743	15.1816	-0.0004
NJ-00-8222	1	>10,000	0.0019	0.7512	-0.9057	-0.0070
	2	>10,000	0.0067	0.6298	-1.1038	-0.0135
	3	>10,000	0.1728	0.3541	1.3831	-0.0003
	Average	>10,000	0.0605	0.5784	-0.2088	-0.0069

Table 16. Repeated Load Test Results for NJ-15 Mixtures

Mixture Designation	Specimen	FN	Regression Coefficients			
			A	B	C	D
NJ-15-5828	1	206	0.0065	0.9984	-1.2256	-0.0384
	2	190	0.3180	0.3257	2.3058	0.0019
	3	263	0.0006	1.3132	-1.4181	-0.0161
	Average	220	0.1084	0.8791	-0.1127	-0.0175
NJ-15-7028	1	1,010	0.0331	0.7518	16.4719	-0.0003
	2	915	0.0620	0.6576	9.2826	-0.0005
	3	584	0.1218	0.6183	9.5836	-0.0009
	Average	836	0.0723	0.6759	11.7794	-0.0006
NJ-15-7628	1	3,085	0.0388	0.6269	11.9927	-0.0001
	2	2,033	0.0342	0.6724	12.9740	-0.0002
	3	1,599	0.0865	0.5638	8.4847	-0.0003
	Average	2,239	0.0532	0.6211	11.1505	-0.0002
NJ-15-6422	1	153	0.1978	0.4127	0.4053	0.0046
	2	131	0.2465	0.3815	0.9187	0.0039
	3	123	0.2426	0.4070	0.5080	0.0054
	Average	136	0.2290	0.4004	0.6107	0.0046
NJ-15-7622	1	648	0.1064	0.6689	17.3666	-0.0006
	2	686	0.0643	0.7340	23.5784	-0.0004
	3	773	0.0874	0.6788	18.5812	-0.0005
	Average	702	0.0860	0.6939	19.8421	-0.0005
NJ-15-8222	1	>10,000	0.0019	0.7512	-0.9057	-0.0070
	2	>10,000	0.0011	0.8069	-1.0248	-0.0094
	3	>10,000	0.0010	0.8015	-0.6352	-0.0065
	Average	>10,000	0.0014	0.7865	-0.8553	-0.0076

Table 17. Average FN Test Results Summary

Mixture Designation	Binder Grade					
	58-28	70-28	76-28	64-22	76-22	82-22
AR-10-	101	639	1,405	115	391	3,492
MA-00-	149	804	---	186	850	>10,000
MS-07-	98	664	1,424	140	450	>10,000
MS-15-	87	568	1,104	88	768	>10,000
NJ-00-	254	1,135	>10,000	180	1,086	>10,000
NJ-15-	220	836	2,239	136	702	>10,000

Table 18. Mixture Ranking by Largest FN

Mixture Rank	Binder Grade					
	PG 58-28	PG 70-28	PG 76-28	PG 64-22	PG 76-22	PG 82-22
1	NJ-00-5828	NJ-00-7028	NJ-00-7628	MA-00-6422	NJ-00-7622	MA-00-8222
2	NJ-15-5828	NJ-15-7028	NJ-15-7628	NJ-00-6422	MA-00-7622	MS-15-8222
3	MA-00-5828	MA-00-7028	MS-07-7628	MS-07-6422	MS-15-7622	NJ-15-8222
4	AR-10-5828	MS-07-7028	AR-10-7628	NJ-15-6422	NJ-15-7622	NJ-00-8222
5	MS-07-5828	AR-10-7028	MS-15-7628	AR-10-6422	MS-07-7622	MS-07-222
6	MS-15-5828	MS-15-7028	MA-00-7628*	MS-15-6422	AR-10-7622	AR-10-8222

* Not tested

4.2 STATIC CREEP RESULTS.

Static creep testing was performed as described in section 3.2. The permanent deformation was recorded as a function of time after the static load was applied. The Francken model was fit to the data to provide a mathematical equation for calculating the FT. Plots of the permanent deformation curves are provided in appendix B. The fitting coefficients and calculated FT for each specimen are given in tables 19 through 24, and a summary of average FT values for each mixture is given in table 25.

Test temperatures were adjusted such that mixtures prepared using PG XX-28 binders were expected to produce similar results to mixtures prepared using PG XX-22 binders. These test results did not match as well as the results from the repeated load test. The variability among the three specimens for each mixture appeared to be greater for the static creep test compared to the repeated load test as well.

Rushing, Little, and Garg [2] recommended a FT greater than 30 for airfield paving mixtures. Of the mixtures prepared with the unmodified binders, only two failed to meet this criterion (MS-07-6422 and MS-15-6422). All mixtures prepared using a polymer-modified binder easily surpassed the FT criterion. The FT improved by a factor of at least 3 when bumping the binder grade twice, and by a factor of at least 10 when using three grade bumps. This test performed well in differentiating performance when using a premium binder.

Table 26 provides the mixture ranking for each binder grade. In five of six cases, the MA-00- or the NJ-00- mixture performed best. In every case, the MS-07- or NJ-15- mixture exhibited the poorest performance. Otherwise, the FT results did not consistently rank mixture performance. For example, the AR-10- mixture ranked in position 1, 2, 2, 3, 4, and 5 for the six different binder grades. Once again, the test results seemed to have greater variability, influencing the average values and distorting rankings for the FT.

Table 19. Static Creep Test Results for AR-10 Mixtures

Mixture Designation	Specimen	FT	Regression Coefficients			
			W	X	Y	Z
AR-10-5828	1	26	0.6457	0.2494	0.9397	0.0165
	2	40	0.6616	0.2758	0.4180	0.0169
	3	67	0.4287	0.3279	0.0109	0.0312
	Average	44	0.5787	0.2844	0.4562	0.0215
AR-10-7028	1	554	0.5537	0.2188	0.0058	0.0044
	2	241	0.4549	0.2593	0.0199	0.0075
	3	183	0.4916	0.2709	0.0097	0.0120
	Average	326	0.5001	0.2497	0.0118	0.0079
AR-10-7628	1	592	0.4996	0.2194	0.0023	0.0049
	2	507	0.5954	0.2100	0.0015	0.0063
	3	433	0.6148	0.2193	0.0011	0.0079
	Average	511	0.5699	0.2162	0.0016	0.0063
AR-10-6422	1	21	0.4380	0.2988	0.5503	0.0236
	2	27	0.4521	0.1653	10.5269	0.0036
	3	31	0.4533	0.2630	0.8656	0.0133
	Average	26	0.4478	0.2424	3.9809	0.0135
AR-10-7622	1	205	0.3284	0.2894	0.0370	0.0070
	2	104	0.3925	0.2615	0.1354	0.0084
	3	99	0.3452	0.3286	0.0270	0.0163
	Average	136	0.3554	0.2931	0.0665	0.0105
AR-10-8222	1	2665	0.1717	0.2923	0.0001	0.0018
	2	2831	0.1988	0.2851	0.0000	0.0020
	3	1533	0.1711	0.3183	0.0001	0.0035
	Average	2343	0.1805	0.2986	0.0001	0.0025

Table 20. Static Creep Test Results for MA-00 Mixtures

Mixture Designation	Specimen	FT	Regression Coefficients			
			W	X	Y	Z
MA-00-5828	1	138	0.8783	0.2696	0.2541	0.0072
	2	67	0.7288	0.2833	0.2151	0.0140
	3	156	0.6621	0.2465	1.2194	0.0031
	Average	120	0.7564	0.2665	0.5629	0.0081
MA-00-7028	1	Specimen Not Available				
	2	Specimen Not Available				
	3	Specimen Not Available				
MA-00-7628	1	Specimen Not Available				
	2	Specimen Not Available				
	3	Specimen Not Available				
MA-00-6422	1	Specimen Not Available				
	2	37	0.6707	0.2769	0.0782	0.0324
	3	Specimen Not Available				
	Average	37	0.6707	0.2769	0.0782	0.0324
MA-00-7622	1	292	0.2924	0.3232	0.0001	0.0185
	2	363	0.4424	0.2367	0.0024	0.0077
	3	166	0.6043	0.2426	0.1028	0.0068
	Average	274	0.4463	0.2675	0.0351	0.0110
MA-00-8222	1	1051	0.2045	0.3108	0.0001	0.0050
	2	2492	0.2065	0.2652	0.0000	0.0027
	3	1479	0.1753	0.3126	0.0001	0.0036
	Average	1674	0.1955	0.2962	0.0000	0.0038

Table 21. Static Creep Test Results for MS-07 Mixtures

Mixture Designation	Specimen	FT	Regression Coefficients			
			W	X	Y	Z
MS-07-5828	1	36	0.8539	0.2696	0.6775	0.0168
	2	45	0.9657	0.4002	0.1792	0.0285
	3	39	0.8207	0.3092	1.3495	0.0127
	Average	40	0.8801	0.3263	0.7354	0.0193
MS-07-7028	1	144	0.6578	0.2476	0.2442	0.0060
	2	109	0.7192	0.2589	0.1318	0.0100
	3	128	0.6830	0.2713	0.0584	0.0113
	Average	127	0.6867	0.2593	0.1448	0.0091
MS-07-7628	1	327	0.9889	0.2031	0.0138	0.0065
	2	287	0.9606	0.1991	0.0217	0.0064
	3	435	0.7542	0.2067	0.0035	0.0064
	Average	350	0.9012	0.2029	0.0130	0.0064
MS-07-6422	1	14	0.7649	0.3587	0.5114	0.0467
	2	18	0.5570	0.3582	0.0755	0.0660
	3	20	0.5536	0.3962	0.0165	0.0974
	Average	17	0.6252	0.3711	0.2011	0.0701
MS-07-7622	1	237	0.4045	0.3079	0.0149	0.0085
	2	245	0.4321	0.2844	0.0245	0.0072
	3	128	0.6227	0.2826	0.0511	0.0116
	Average	203	0.4864	0.2916	0.0301	0.0091
MS-07-8222	1	866	0.3737	0.2707	0.0012	0.0036
	2	765	0.3522	0.2640	0.0144	0.0026
	3	639	0.4598	0.2496	0.0121	0.0035
	Average	757	0.3952	0.2615	0.0092	0.0032

Table 22. Static Creep Test Results for MS-15 Mixtures

Mixture Designation	Specimen	FT	Regression Coefficients			
			W	X	Y	Z
MS-15-5828	1	23	0.7267	0.3797	0.4958	0.0317
	2	37	0.7350	0.5901	6.5494	-0.0182
	3	37	0.7484	0.6772	17.0865	-0.0109
	Average	32	0.7367	0.5490	8.0439	0.0009
MS-15-7028	1	190	0.4158	0.3090	0.0192	0.0099
	2	173	0.6852	0.2206	0.1574	0.0055
	3	166	0.4610	0.3092	0.0140	0.0125
	Average	176	0.5207	0.2796	0.0635	0.0093
MS-15-7628	1	259	0.7152	0.2591	0.0004	0.0171
	2	533	0.4360	0.2605	0.0002	0.0086
	3	Specimen Not Available				
	Average	396	0.5756	0.2598	0.0003	0.0128
MS-15-6422	1	11	0.5615	0.4579	0.0505	0.1244
	2	11	0.5885	0.3848	0.6993	0.0477
	3	13	0.7598	0.5358	0.0346	0.1406
	Average	12	0.6366	0.4595	0.2615	0.1042
MS-15-7622	1	169	0.4504	0.2821	0.0366	0.0092
	2	131	0.3945	0.3269	0.0100	0.0168
	3	126	0.3347	0.3372	0.0222	0.0138
	Average	142	0.3932	0.3154	0.0230	0.0133
MS-15-8222	1	1146	0.1251	0.3898	0.0001	0.0043
	2	1079	0.2454	0.3108	0.0001	0.0050
	3	3197	0.1868	0.2705	0.0001	0.0017
	Average	1807	0.1858	0.3237	0.0001	0.0037

Table 23. Static Creep Test Results for NJ-00 Mixtures

Mixture Designation	Specimen	FT	Regression Coefficients			
			W	X	Y	Z
NJ-00-5828	1	23	0.9350	0.1471	0.7165	0.0181
	2	52	0.6265	0.2260	0.0213	0.0310
	3	55	0.5619	0.2586	0.0034	0.0472
	Average	43	0.7078	0.2106	0.2471	0.0321
NJ-00-7028	1	505	0.5658	0.2037	0.0071	0.0044
	2	391	0.4732	0.2508	0.0013	0.0085
	3	Specimen Not Available				
	Average	448	0.5195	0.2272	0.0042	0.0064
NJ-00-7628	1	2483	0.6554	0.0956	0.0502	0.0004
	2	Specimen Not Available				
	3	1955	0.2060	0.2820	0.0000	0.0031
	Average	2219	0.4307	0.1888	0.0251	0.0017
NJ-00-6422	1	35	0.4916	0.2570	0.0789	0.0296
	2	104	0.4492	0.2333	0.8503	0.0041
	3	38	0.5214	0.1619	2.0296	0.0059
	Average	59	0.4874	0.2174	0.9862	0.0132
NJ-00-7622	1	Specimen Not Available				
	2	193	0.6124	0.2738	0.0171	0.0105
	3	231	0.6091	0.2725	0.0026	0.0134
	Average	212	0.6108	0.2731	0.0098	0.0119
NJ-00-8222	1	1361	0.3069	0.2686	0.0001	0.0038
	2	872	0.5240	0.2214	0.0019	0.0036
	3	1308	0.6399	0.1869	0.0009	0.0027
	Average	1180	0.4902	0.2256	0.0010	0.0034

Table 24. Static Creep Test Results for NJ-15 Mixtures

Mixture Designation	Specimen	T	Regression Coefficients			
			W	X	Y	Z
NJ-15-5828	1	17	0.5875	0.4378	0.0002	0.2809
	2	Specimen Not Available				
	3	21	0.8717	0.3742	0.0012	0.1734
	Average	19	0.7296	0.4060	0.0007	0.2271
NJ-15-7028	1	122	0.5466	0.2007	0.3486	0.0050
	2	87	0.7273	0.1880	0.3983	0.0069
	3	73	0.4967	0.3404	0.0084	0.0320
	Average	94	0.5902	0.2430	0.2518	0.0146
NJ-15-7628	1	1078	0.7962	0.1450	0.0009	0.0030
	2	662	0.2494	0.2985	0.0004	0.0061
	3	466	0.6463	0.1704	0.0157	0.0037
	Average	735	0.5639	0.2046	0.0057	0.0043
NJ-15-6422	1	14	0.5386	0.3905	0.1269	0.0746
	2	83	0.4509	0.3618	0.1011	0.0147
	3	32	0.5777	0.6656	5.5133	-0.0211
	Average	43	0.5224	0.4726	1.9138	0.0227
NJ-15-7622	1	Specimen Not Available				
	2	168	0.4708	0.2879	0.0039	0.0159
	3	95	0.6272	0.3222	0.0084	0.0258
	Average	132	0.5490	0.3050	0.0061	0.0209
NJ-15-8222	1	1418	0.2889	0.2607	0.0000	0.0046
	2	1073	0.2475	0.2855	0.0000	0.0063
	3	614	0.3497	0.2815	0.0010	0.0057
	Average	1035	0.2954	0.2759	0.0004	0.0055

Table 25. Average FT Test Results Summary

Mixture Designation	Binder Grade					
	58-28	70-28	76-28	64-22	76-22	82-22
AR-10-5828	44	326	511	26	136	2343
MA-00-5828	120	---	---	37	274	1674
MS-07-5828	40	127	350	17	203	757
MS-15-5828	32	176	396	12	142	1807
NJ-00-5828	43	448	2219	59	212	1180
NJ-15-5828	19	94	735	43	132	1035

Table 26. Mixture Rankings by Largest FT

Mixture Rank	Binder Grade					
	PG 58-28	PG 70-28	PG 76-28	PG 64-22	PG 76-22	PG 82-22
1	MA-00-5828	NJ-00-7028	NJ-00-7628	NJ-00-6422	MA-00-7622	AR-10-8222
2	AR-10-5828	AR-10-7028	NJ-15-7628	NJ-15-6422	NJ-00-7622	MS-15-8222
3	NJ-00-5828	MS-15-7028	AR-10-7628	MA-00-6422	MS-07-7622	MA-00-8222
4	MS-07-5828	MS-07-7028	MS-15-7628	AR-10-6422	MS-15-7622	NJ-00-8222
5	MS-15-5828	NJ-15-7028	MS-07-7628	MS-07-6422	AR-10-7622	NJ-15-8222
6	NJ-15-5828	MA-00-7028*	MA-00-7628*	MS-15-6422	NJ-15-7622	MS-07-8222

* Not tested

4.3 INDIRECT TENSILE STRENGTH TEST RESULTS.

IDT strength test results for all specimens are presented in table 27. The average IDT values for each mixture along with the requirements for light- and heavy-duty pavements as recommended by Advanced Asphalt Technologies [4] are given in table 28. Although each mixture was designed for airfield pavements classified as being heavy duty, the IDT strength test results show all mixtures failed to meet the FAA requirements. The number of mixtures passing or failing the light-duty requirements was inconsistent. For example, four of six mixtures met the light-duty requirements for a PG 58-28 binder, but no mixture met the requirements for a PG 70-28 or 76-28 binder. Five of six mixtures met light-duty requirements for a PG 64-22 binder, two of six for the PG 76-22 binder, and three of six for the PG 82-22 binder.

The mixture rankings according to IDT strength test results (table 29) were inconsistent among binder PG grades. The MS-07- mixture and the MA-00- mixture ranked as the best two performing mixtures for all binder grades other than the PG 76-22. The remaining mixtures had no consistent ranking. The MS-15- mixture ranked last for three of six binders. Others did not clearly differentiate themselves.

The difference in average IDT values for the mixtures prepared with a given binder ranged from 35 to 74 kPa for all mixtures except the PG 82-22. The difference between the highest and lowest average test value for this binder was 158 kPa. Most test values were similar, indicating that the mixture performance was similar for these materials.

Table 27. The IDT Strength Test Results (kPa)

Mixture Designation		Binder					
		58-28	70-28	76-28	64-22	76-22	82-22
AR-10-	1	209.0	368.8	382.5	311.4	535.6	785.2
	2	207.2	369.3	335.6	315.7	534.5	763.1
	3	178.2	399.5	344.0	315.9	577.0	727.2
	Average	198.1	379.2	354.0	314.3	549.0	758.5
MA-00-	1	206.9	385.4	413.4	362.4	527.8	783.3
	2	219.9	385.6	393.8	355.1	497.6	780.5
	3	215.8	393.3	377.0	363.8	531.8	758.2
	Average	214.2	388.1	394.8	360.5	519.1	774.0
MS-07-	1	209.2	389.2	413.4	366.1	534.7	790.6
	2	222.1	390.4	393.8	358.4	501.6	790.2
	3	218.1	396.2	377.0	367.9	536.2	766.7
	Average	216.5	391.9	394.8	364.1	524.2	782.5
MS-15-	1	164.9	373.0	339.4	296.9	554.8	680.9
	2	187.1	375.4	332.4	292.2	577.3	636.6
	3	172.7	383.8	324.0	283.0	522.7	680.4
	Average	174.9	377.4	331.9	290.7	551.6	666.0
NJ-00-	1	214.6	367.0	333.6	314.1	557.1	640.8
	2	214.2	355.8	394.1	312.9	541.9	599.3
	3	199.8	351.9	423.4	309.0	514.0	632.8
	Average	209.5	358.2	383.7	312.0	537.6	624.3
NJ-15-	1	207.4	366.1	396.7	318.6	576.7	726.5
	2	210.0	346.0	384.9	310.7	553.7	706.9
	3	205.5	359.0	391.2	321.3	576.7	692.8
	Average	207.6	357.0	390.9	316.9	569.1	708.8

Table 28. The IDT Strength Test Results Summary

Mixture Designation	Binder Grade					
	58-28	70-28	76-28	64-22	76-22	82-22
AR-10-	198	379	354	314	549	759
MA-00-	214	388	395	361	519	774
MS-07-	217	392	395	364	524	783
MS-15-	175	377	332	291	552	666
NJ-00-	210	359	383	312	538	624
NJ-15-	208	357	391	317	569	709
Light-duty requirement	207	414	552	310	552	758
Heavy-duty requirement	276	552	758	414	758	965

Table 29. Mixture Ranking by Largest IDT Strength

Mixture Rank	Binder Grade					
	PG 58-28	PG 70-28	PG 76-28	PG 64-22	PG 76-22	PG 82-22
1	MS-07-5828	MS-07-7028	MS-07-7628	MS-07-6422	NJ-15-7622	MS-07-8222
2	MA-00-5828	MA-00-7028	MA-00-7628	MA-00-6422	MS-15-7622	MA-00-8222
3	NJ-00-5828	AR-10-7028	NJ-15-7628	NJ-15-6422	AR-10-7622	AR-10-8222
4	NJ-15-5828	MS-15-7028	NJ-00-7628	AR-10-6422	NJ-00-7622	NJ-15-8222
5	AR-10-5828	NJ-00-7028	AR-10-7628	NJ-00-6422	MS-07-7622	MS-15-8222
6	MS-15-5828	NJ-15-7028	MS-15-7628	MS-15-6422	MA-00-7622	NJ-00-8222

4.4 THE APA TEST RESULTS.

The APA records the average rut depth of the two specimens with each load cycle into a Microsoft® Excel® spreadsheet. Data from the spreadsheet were used to determine one of two values. The rut depth after 4000 APA cycles was extracted to determine if the mixture met the requirement of less than 10-mm rutting as recommended by Rushing et al. [14] for airfield pavements. These data are given in table 30. Some mixtures experienced failure before 4000 cycles. To account for these cases, the number of APA cycles resulting in 10-mm rutting was also extracted from the spreadsheet. These data are given in table 31.

The APA test temperatures were adjusted for the different binders such that the performance of the PG XX-28 binders and the PG XX-22 binders were expected to be similar. In general, this expectation was met. It was a surprising result that many mixtures failed to meet the requirement of less than 10-mm rutting after 4000 APA cycles. Only one mixture (MA-00-) met this requirement for the PG 58-28 binder, while three mixtures met this requirement for the PG 64-22 binder (MA-00-, NJ-00-, and NJ-15-). Only one mixture (AR-10-7028) failed to meet the APA requirement when prepared using a polymer-modified binder. The benefits of using a higher PG binder were clearly noted. In all cases, the performance was better for mixtures with three grade bumps compared to mixtures with two grade bumps.

The mixture rankings (table 32) according to the APA results were fairly consistent. In four of six cases, the MA-00-, NJ-00-, and NJ-15- mixtures performed better than the AR-10-, MS-07-, and MS-15 mixtures.

Table 30. Rut Depth After 4000 APA Cycles (mm)

Mixture Designation		Binder					
		58-28	70-28	76-28	64-22	76-22	82-22
AR-10-	1	>10	11.5	3.1	>10	6.7	2.7
	2	>10	8.1	4.1	>10	5.0	2.2
	3	>10	10.8	3.7	>10	7.3	3.3
	Average	>10	10.1	3.6	>10	6.3	2.7
MA-00-	1	7.5	4.9	2.2	4.4	4.5	1.5
	2	10.1	4.5	2.6	5.1	4.3	3.0
	3	7.6	5.8	1.9	4.3	4.3	2.1
	Average	8.4	5.1	2.2	4.6	4.3	2.2
MS-07-	1	>10	5.2	3.6	>10	5.2	3.2
	2	>10	5.6	3.8	>10	3.7	2.9
	3	>10	7.3	3.5	>10	5.0	3.3
	Average	>10	6.0	3.6	>10	4.7	3.1
MS-15-	1	>10	7.4	3.5	>10	5.5	3.5
	2	>10	4.3	3.9	>10	5.9	4.0
	3	>10	5.8	3.7	>10	5.4	3.3
	Average	>10	5.8	3.7	>10	5.6	3.6
NJ-00-	1	>10	6.4	1.6	4.7	4.4	3.2
	2	>10	4.5	2.1	2.4	5.3	3.2
	3	>10	4.6	1.4	1.7	4.1	2.4
	Average	>10	5.2	1.7	3.0	4.6	2.9
NJ-15-	1	9.9	2.1	2.1	8.6	4.8	3.4
	2	>10	3.3	3.0	7.2	5.9	4.0
	3	>10	2.3	2.6	8.9	7.3	3.2
	Average	>10	2.6	2.6	8.2	6.0	3.5

Table 31. The APA Cycles to 10-mm Rut Depth

Mixture Designation		Binder					
		58-28	70-28	76-28	64-22	76-22	82-22
AR-10-	1	1436	3066	>8000	1975	6696	>8000
	2	1650	6814	>8000	1879	>8000	>8000
	3	2180	3187	>8000	1684	7099	>8000
	Average	1755	4356	>8000	1846	7265	>8000
MA-00-	1	6698	>8000	>8000	>8000	>8000	>8000
	2	3976	>8000	>8000	>8000	>8000	>8000
	3	6845	>8000	>8000	>8000	>8000	>8000
	Average	5840	>8000	>8000	>8000	>8000	>8000
MS-07-	1	1920	>8000	>8000	1882	>8000	>8000
	2	2442	>8000	>8000	2351	>8000	>8000
	3	2858	>8000	>8000	3073	>8000	>8000
	Average	2407	>8000	>8000	2435	>8000	>8000
MS-15-	1	2986	>8000	>8000	1168	>8000	>8000
	2	3110	>8000	>8000	1600	>8000	>8000
	3	3079	>8000	>8000	1457	>8000	>8000
	Average	3058	>8000	>8000	1408	>8000	>8000
NJ-00-	1	2939	>8000	>8000	>8000	>8000	>8000
	2	2886	>8000	>8000	>8000	>8000	>8000
	3	2973	>8000	>8000	>8000	>8000	>8000
	Average	2933	>8000	>8000	>8000	>8000	>8000
NJ-15-	1	4023	>8000	>8000	1168	>8000	>8000
	2	3554	>8000	>8000	1600	>8000	>8000
	3	2725	>8000	>8000	1457	>8000	>8000
	Average	3434	>8000	>8000	1408	>8000	>8000

Table 32. Mixture Ranking by Smallest APA Rut Depth

Mixture Rank	Binder Grade					
	PG 58-28	PG 70-28	PG 76-28	PG 64-22	PG 76-22	PG 82-22
1	MA-00-5828	NJ-15-7028	NJ-00-7628	NJ-00-6422	MA-00-7622	MA-00-8222
2	NJ-15-5828	MA-00-7028	MA-00-7628	MA-00-6422	NJ-00-7622	AR-10-8222
3	NJ-00-5828	NJ-00-7028	NJ-15-7628	NJ-15-6422	MS-07-7622	NJ-00-8222
4	AR-10-5828	MS-15-7028	AR-10-7628	MS-07-6422	MS-15-7622	MS-07-8222
5	MS-15-5828	MS-07-7028	MS-07-7628	AR-10-6422	NJ-15-7622	NJ-15-8222
6	MS-07-5828	AR-10-7028	MS-15-7628	MS-15-6422	AR-10-7622	MS-15-8222

4.5 STATISTICAL CONSIDERATIONS.

Analyses were performed to evaluate the ability of each test method to differentiate mixture performance based on either the mixture composition or the binder type considering statistical significance. All analyses were performed using SigmaStat® software at a 95% confidence level. The analysis of variance (ANOVA) procedure, including the Tukey test for all pairwise comparison, was used to evaluate data sets. The test values included in the analyses were the IDT strength, APA rut depth after 4000 cycles, FN, and FT. The fact that only three replicates were available likely influenced the results of the statistical analyses. However, the intent was to gain a broad perspective on the effectiveness of each test and not to draw definitive conclusions about any particular mixture or comparison.

Table 33 provides results from the statistical analyses comparing FN results for all mixtures. Results from the FN comparisons indicated three different comparisons resulted in significant differences for at least three binder types. The NJ-00- mixture was different from the AR-10-, MS-07-, and MS-15- mixtures in these cases. Nine other comparisons resulted in significant differences for one or two binder types. Overall, 21 of 85 possible combinations resulted in significant differences among mixture types.

Table 33. Statistical Analysis of Repeated Load Data by Mixture Type

	AR-10-	MA-00-	MS-07-	MS-15-	NJ-00-	NJ-10-
AR-10-	---	---	---	---	---	---
MA-00-	64-22 76-22	---	---	---	---	---
MS-07-	---	76-22	---	---	---	---
MS-15-	76-22	64-22	---	---	---	---
NJ-00-	58-28 76-28 76-22	58-28	58-28 76-28 76-22	58-28 70-28 76-28 64-22	---	---
NJ-15-	58-28	---	58-28	58-28	76-28 76-22	---

Table 34 provides results from the statistical analyses comparing FT results for all mixtures. Results from the FT comparisons indicated there were no comparisons that resulted in significant differences for at least three binder types. Nine comparisons resulted in significant differences for one or two binder types. Overall, 11 of 80 possible combinations resulted in significant differences between mixture types.

Table 34. Statistical Analysis of Static Creep Data by Mixture Type

	AR-10-	MA-00-	MS-07-	MS-15-	NJ-00-	NJ-10-
AR-10-	---	---	---	---	---	---
MA-00-	58-28	---	---	---	---	---
MS-07-	---	58-28	---	---	---	---
MS-15-	---	58-28	---	---	---	---
NJ-00-	76-28	58-28	70-28 76-28	76-28	---	---
NJ-15-	---	58-28	---	---	70-28 76-28	---

Table 35 provides results from the statistical analyses comparing IDT results for all mixtures. Cells list the binder types for which a significant difference was determined for a particular mixture comparison. Tests with three of the six binders indicated significant differences between the MS-15- mixture and the MS-07- mixture. Ten other comparisons resulted in significant differences for one or two binder types. Overall, 18 of 90 possible combinations resulted in significant differences between mixture types. Actual field performance is unknown, but some differences are expected given the different aggregate types.

Table 35. Statistical Analysis of IDT Data by Mixture Type

	AR-10-	MA-00-	MS-07-	MS-15-	NJ-00-	NJ-10-
AR-10-	---	---	---	---	---	---
MA-00-	---	---	---	---	---	---
MS-07-	---	---	---	---	---	---
MS-15-	82-22	82-22 58-28	64-22 82-22 58-28	---	---	---
NJ-00-	82-22	82-22 70-28	82-22 70-28	58-28	---	---
NJ-15-	---	82-22 70-28	82-22 70-28	58-28	82-22	---

Table 36 provides results from the statistical analyses comparing APA results for all mixtures. Results from the APA comparisons indicated six different comparisons resulted in significant differences for at least three binder types. Seven other comparisons resulted in significant differences for one or two binder types. Overall, 32 of 90 possible combinations resulted in significant differences between mixture types.

Table 36. Statistical Analysis of APA Data by Mixture Type

	AR-10-	MA-00-	MS-07-	MS-15-	NJ-00-	NJ-10-
AR-10-	---	---	---	---	--	---
MA-00-	70-28 58-28 76-28 64-22	---	---	---	---	---
MS-07-	70-28	58-28 76-28 64-22	---	---	---	---
MS-15-	70-28	58-28 76-28 64-22 82-22	---	---	---	---
NJ-00-	70-28 76-28 64-22	58-28	76-28 64-22	76-28 64-22	---	---
NJ-15-	70-28 76-28 64-22	58-28 64-22	70-28 76-28 64-22	76-28 64-22	64-22	---

Next, the ANOVA procedure was performed on each mixture to evaluate the ability of each test method to differentiate mixture performance based on binder grade. The test values included in the analyses were the IDT strength, APA rut depth after 4000 cycles, FN, and FT. Tables 37 through 40 provide results from the statistical analyses. Cells list the mixtures for which a significant difference was determined when comparing results among binder grades. Increasing the high temperature grade for a given binder was expected to result in enhanced performance. The higher costs of using polymer-modified binders are often justified by the greater rutting performance they offer. For all tests except the IDT strength tests, the test temperature was adjusted in such a way that performance was expected to be similar for mixtures produced with neat binders and their counterparts with two or three grade bumps.

Table 37 gives the results from the statistical analysis for the repeated load test. The test temperatures were adjusted in a manner that should have resulted in similar performance between the mixtures prepared with the PG 58-28 and PG 64-22 binders as well as their modified counterparts. There were 60 comparisons resulting in significant differences among binder types for the 68 comparisons where difference would be expected. Thirteen of seventeen comparisons did not find statistical difference for comparisons where no differences were expected. The four comparisons showing these differences were all for mixtures prepared with the highest PG binder grades where permanent deformation was very small. Overall, the repeated load test performed well in differentiating performance among binder grades.

Table 37. Statistical Analysis of Repeated Load Data by Binder Grade

	58-28	70-28	76-28	64-22	76-22	82-22
58-28	---	---	---	---	---	---
70-28	MA-00 MS-07 MS-15 NJ-00	---	---	---	---	---
76-28	AR-10 MS-07 MS-15 NJ-00 NJ-15	AR-10 MS-07 MS-15 NJ-00 NJ-15	---	---	---	---
64-22	---	MA-00 MS-07 MS-15 NJ-00	AR-10 MS-07 MS-15 NJ-00 NJ-15	---	---	---
76-22	MA-00 MS-07 MS-15 NJ-00	---	AR-10 MS-07 MS-15 NJ-00 NJ-15	MA-00 MS-07 MS-15 NJ-00	---	---
82-22	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MS-07 MS-15 NJ-15	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	---

Table 38 gives the results from the statistical analysis for the static creep test. The test temperatures were adjusted in a manner that should have resulted in similar performances between the mixtures prepared with the PG 58-28 and PG 64-22 binders as well as their modified counterparts. There were 29 comparisons resulting in significant differences among binder types for the 64 comparisons where differences would be expected. Most comparisons that resulted in significant difference were for the PG 82-22 binder. Thirteen of sixteen comparisons did not find statistical difference for comparisons where no differences were expected. Overall, the static creep test did not do a very good job of differentiating performance among binder grades. The variability of the test results seemed to mask differences during the statistical analysis.

Table 38. Statistical Analysis of Static Creep Data by Binder Grade

	58-28	70-28	76-28	64-22	76-22	82-22
58-28	---	---	---	---	---	---
70-28	---	---	---	---	---	---
76-28	MS-07	MS-07	---	---	---	---
64-22	---	---	MS-07 NJ-00	---	---	---
76-22	---	---	NJ-00	MS-07	---	---
82-22	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MS-07 MS-15 NJ-00 NJ-15	AR-10 MS-07 NJ-00	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	---

Table 39 gives the results from the statistical analysis for the IDT test. Since all testing was performed at the same temperature, differences were expected for each binder grade with the exception of the comparisons between the PG 76-28 and PG 76-22. It was assumed these two mixtures would have similar rutting performance since they were expected to have similar viscosities at high temperature. For 12 of 15 comparisons, a significant difference was observed in IDT results for all 6 mixtures. When comparing the mixtures prepared with the PG 76-28 binder to those with the PG 70-28 or PG 64-22 binder, only the NJ-15- mixture had significantly different performance. This result was surprising since the PG 76-28 would be expected to outperform the binders with a lower PG grade. The PG 76-28 binder was from a different source than the other binders. The chemical composition may have influenced the results even though the PG grade indicated a high level of modification. Overall, the IDT strength test performed well in differentiating performance among binder grades.

Table 39. Statistical Analysis of IDT Data by Binder Grade

	58-28	70-28	76-28	64-22	76-22	82-22
58-28	---	---	---	---	---	---
70-28	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	---	---	---	---	---
76-28	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	NJ-15	---	---	---	---
64-22	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MS-15 NJ-00 NJ-15	NJ-15	---	---	---
76-22	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	---	---
82-22	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	AR-10 MA-00 MS-07 MS-15 NJ-00 NJ-15	---

Table 40 gives the results from the statistical analysis for the APA test. The test temperatures were adjusted in a manner that should have resulted in similar performance between the mixtures prepared with the PG 58-28 and PG 64-22 binders as well as their modified counterparts. There were 56 comparisons resulting in significant differences among binder types for the 72 comparisons where differences were expected. Fourteen of eighteen comparisons did not find statistical difference for comparisons where no differences were expected. Overall, the APA test performed well in differentiating performance among binder grades.

Table 40. Statistical Analysis of APA Data by Binder Grade

	58-28	70-28	76-28	64-22	76-22	82-22
58-28	---	---	---	---	---	---
70-28	NJ-00 NJ-15 MS-07 MS-15 MA-00	---	---	---	---	---
76-28	NJ-00 NJ-15 MS-07 MS-15 AR-10 MA-00	NJ-00 MS-07 AR-10 MA-00	---	---	---	---
64-22	NJ-00 MA-00	NJ-15 MS-07 MS-15	NJ-15 MS-07 MS-15 AR-10 MA-00	---	---	---
76-22	NJ-00 NJ-15 MS-07 MS-15 AR-10 MA-00	NJ-15 AR-10	NJ-00 NJ-15 MS-15 AR-10 MA-00	NJ-15 MS-07 MS-15 AR-10	---	---
82-22	NJ-00 NJ-15 MS-07 MS-15 AR-10 MA-00	MS-07 AR-10 MA-00	---	NJ-15 MS-07 MS-15 AR-10 MA-00	NJ-15 MS-15 AR-10 MA-00	---

5. DISCUSSION OF RESULTS.

Ultimately, binder selection should result in acceptable rutting performance depending on the climate and traffic load and volume. Using the recommended performance criteria provided a good metric to compare the results for the different mixture types and binder grades. A summary of these performance criteria is provided in table 41.

Table 41. Recommended Performance Test Acceptance Threshold Values

Repeated Load	Static Creep	Indirect Tensile Strength	APA
Minimum FN of 200	Minimum FT of 30 seconds	Requirements vary by binder grade (see table 10)	Less than 10-mm rutting after 4000 APA cycles using 1113 kN load and 1724 kPa pressure

Table 42 provides a summary of all average test values for each mixture included in this study. The shaded areas in the table indicate a test value that failed to meet the associated performance criterion.

Only two mixtures with unmodified binder passed the FN requirement, while all polymer-modified mixtures met the requirement. The improvement in FN was very evident when modified binders were used. Some mixtures are expected to have adequate performance in moderate loading scenarios when prepared using an unmodified binder. The criterion for FN may be too exclusive to practically screen poor airfield mixtures. New criteria could be tailored to specific aircraft tire pressures or traffic volumes to better identify when polymer modification should be used to improve mixture performance.

Only four mixtures failed to meet the FT requirement. These mixtures contained unmodified binder and were typically the poorest performers among those tested. The test criterion appears acceptable as a mixture screening tool, although the test variability seemed to be greater than the other methods. The FT test clearly identified the improvement in rutting performance when polymer-modified binders are used.

None of the mixtures passed the requirement for heavy-duty mixtures according to the IDT strength test. These results were unexpected since several of the mixtures are expected to give good rutting performance, particularly when polymer-modified binders are used. Only 15 of 36 mixtures passed the IDT requirement for light-duty mixtures. Every mixture tested should be adequate for light-duty airfields. The test requirements are too exclusive to practically screen for mixture rutting performance. The test results were influenced more by the binder grade than by the aggregate type and gradation. This fact limited the ability of the test to rank mixtures. Having acceptance criteria that increases with increasing binder grade does not allow the designer to showcase the improved performance when selecting the binder grade and does not allow adequate justification for the increased cost.

Seven of twelve mixtures with unmodified binder did not pass the APA requirement. Many of these were very close to achieving the specified rutting performance. The MS-07-, MS-15-, and AR-10- mixtures had the poorest performances. These were commonly the poorest performers in each test. These results were in general agreement with data presented by Rushing, Little, and Garg [2]. Increasing the binder grade improved performance of the mixtures to acceptable levels. Overall, the APA provided a reasonable approach for screening mixtures according to rutting performance.

Table 42. Test Results Compared to Criteria

Mix ID	FN ≥ 200	FT ≥ 30 second	IDT Heavy Duty	IDT Light Duty	APA ≤ 10 mm
			Based on PG (see table 10)		
NJ-00-5828	251	43	---	30	10.0
NJ-00-7028	1,135	448	---	52	5.2
NJ-00-7628	10,000	2,219	---	56	1.7
NJ-00-6422	180	59	---	45	3.0
NJ-00-7622	1,086	212	---	78	4.6
NJ-00-8222	10,000	1,180	---	91	2.9
NJ-15-5828	220	19	---	30	9.9
NJ-15-7028	836	94	---	52	2.6
NJ-15-7628	2,239	735	---	57	2.6
NJ-15-6422	136	43	---	46	8.2
NJ-15-7622	702	132	---	83	6.0
NJ-15-8222	10,000	1,035	---	103	3.5
MS-07-5828	98	40	---	23	10.0
MS-07-7028	664	127	---	49	6.0
MS-07-7628	1,424	350	---	57	3.6
MS-07-6422	140	17	---	39	10.0
MS-07-7622	450	203	---	75	4.7
MS-07-8222	10,000	757	---	88	3.1
MS-15-5828	87	32	---	25	10.0
MS-15-7028	568	176	---	55	5.8
MS-15-7628	1,104	396	---	48	3.7
MS-15-6422	88	12	---	42	10.0
MS-15-7622	768	142	---	80	5.6
MS-15-8222	10,000	1,807	---	97	3.6
AR-10-5828	101	44	---	29	10.0
AR-10-7028	639	326	---	55	10.1
AR-10-7628	1,405	511	---	51	3.6
AR-10-6422	115	26	---	46	10.0
AR-10-7622	391	136	---	80	6.3
AR-10-8222	3,212	2,343	---	110	2.7
MA-00-5828	149	120	---	31	8.4
MA-00-7028	804	Not tested	---	56	5.1
MA-00-7628	Not tested	Not tested	---	57	2.2
MA-00-6422	186	37	---	52	4.6
MA-00-7622	850	274	---	75	4.3
MA-00-8222	10,000	1,674	---	112	2.2

Note: Shaded areas in the table indicate test values failing to meet performance criteria.

6. CONCLUSIONS AND RECOMMENDATIONS.

6.1 CONCLUSIONS.

The introduction of a new hot-mix asphalt (HMA) mixture design procedure based solely on volumetric properties and operational changes that allow heavier aircraft with higher tire pressures to operate on given classes of pavements reveals the need to include performance testing during HMA design and construction to ensure adequate rutting performance. Using polymer-modified binders is one means to enhance rutting performance of an asphalt mixture without changing the aggregate sources or proportions. This study quantified the performance enhancement resulting from the use of polymer-modified binders according to four laboratory test methods. The following conclusions were made from this study.

- The test values were improved for all mixtures when comparing specimens prepared with polymer-modified binders to those with unmodified binder according to each test method. Increasing the polymer content (or performance grade) resulted in even greater performance.

- In general, the mixture performance rankings of the different aggregate blends were similar among the repeated load, static creep, and asphalt pavement analyzer (APA) tests. Mixture rankings using indirect tensile (IDT) results were inconsistent among aggregate blends.

- The performance criteria used resulted in some unmodified mixtures failing to meet requirements according to the repeated load, static creep, and APA tests. Almost every polymer-modified mixture met these criteria.

- None of the mixtures met the heavy-duty pavement criteria for IDT results. Some mixtures met the criteria for light-duty pavements.

6.2 RECOMMENDATIONS.

Mixtures prepared using polymer-modified binders exhibited significant improvements in rutting performance according to all four test methods used in this study. Implementing a laboratory performance test that can accompany mixture design and potentially quality assurance testing during construction will aid in ensuring rut-prone mixtures are not placed on Federal Aviation Administration facilities. Based on the results and conclusions from this study, the APA is the test method most suitable for implementation as a companion performance test. The repeated load test is preferred over the static creep test because of reduced variability, but neither test can be performed on field cores because of the required specimen geometry. The IDT strength test could be used to ensure proper binders are selected, but these results showed little ability to differentiate mixture performance based on aggregate structure.

The APA testing parameters and acceptance criteria used in this study are recommended for incorporation into preliminary protocol for airport paving. Mixtures that are prone to rutting can be improved by using polymer-modified binders. Encouraging the use of polymer-modified binders through laboratory test requirements will likely lead to enhanced field performance.

Requirements for field cores may need to be adjusted to compensate for stiffening of the binder that is expected to take place during mixture production. Data should be collected from selected paving projects to further evaluate the applicability of the test methods and criteria during an implementation phase.

7. REFERENCES.

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APPENDIX A—REPEATED LOAD TEST RESULTS

Figures A-1 through A-36 show the repeated load test results for all specimens tested using each mixture type. The mixtures are designated by source origin (Arkansas (AR), Massachusetts (MA), New Jersey (NJ) or Mississippi (MS)), followed by the percentage of natural sand, and the binder grade used in the mixture.

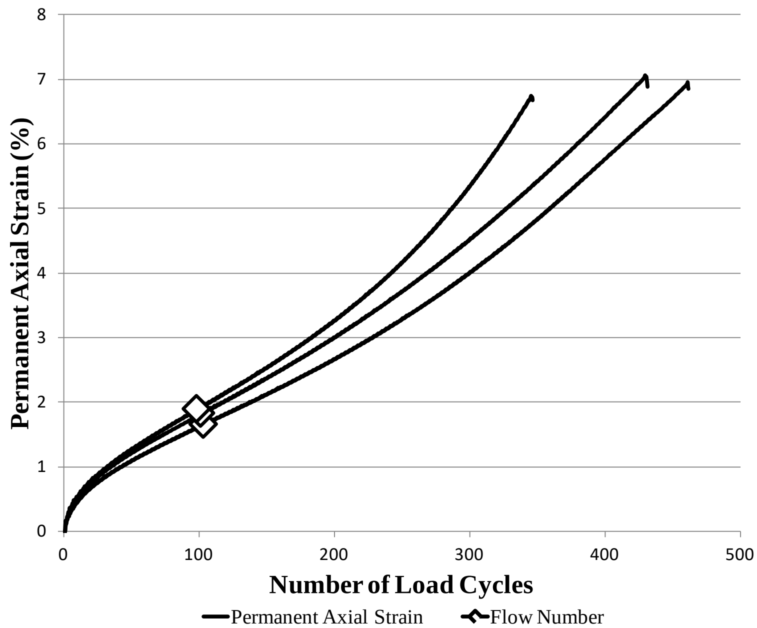

Figure A-1. Mixture AR-10-5828 Repeated Load Test Results

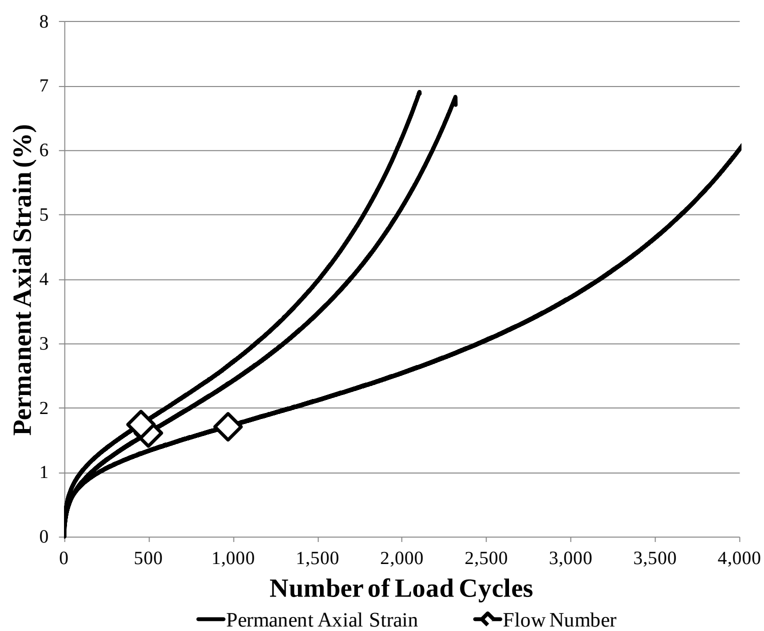

Figure A-2. Mixture AR-10-7028 Repeated Load Test Results

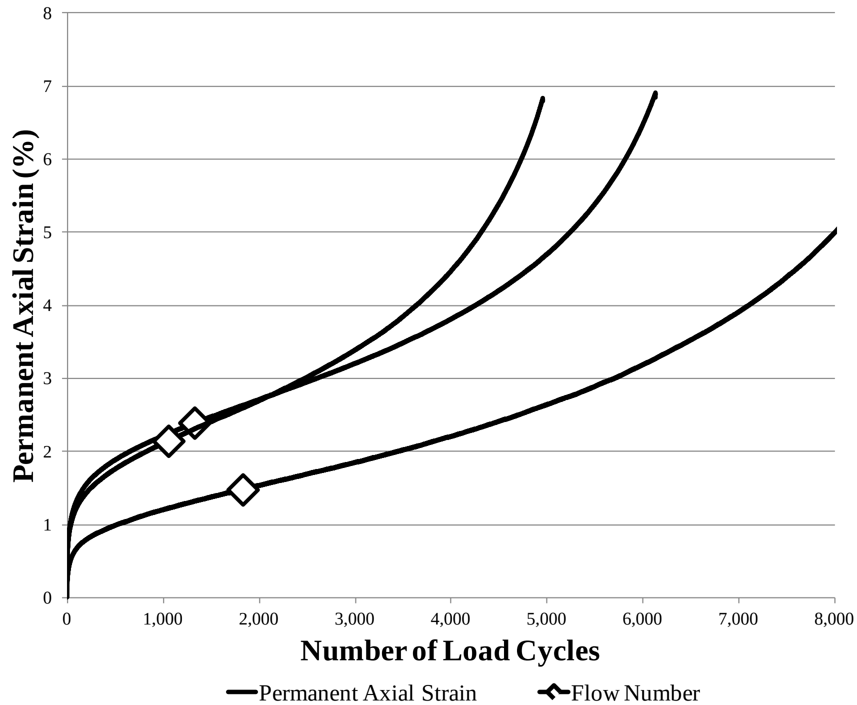

Figure A-3. Mixture AR-10-7628 Repeated Load Test Results

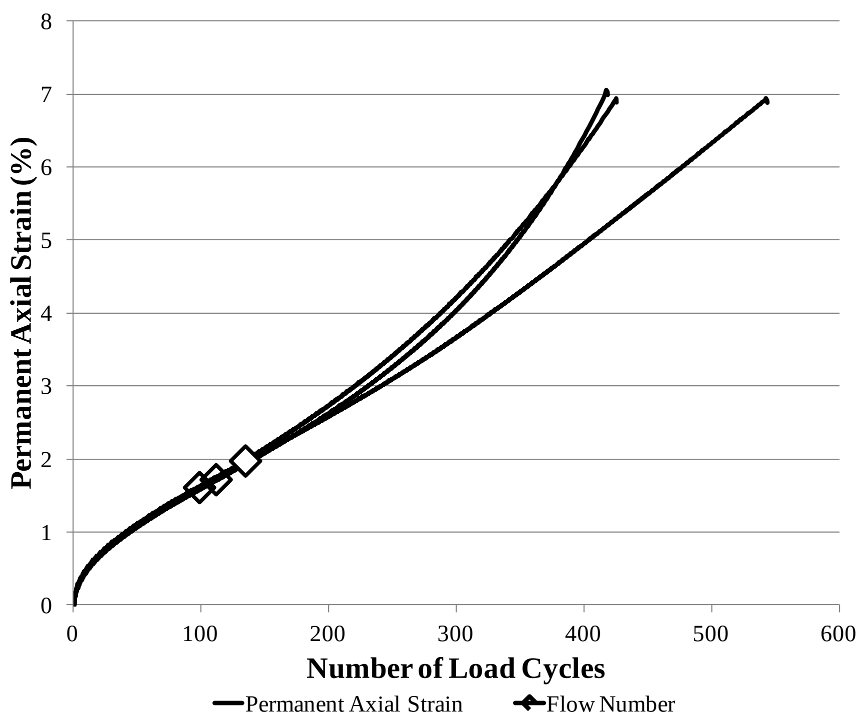

Figure A-4. Mixture AR-10-6422 Repeated Load Test Results

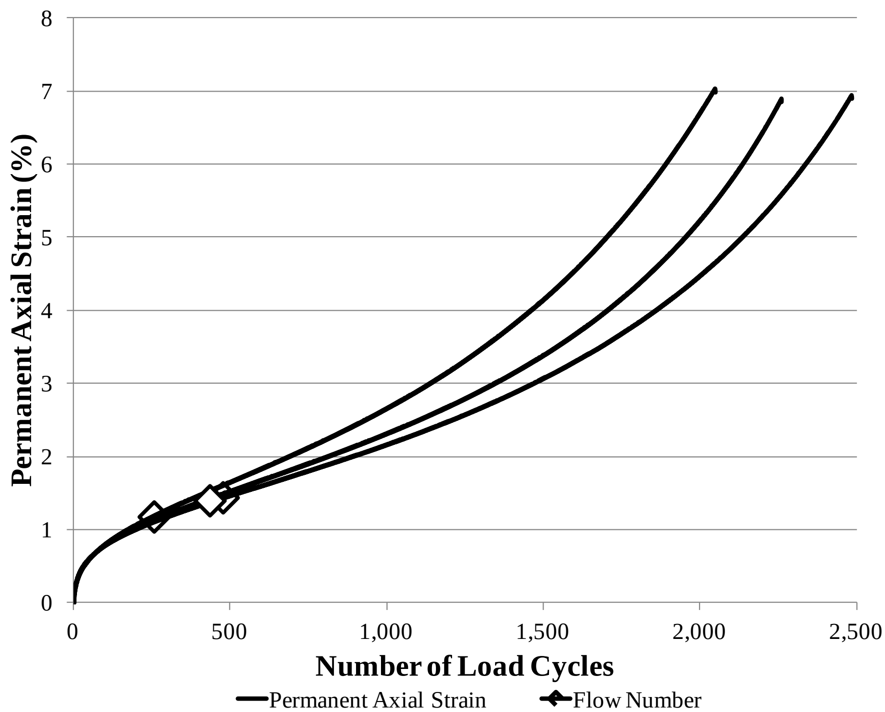

Figure A-5. Mixture AR-10-7622 Repeated Load Test Results

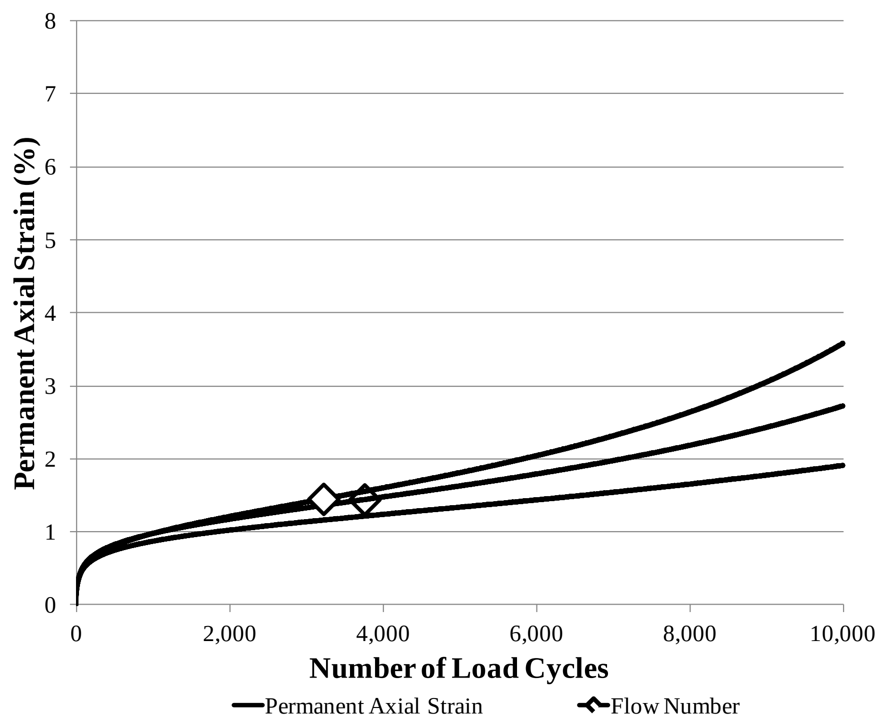

Figure A-6. Mixture AR-10-8222 Repeated Load Test Results

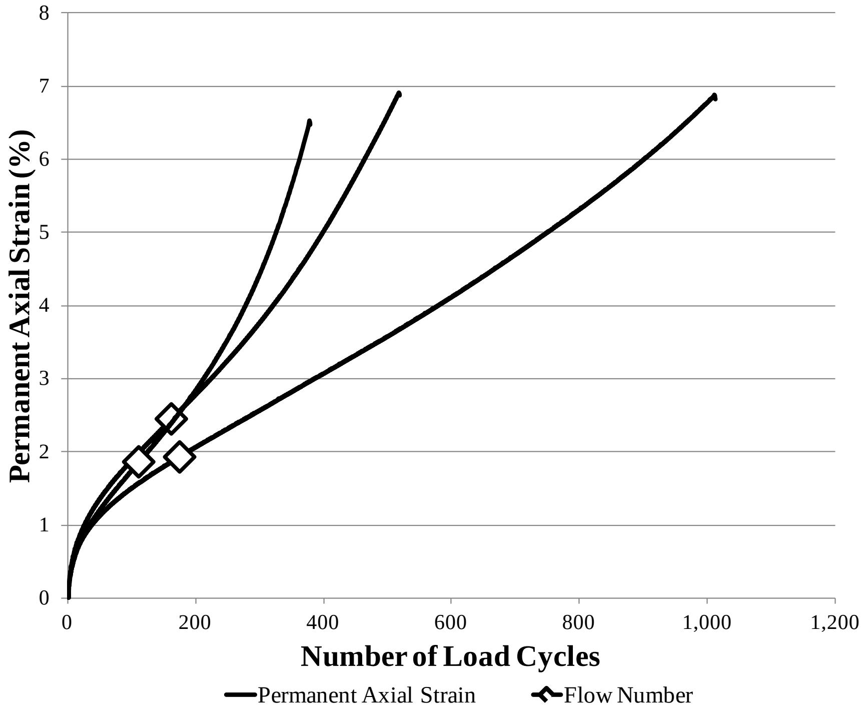

Figure A-7. Mixture MA-00-5828 Repeated Load Test Results

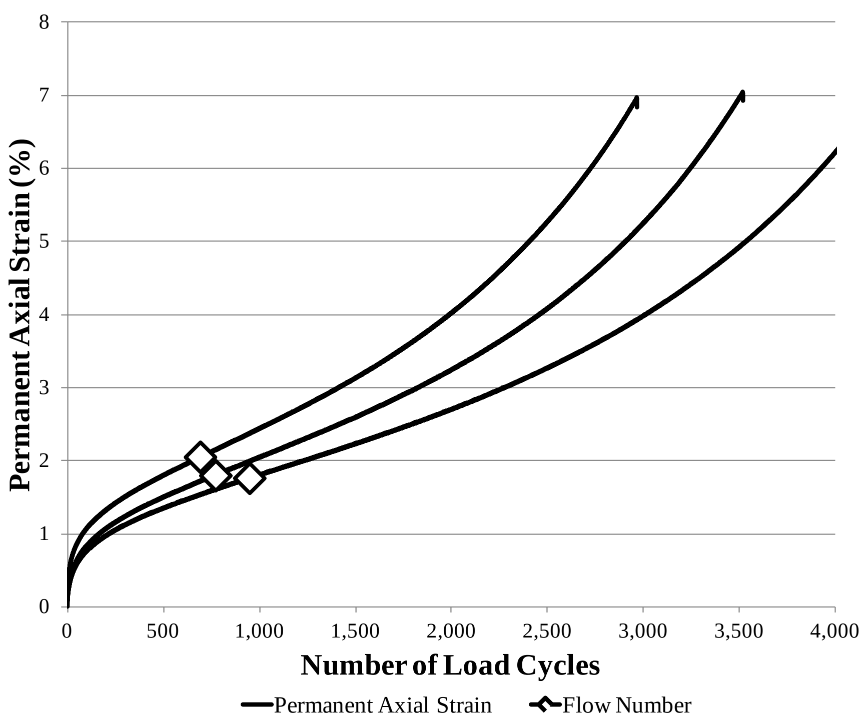

Figure A-8. Mixture MA-00-7028 Repeated Load Test Results

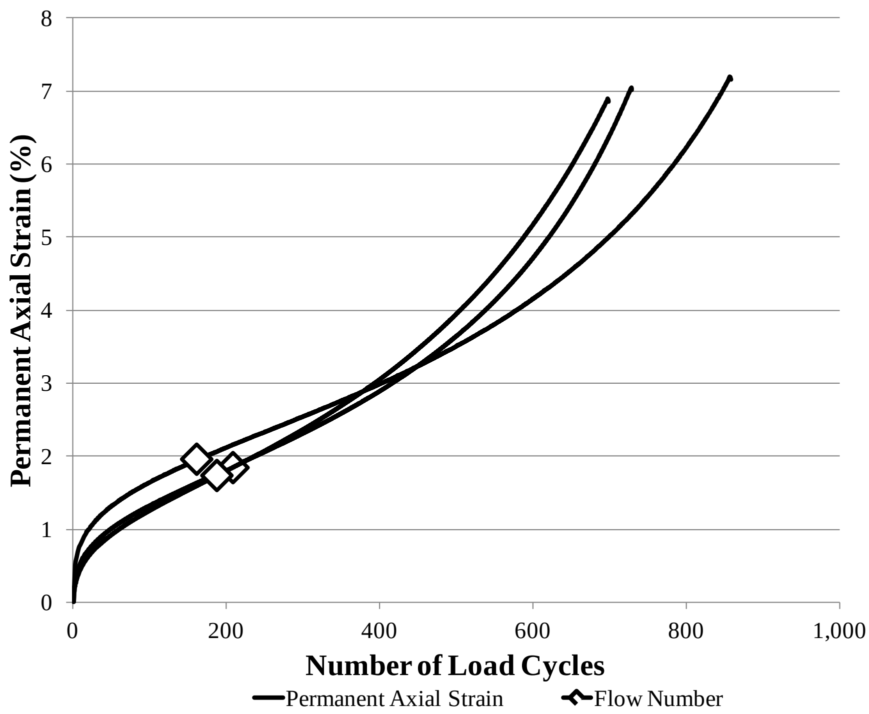

Figure A-9. Mixture MA-00-6422 Repeated Load Test Results

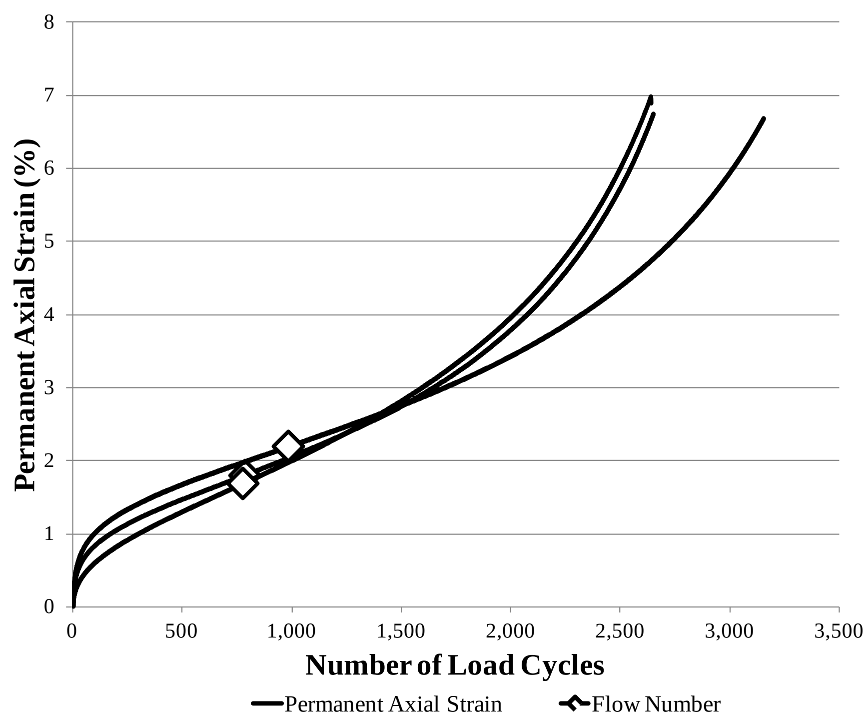

Figure A-10. Mixture MA-00-7622 Repeated Load Test Results

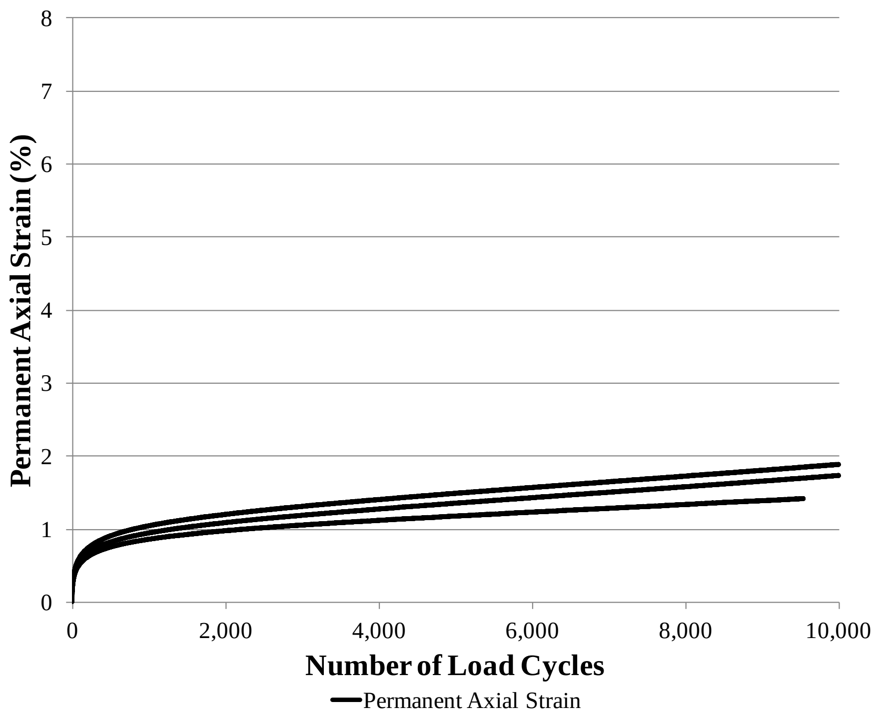

Figure A-11. Mixture MA-00-8222 Repeated Load Test Results

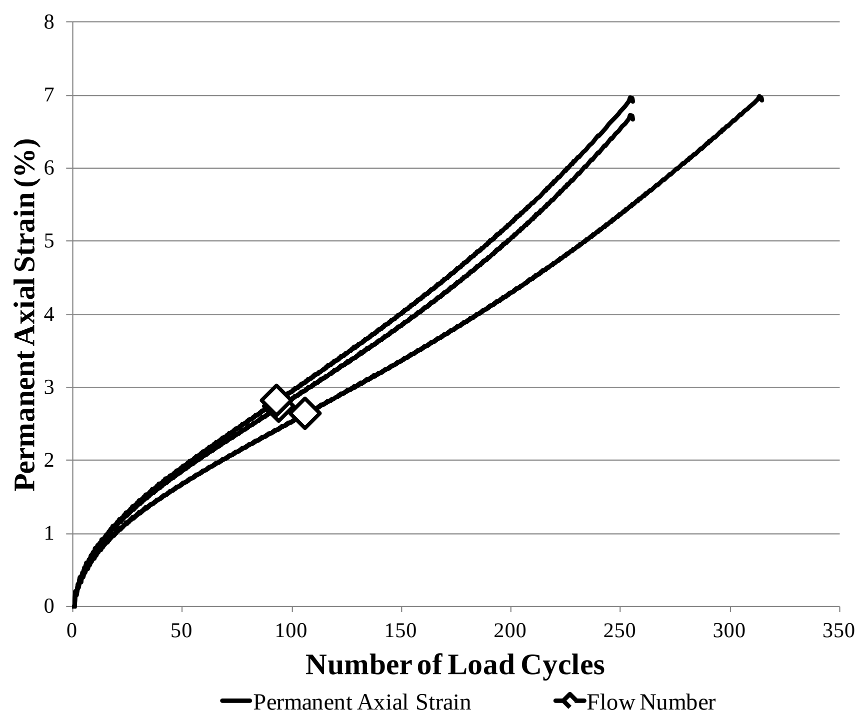

Figure A-12. Mixture MS-07-5828 Repeated Load Test Results

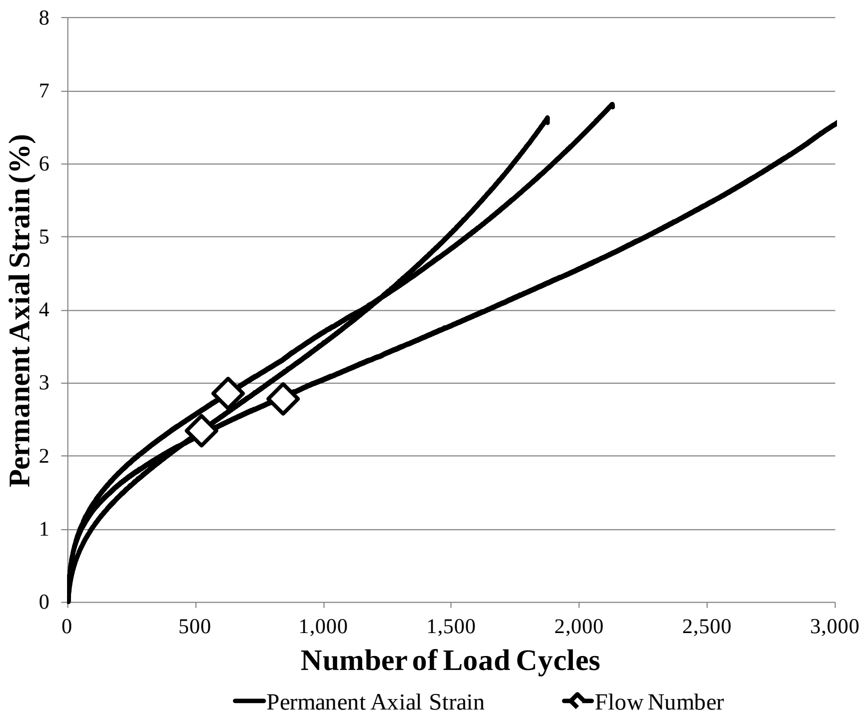

Figure A-13. Mixture MS-07-7028 Repeated Load Test Results

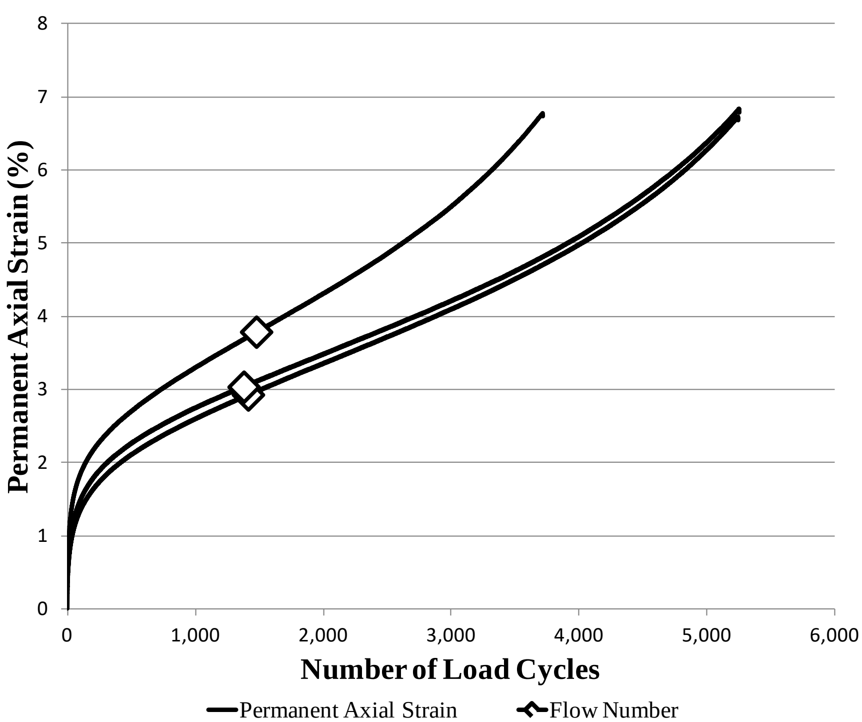

Figure A-14. Mixture MS-07-7628 Repeated Load Test Results

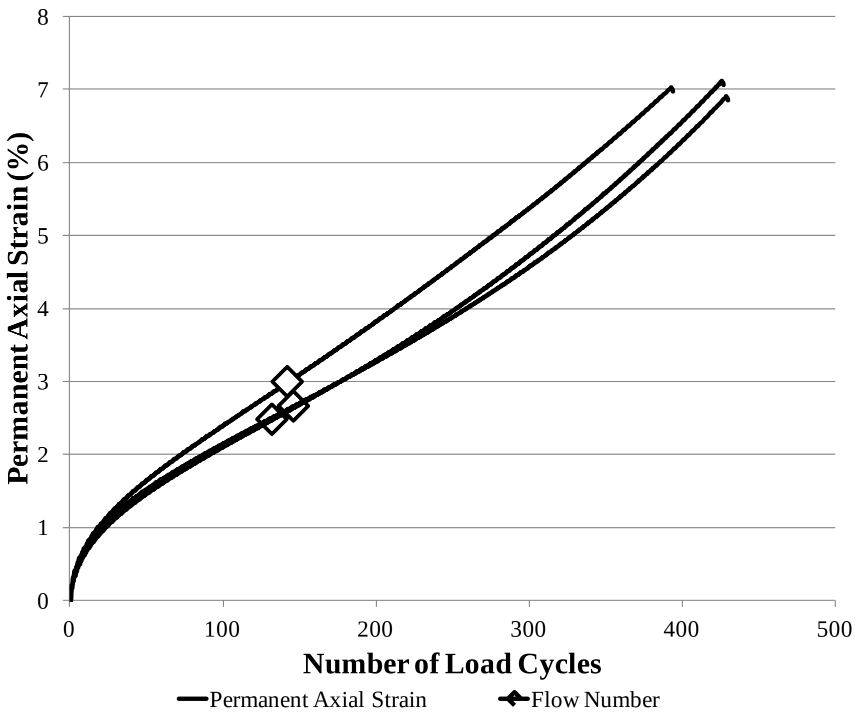

Figure A-15. Mixture MS-07-6422 Repeated Load Test Results

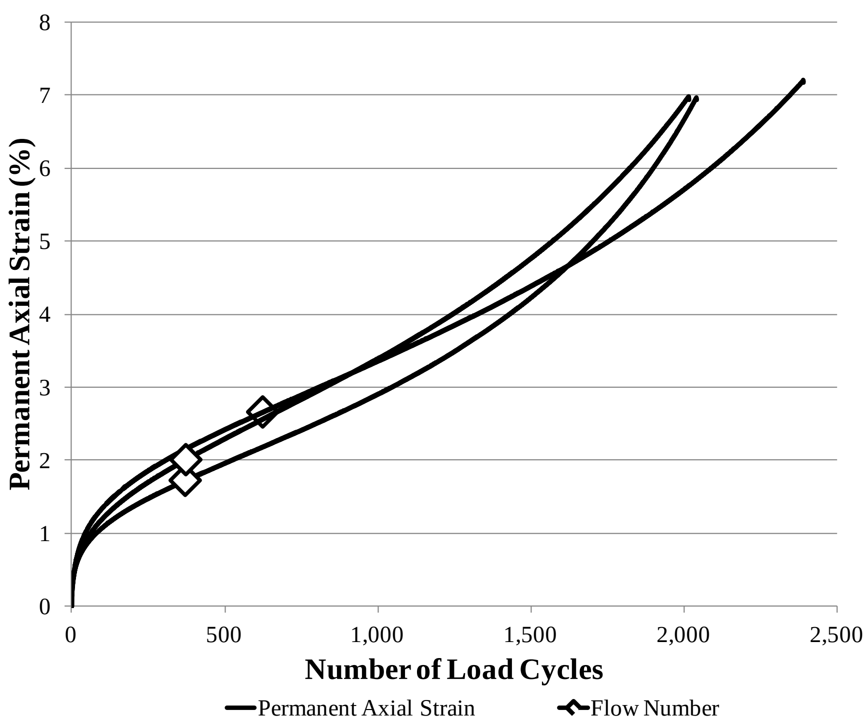

Figure A-16. Mixture MS-07-7622 Repeated Load Test Results

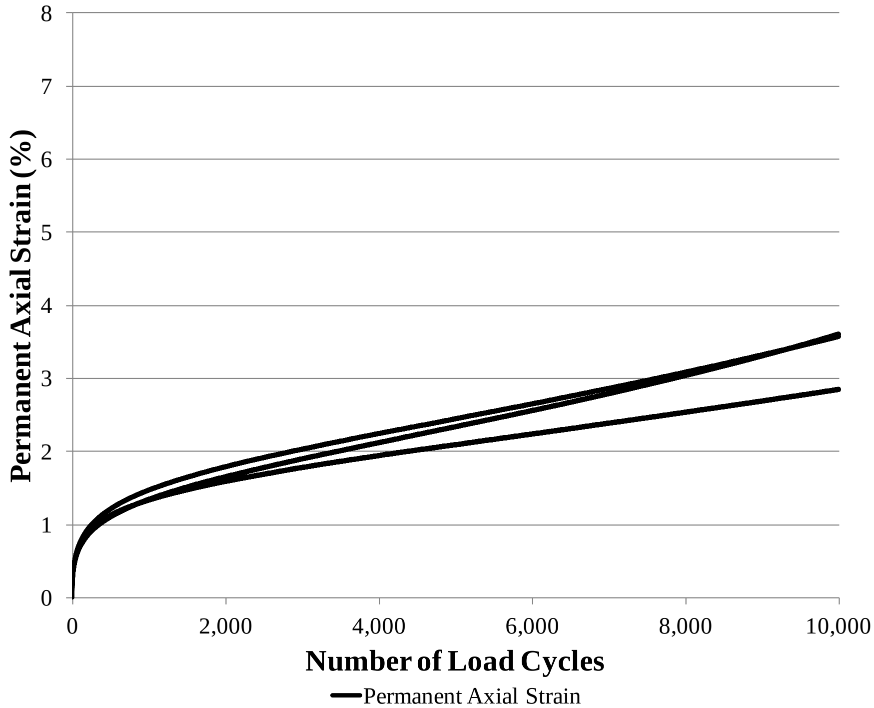

Figure A-17. Mixture MS-07-8222 Repeated Load Test Results

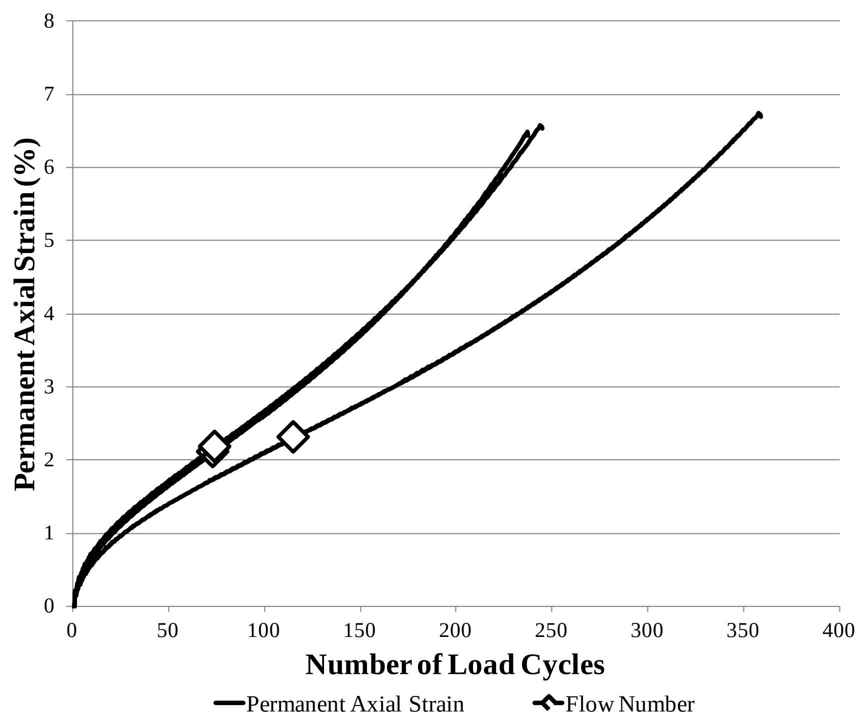

Figure A-18. Mixture MS-15-5828 Repeated Load Test Results

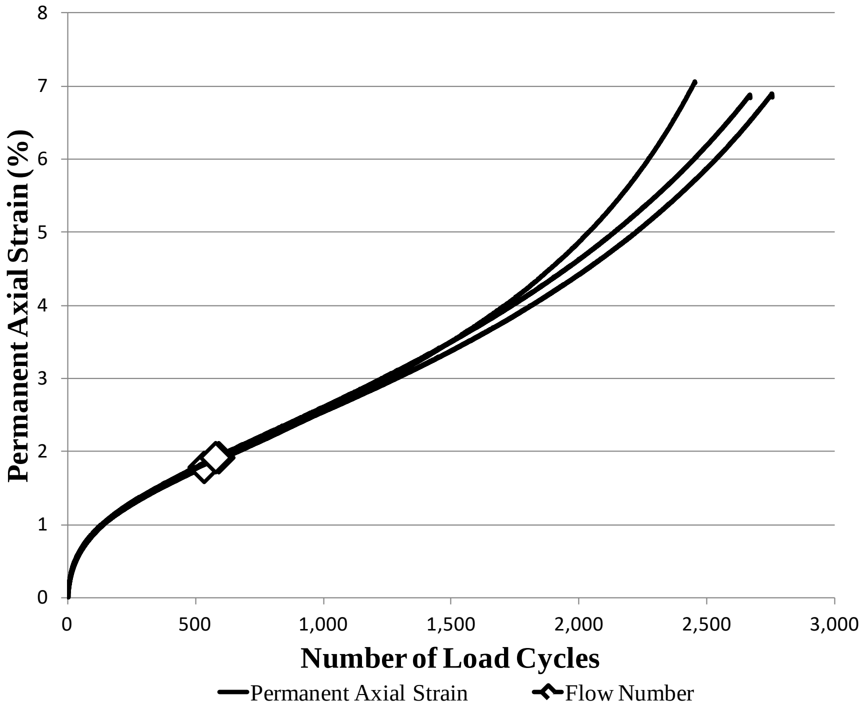

Figure A-19. Mixture MS-15-7028 Repeated Load Test Results

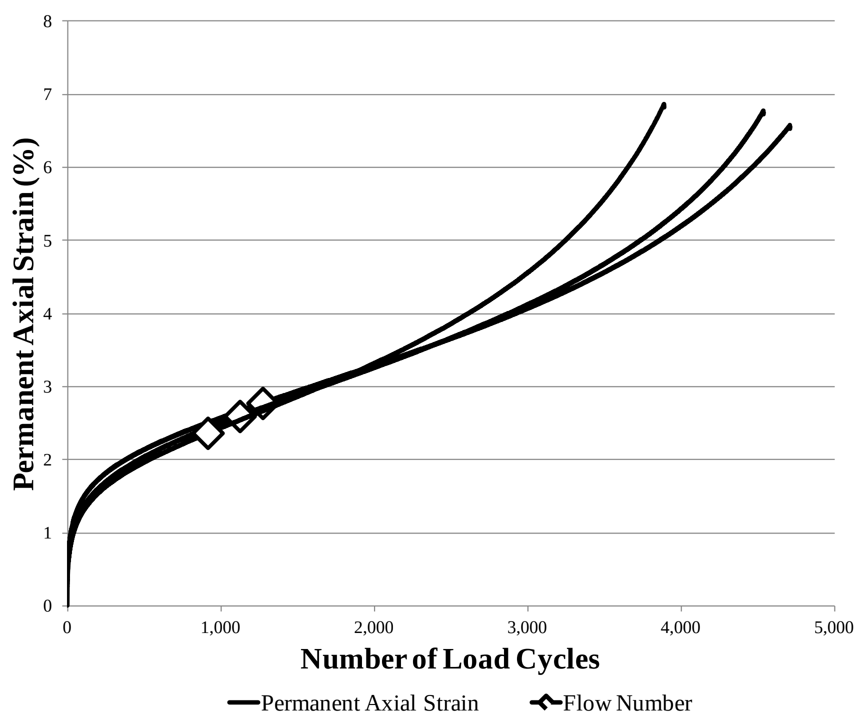

Figure A-20. Mixture MS-15-7628 Repeated Load Test Results

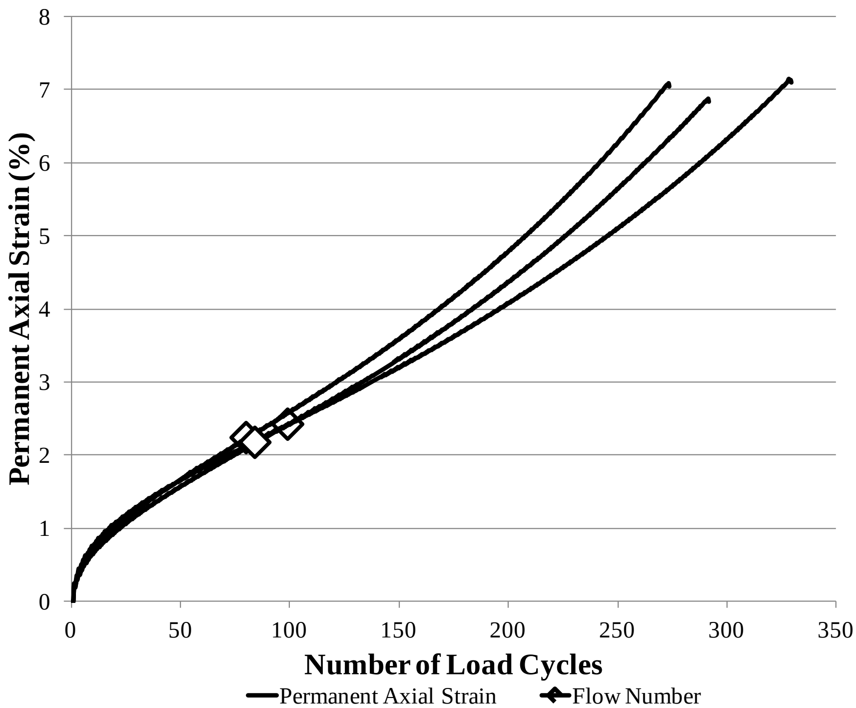

Figure A-21. Mixture MS-15-6422 Repeated Load Test Results

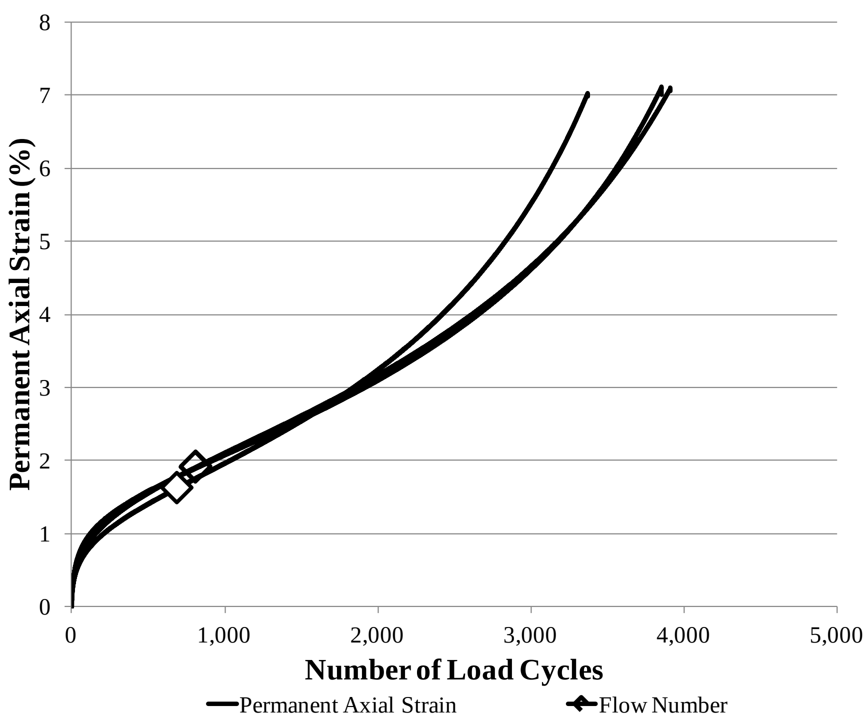

Figure A-22. Mixture MS-15-7622 Repeated Load Test Results

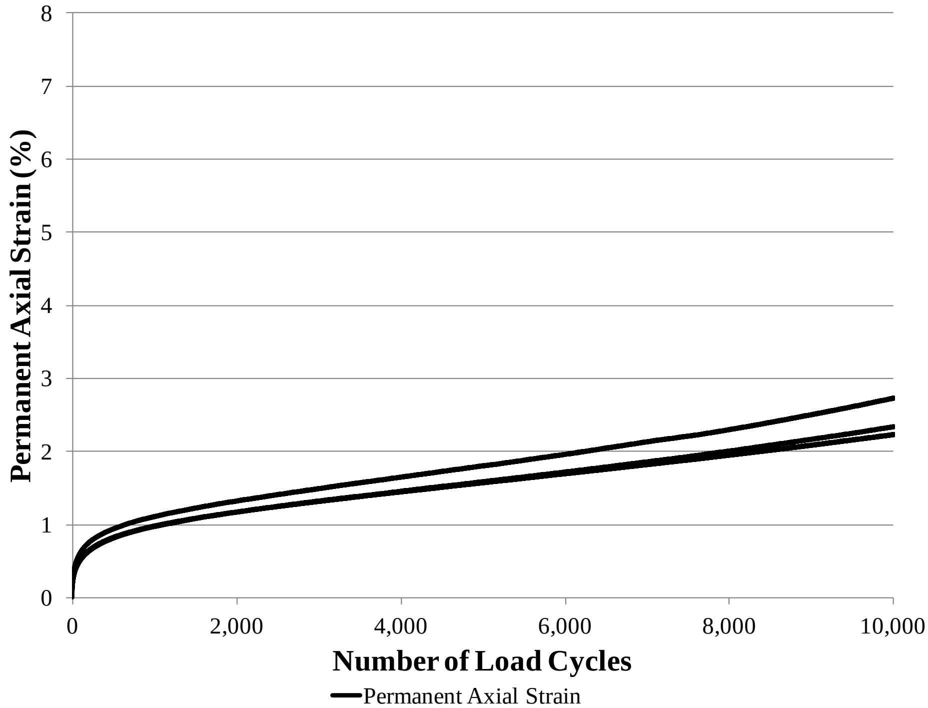

Figure A-23. Mixture MS-15-8222 Repeated Load Test Results

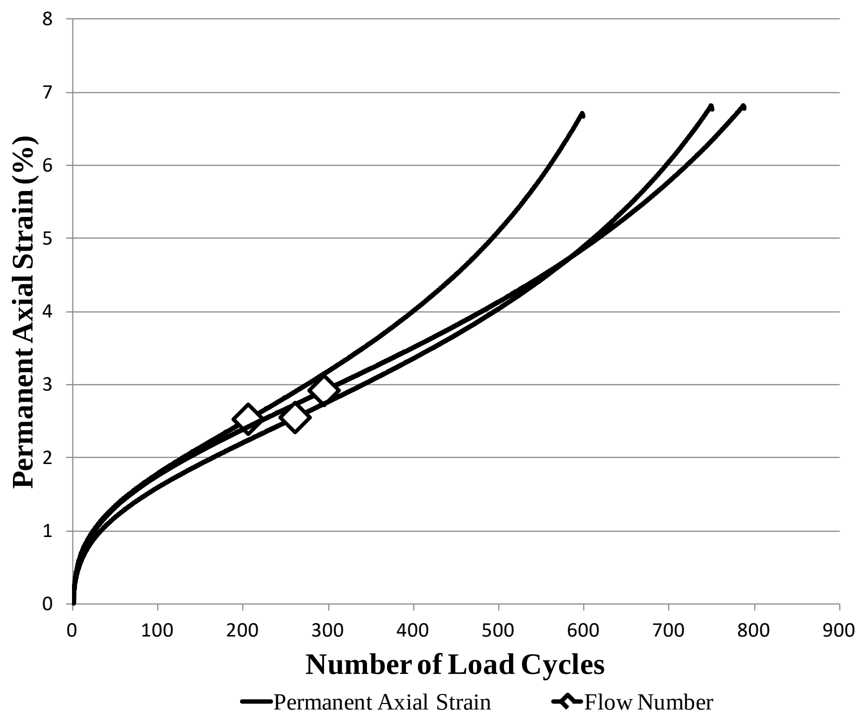

Figure A-24. Mixture NJ-00-5828 Repeated Load Test Results

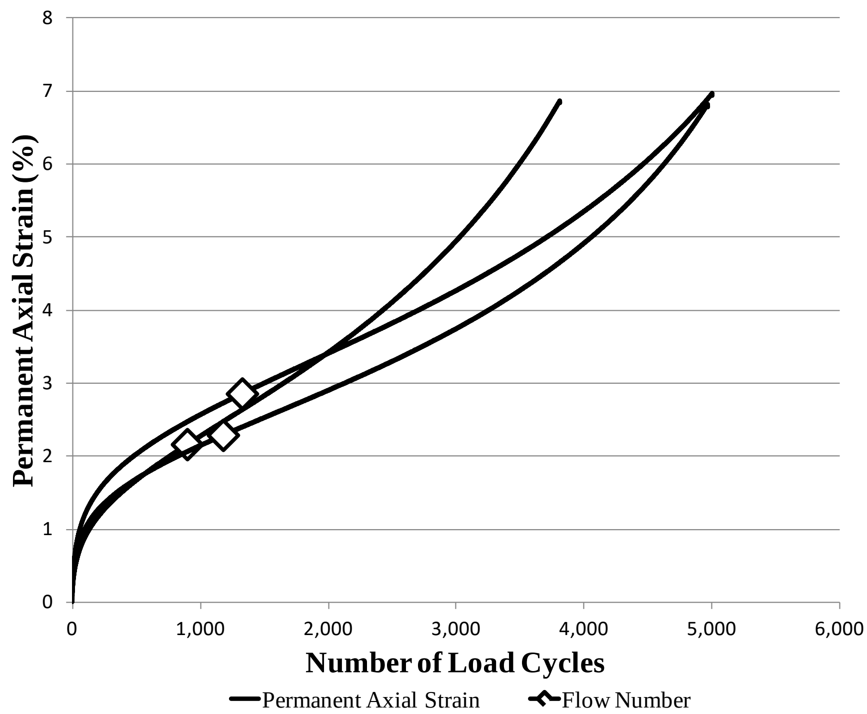

Figure A-25. Mixture NJ-00-7028 Repeated Load Test Results

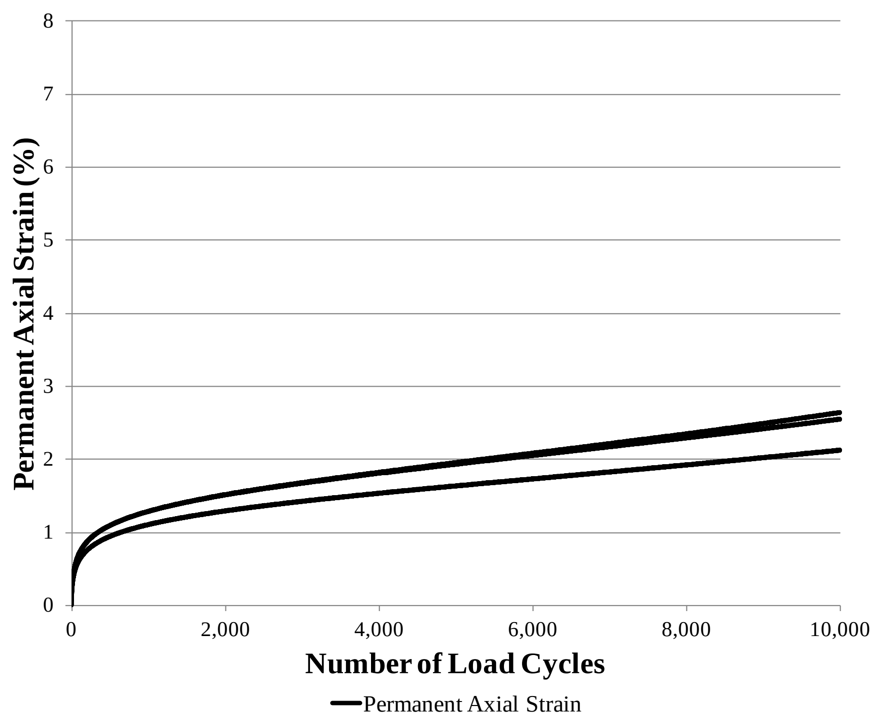

Figure A-26. Mixture NJ-00-7628 Repeated Load Test Results

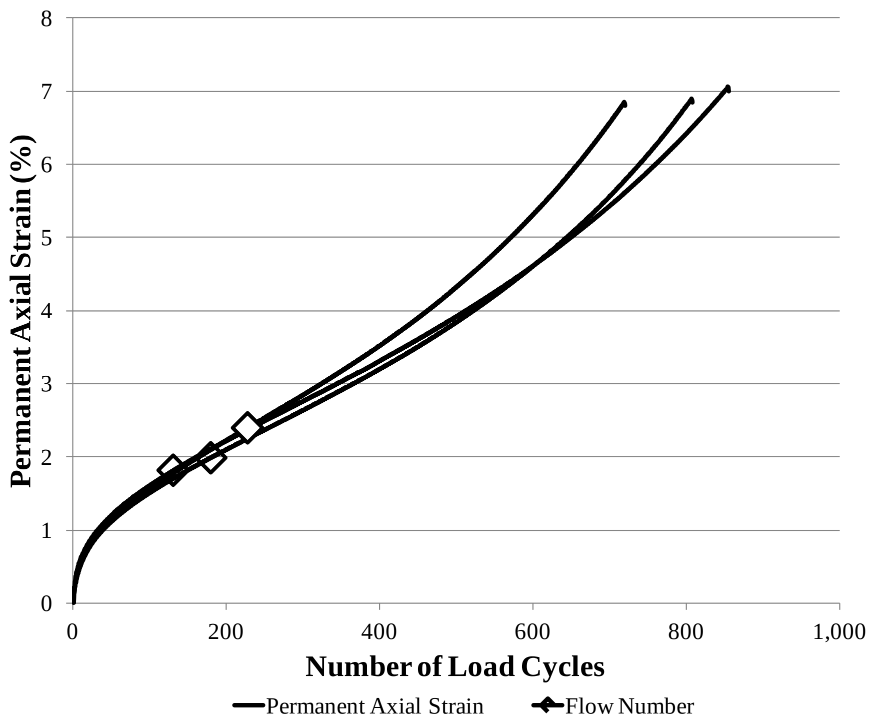

Figure A-27. Mixture NJ-00-6422 Repeated Load Test Results

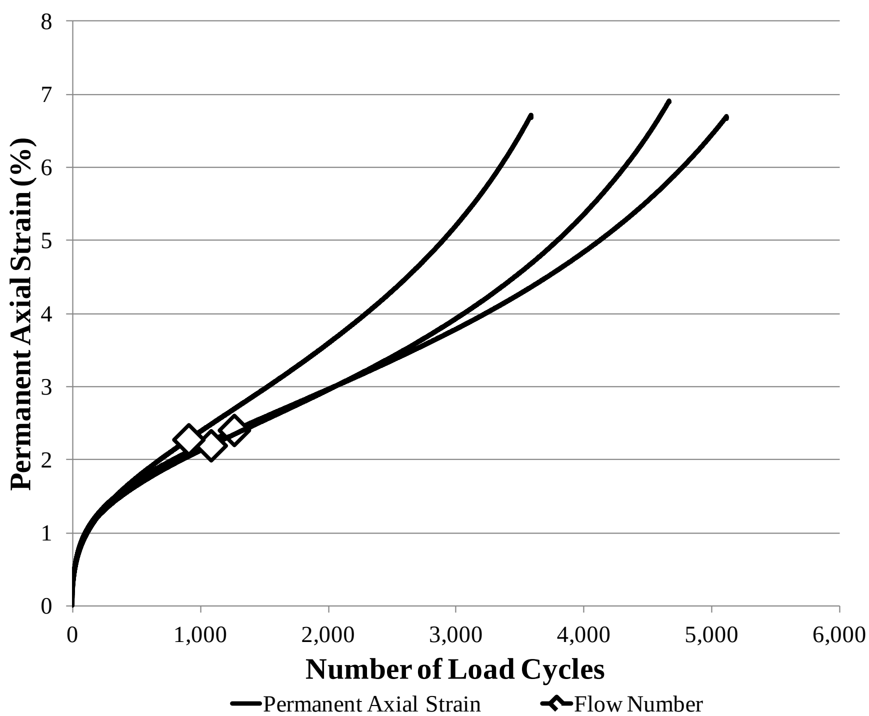

Figure A-28. Mixture NJ-00-7622 Repeated Load Test Results

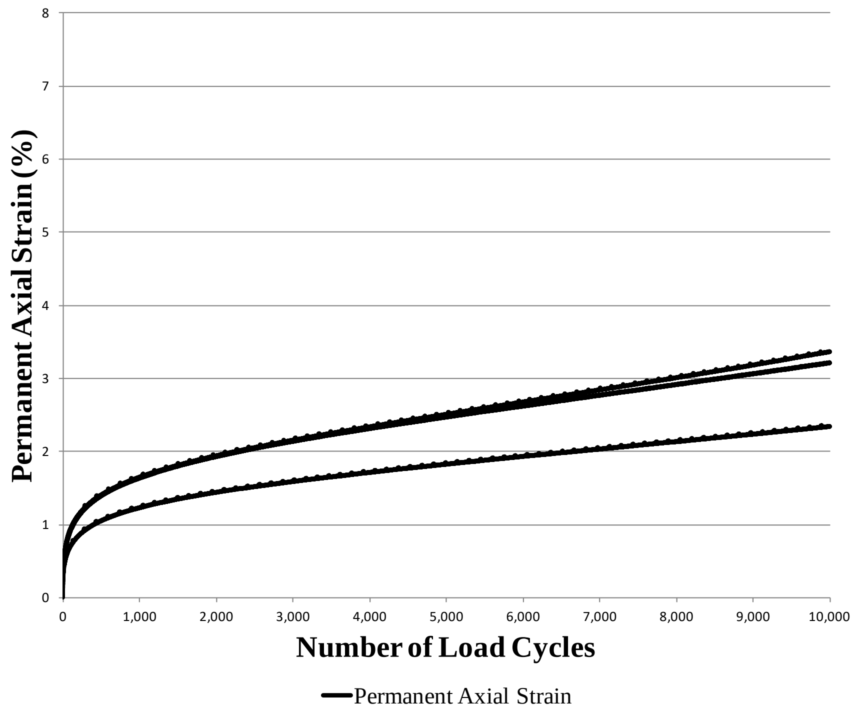

Figure A-29. Mixture NJ-00-8222 Repeated Load Test Results

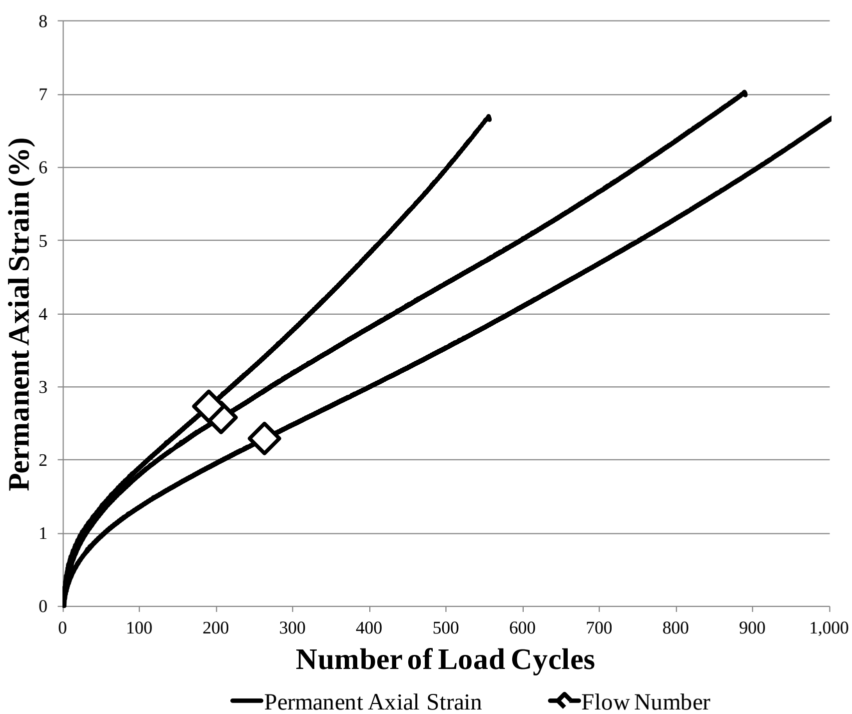

Figure A-30. Mixture NJ-15-5828 Repeated Load Test Results

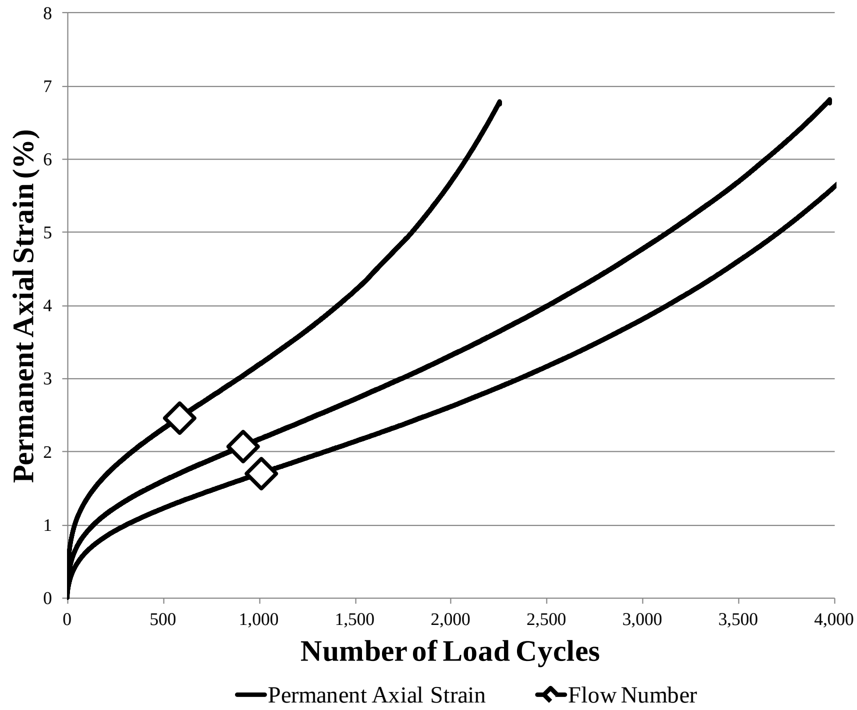

Figure A-31. Mixture NJ-15-7028 Repeated Load Test Results

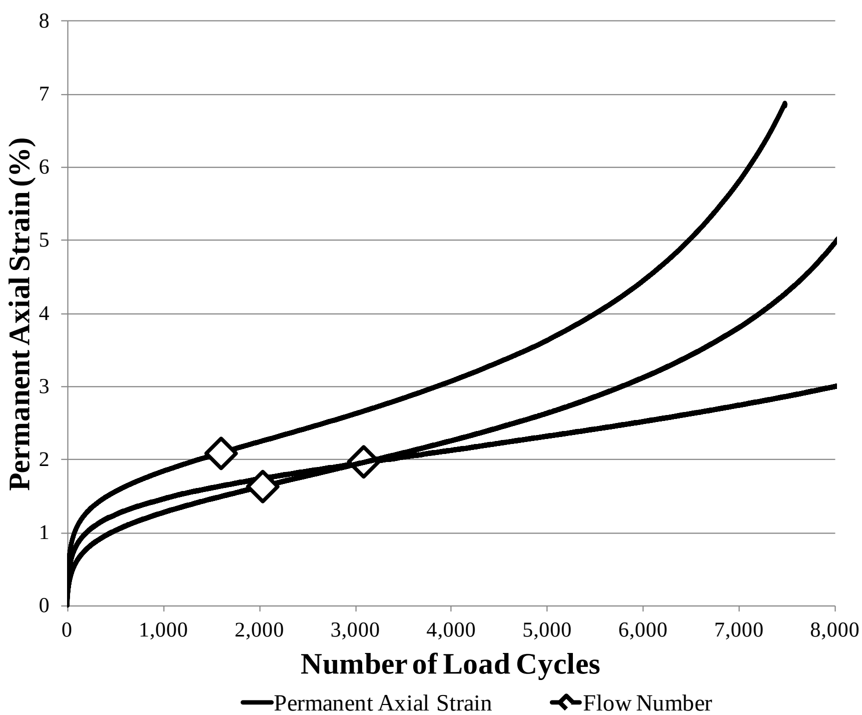

Figure A-32. Mixture NJ-15-7628 Repeated Load Test Results

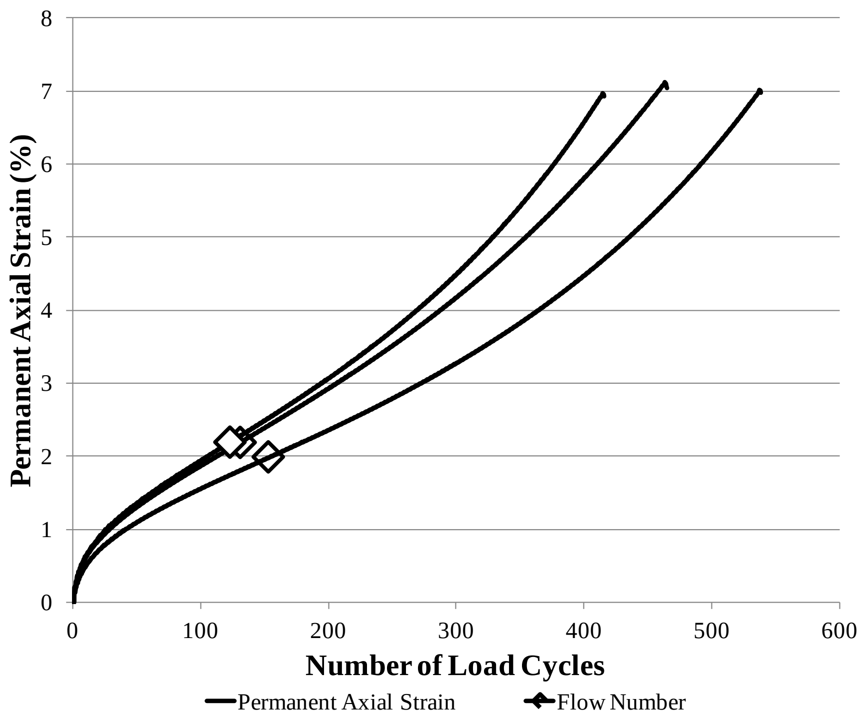

Figure A-33. Mixture NJ-15-6422 Repeated Load Test Results

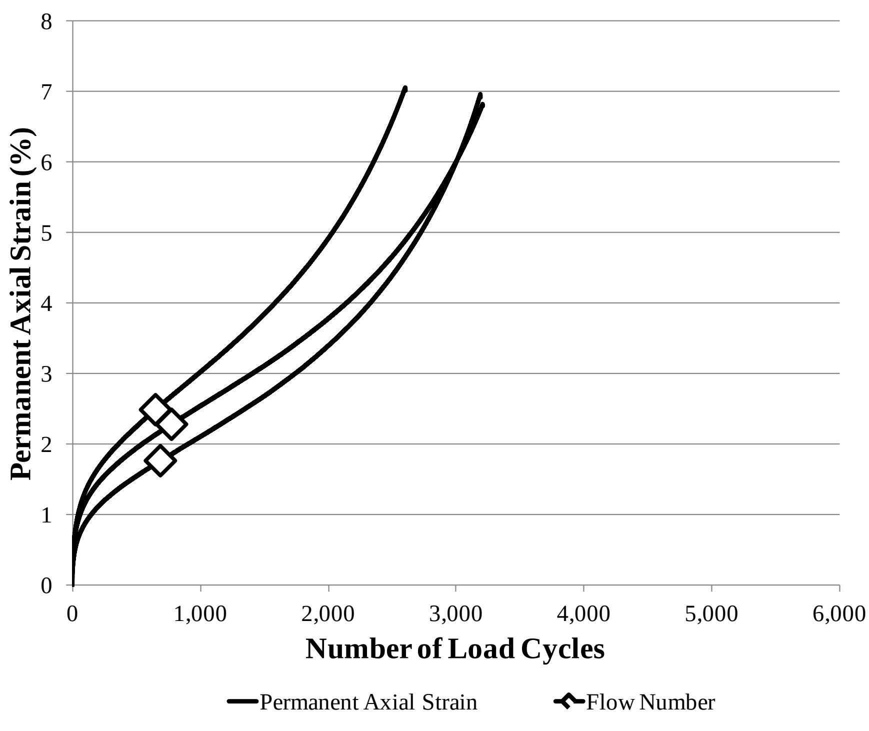

Figure A-34. Mixture NJ-15-7622 Repeated Load Test Results

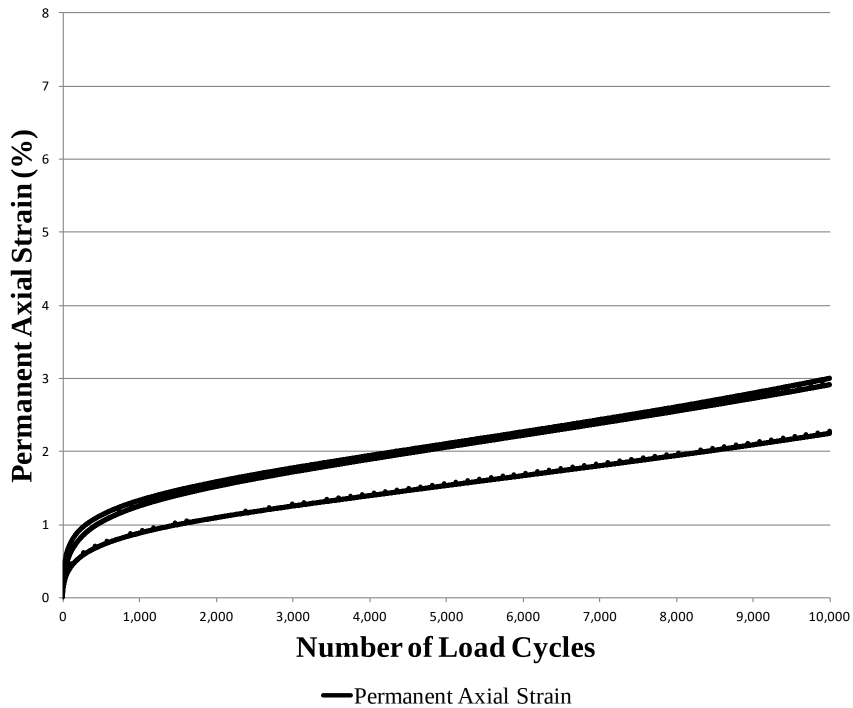

Figure A-35. Mixture NJ-15-8222 Repeated Load Test Results

APPENDIX B—STATIC CREEP TEST RESULTS

Figures B-1 through B-34 show the static creep test results for all specimens tested using each mixture type. The mixtures are designated by source origin (Arkansas (AR), Massachusetts (MA), New Jersey (NJ) or Mississippi (MS)), followed by the percentage of natural sand, and the binder grade used in the mixture.

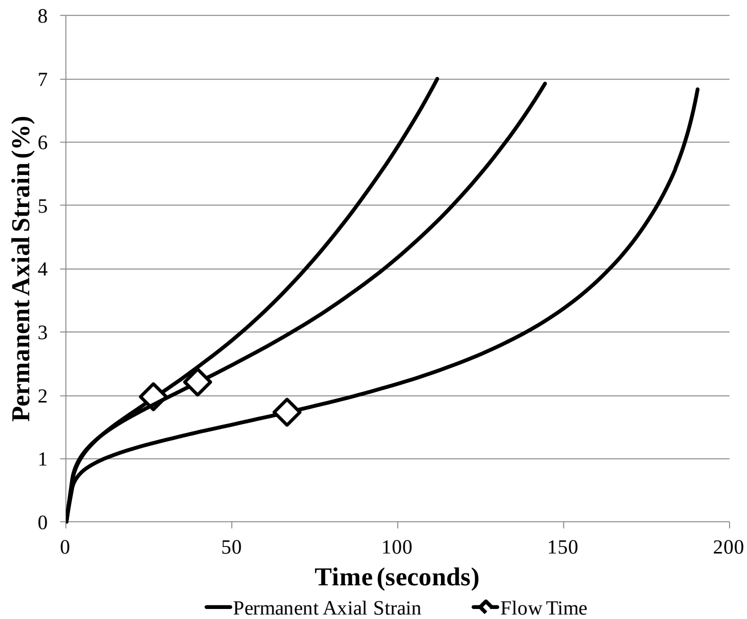

Figure B-1. Mixture AR-10-5828 Static Creep Test Results

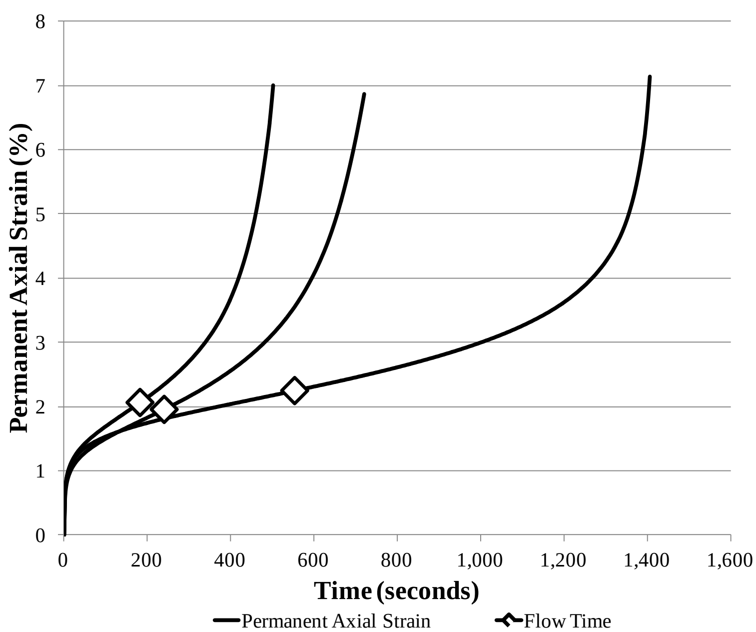

Figure B-2. Mixture AR-10-7028 Static Creep Test Results

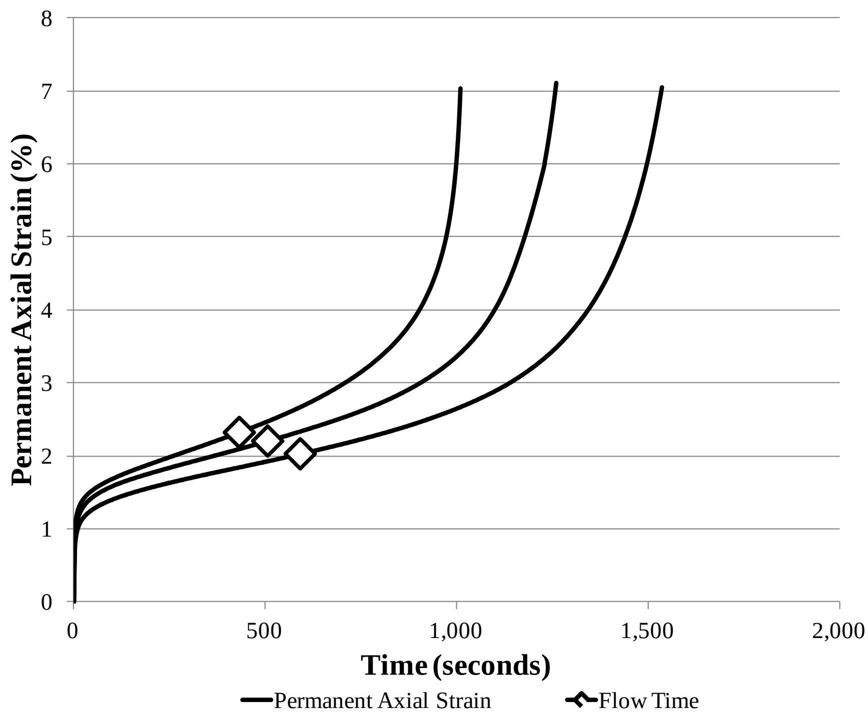

Figure B-3. Mixture AR-10-7628 Static Creep Test Results

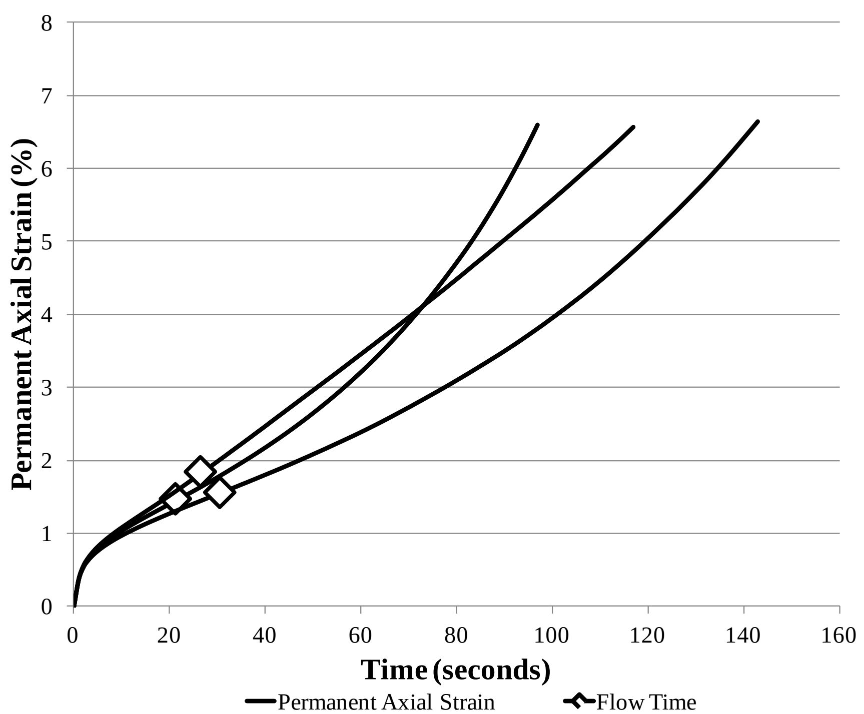

Figure B-4. Mixture AR-10-6422 Static Creep Test Results

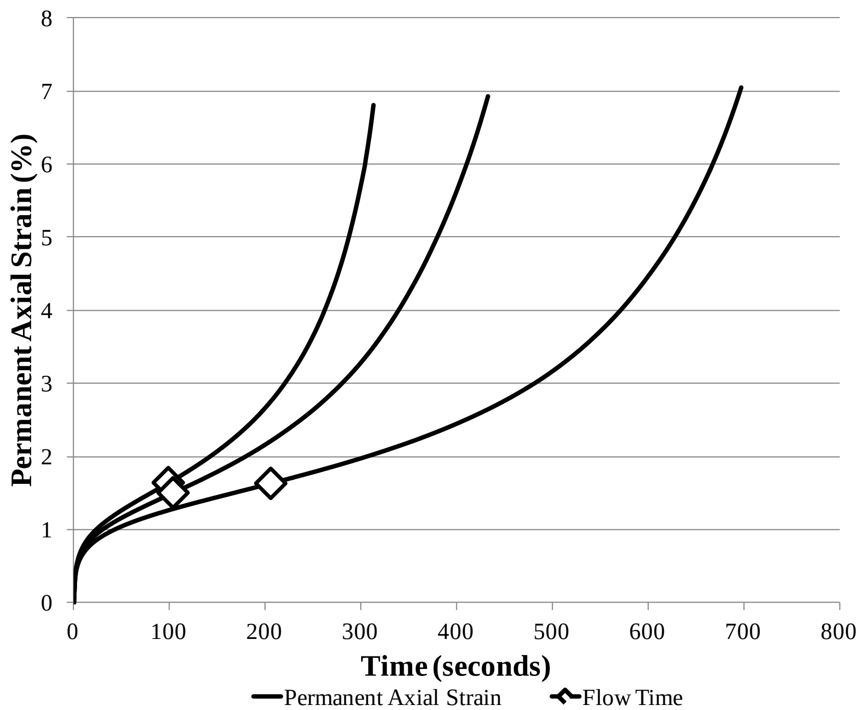

Figure B-5. Mixture AR-10-7622 Static Creep Test Results

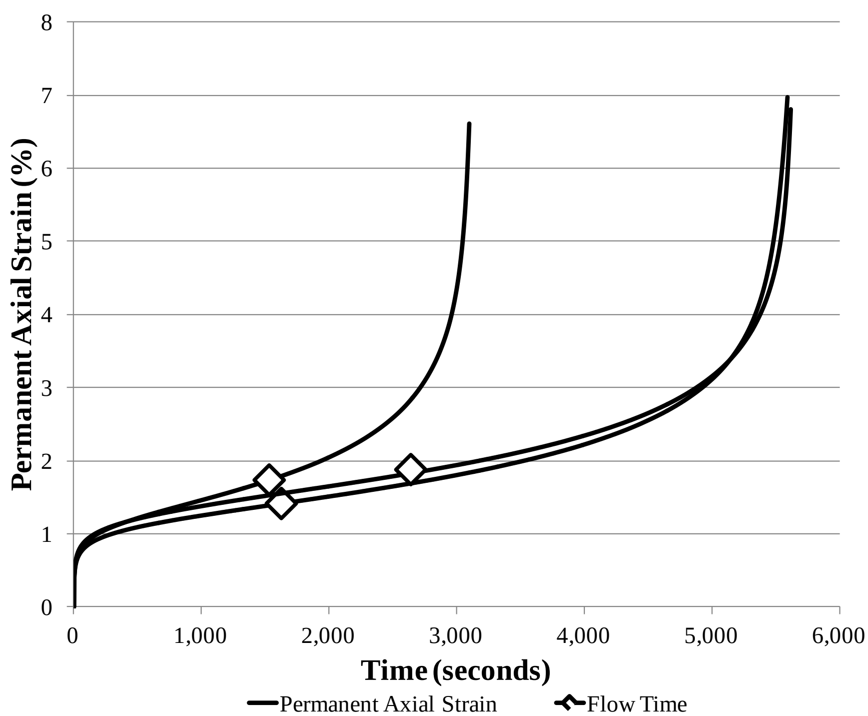

Figure B-6. Mixture AR-10-8222 Static Creep Test Results

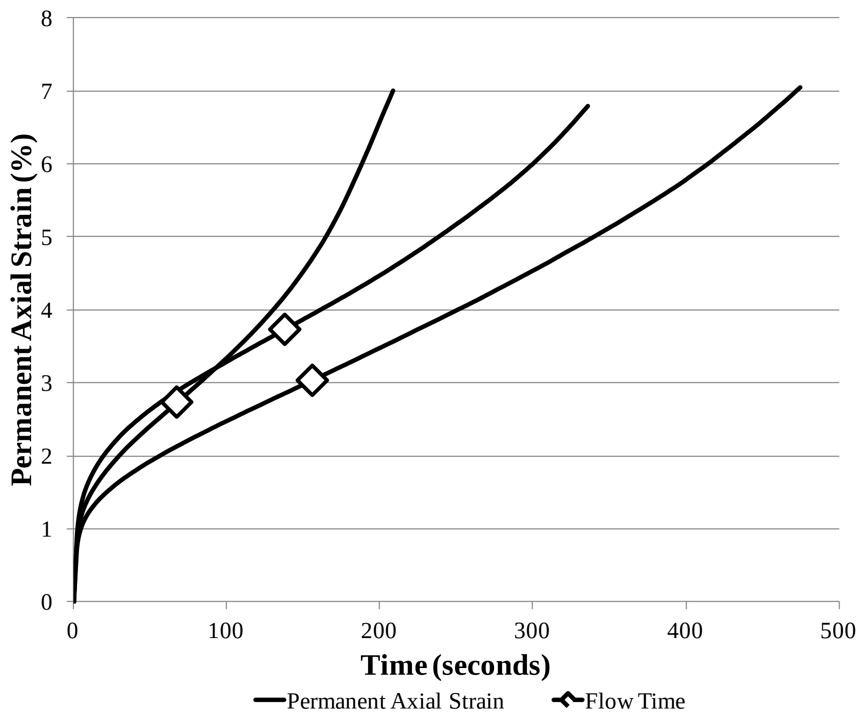

Figure B-7. Mixture MA-00-5828 Static Creep Test Results

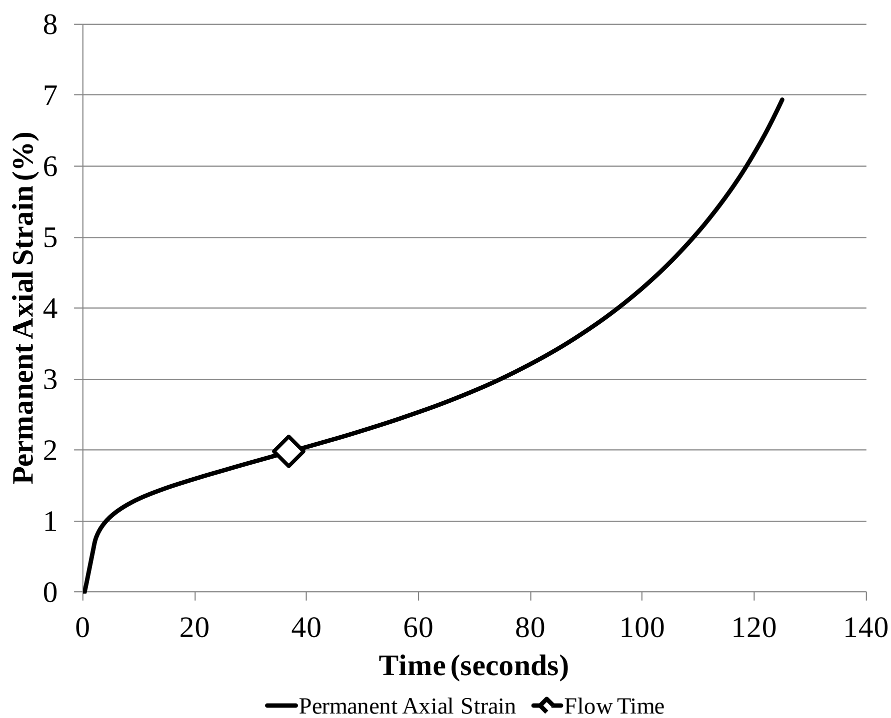

Figure B-8. Mixture MA-00-6422 Static Creep Test Results

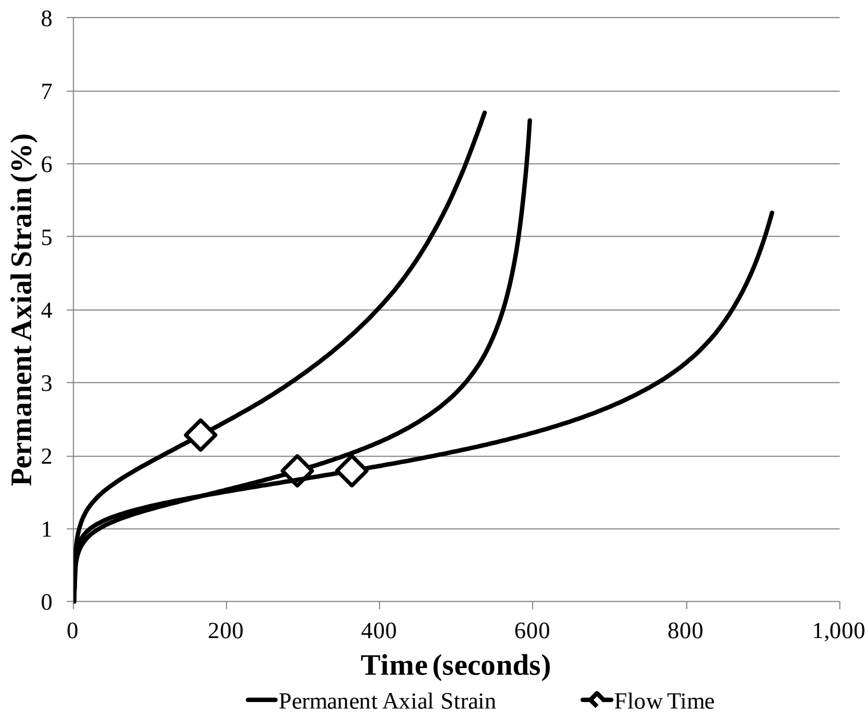

Figure B-9. Mixture MA-00-7622 Static Creep Test Results

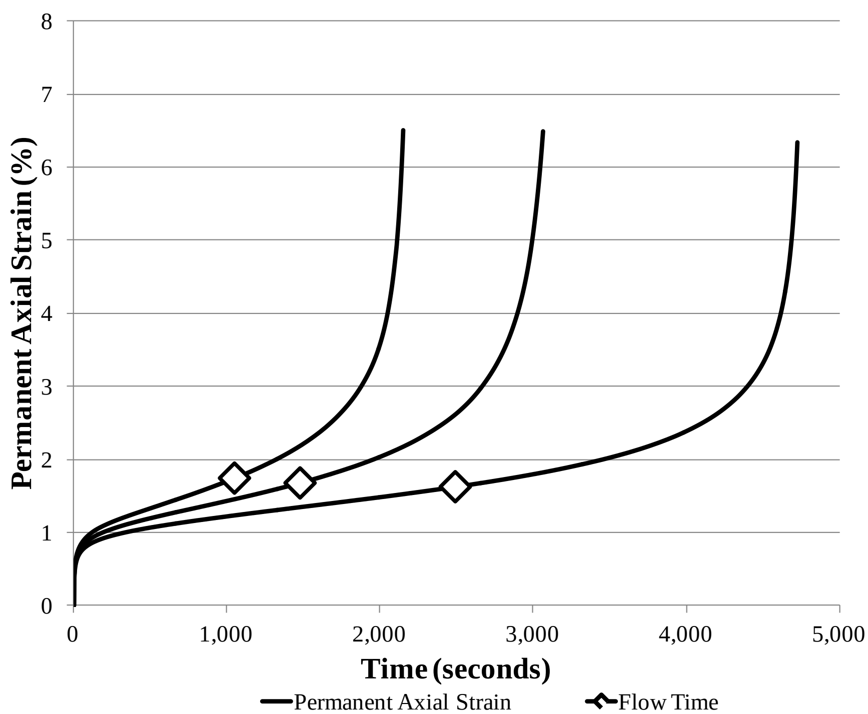

Figure B-10. Mixture MA-00-8222 Static Creep Test Results

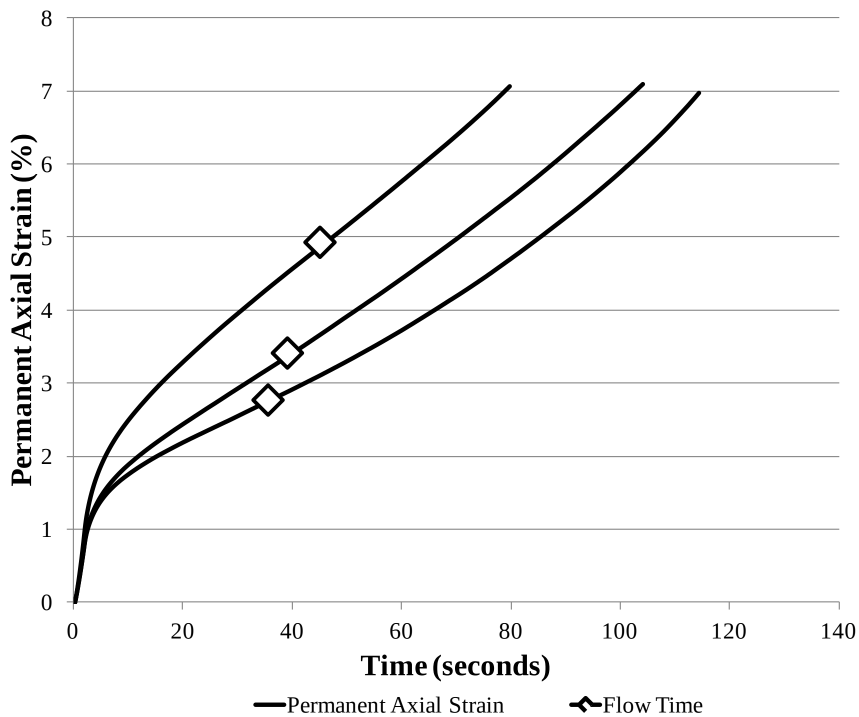

Figure B-11. Mixture MS-07-5828 Static Creep Test Results

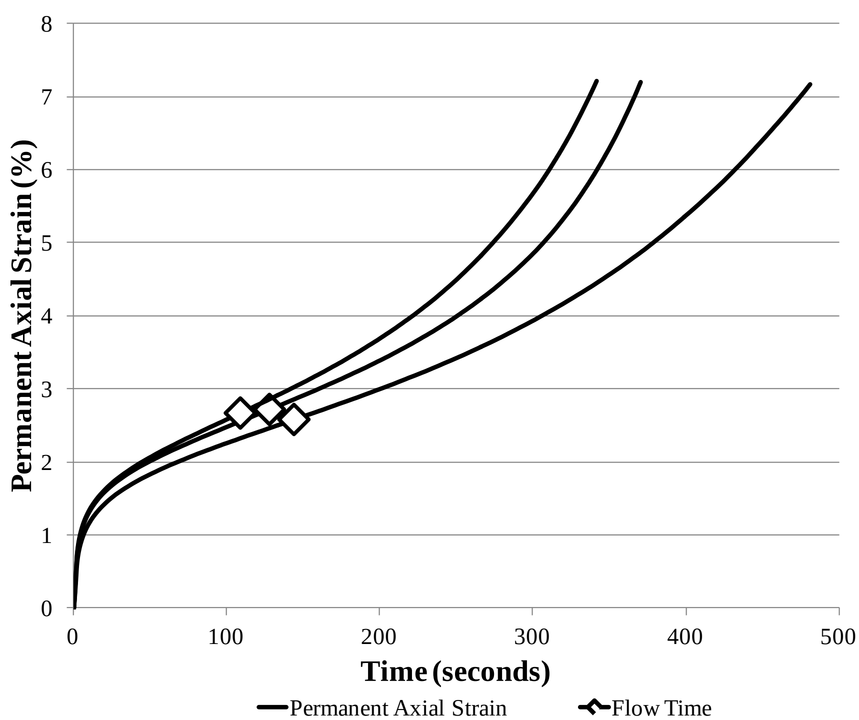

Figure B-12. Mixture MS-07-7028 Static Creep Test Results

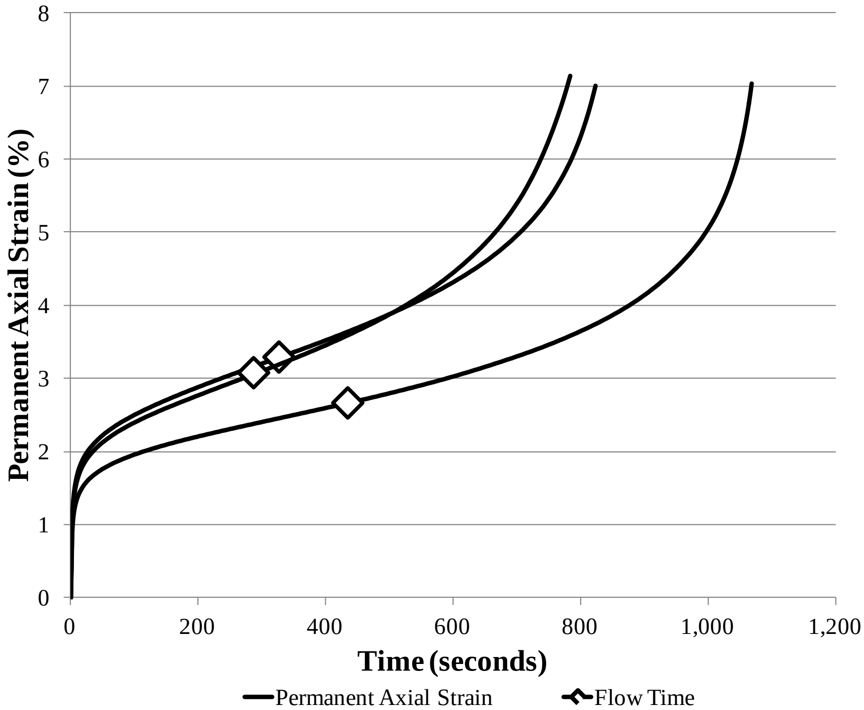

Figure B-13. Mixture MS-07-7628 Static Creep Test Results

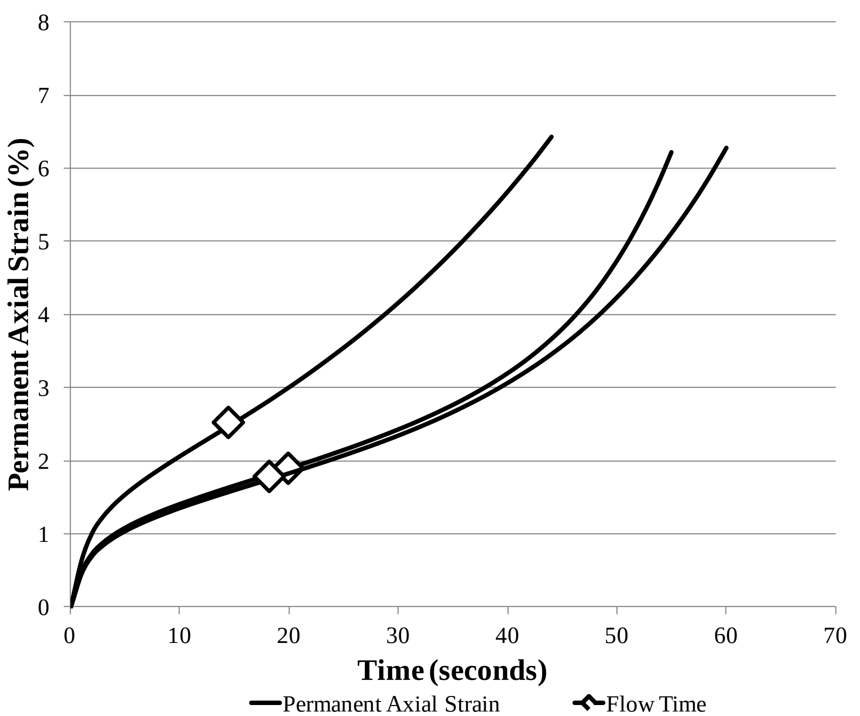

Figure B-14. Mixture MS-07-6422 Static Creep Test Results

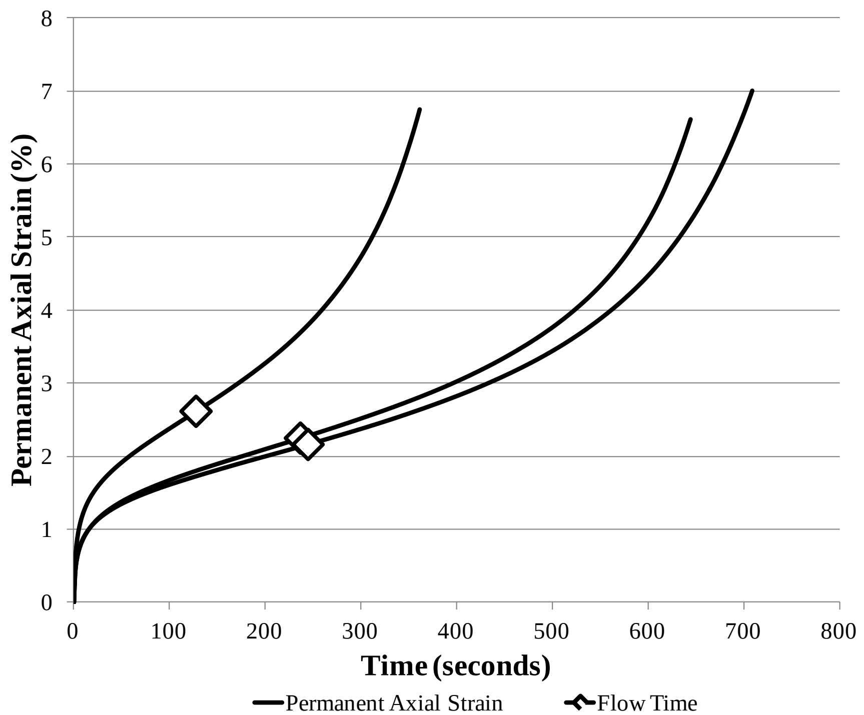

Figure B-15. Mixture MS-07-7622 Static Creep Test Results

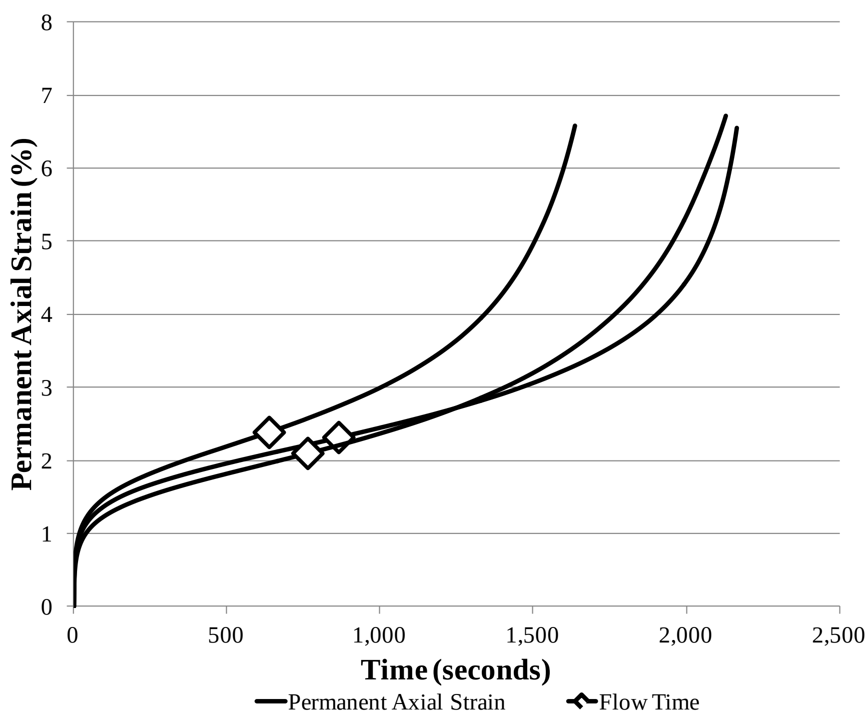

Figure B-16. Mixture MS-07-8222 Static Creep Test Results

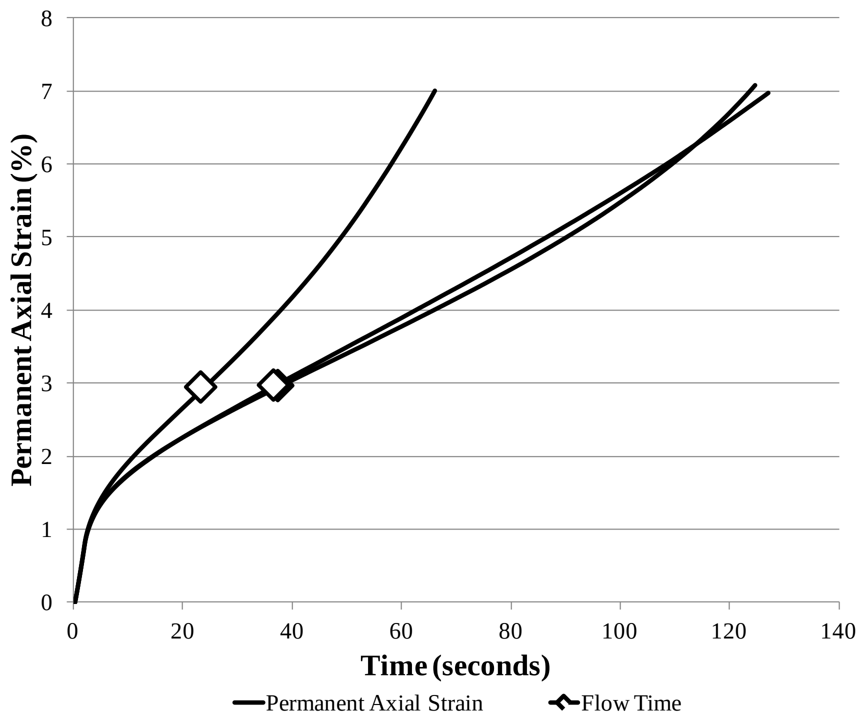

Figure B-17. Mixture MS-15-5828 Static Creep Test Results

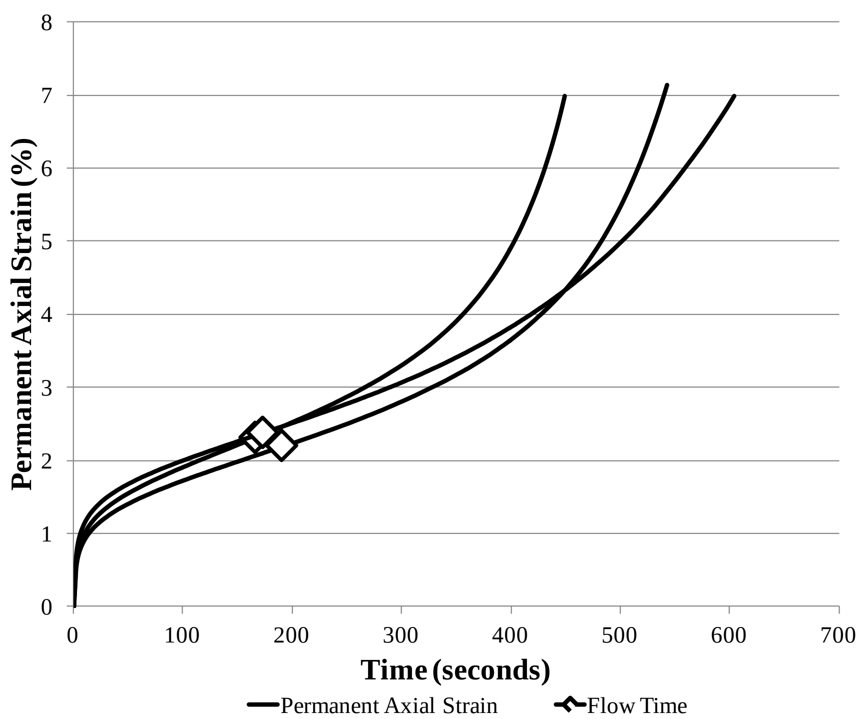

Figure B-18. Mixture MS-15-7028 Static Creep Test Results

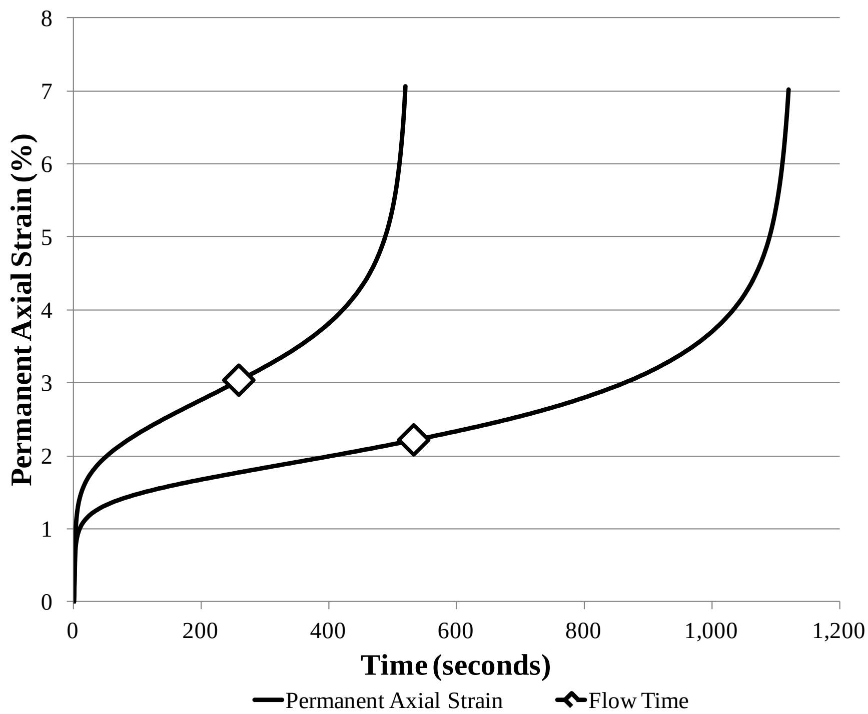

Figure B-19. Mixture MS-15-7628 Static Creep Test Results

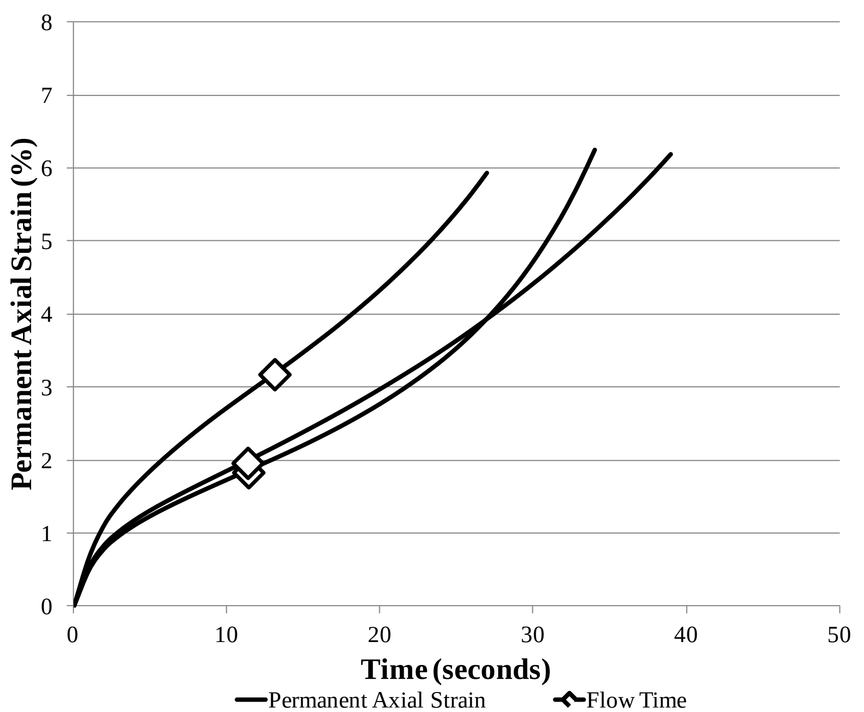

Figure B-20. Mixture MS-15-6422 Static Creep Test Results

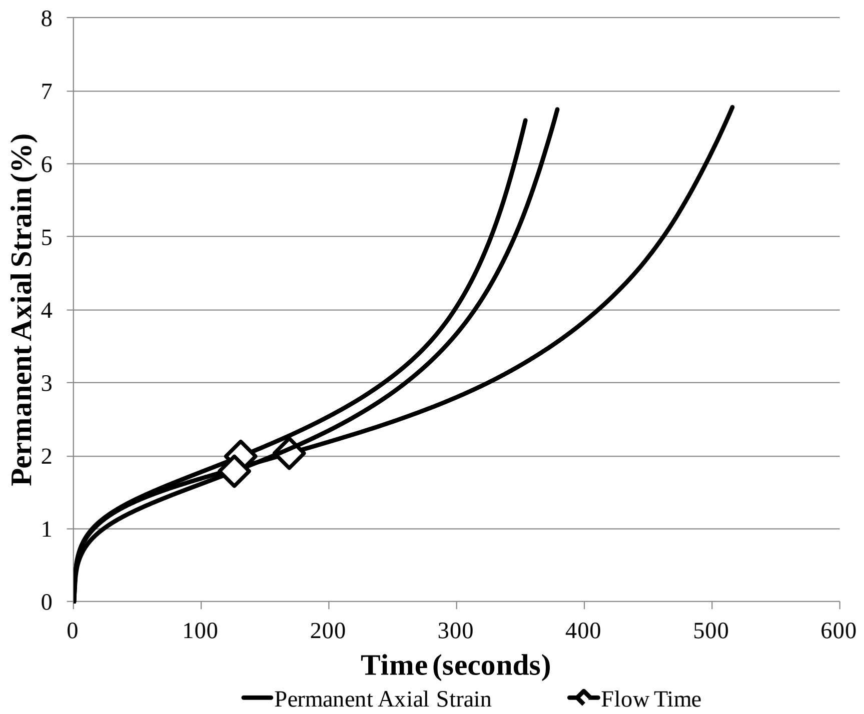

Figure B-21. Mixture MS-15-7622 Static Creep Test Results

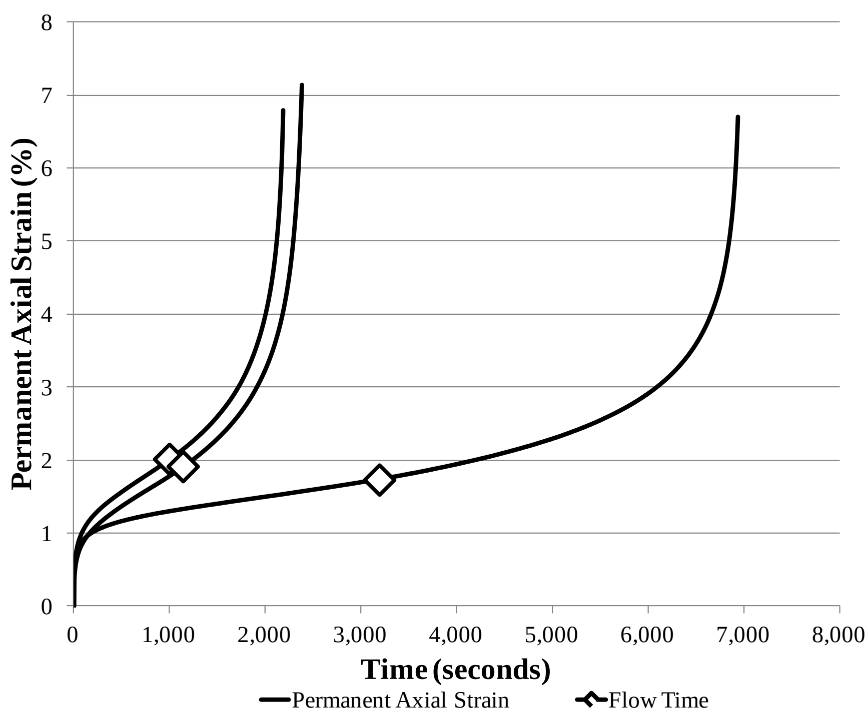

Figure B-22. Mixture MS-15-8222 Static Creep Test Results

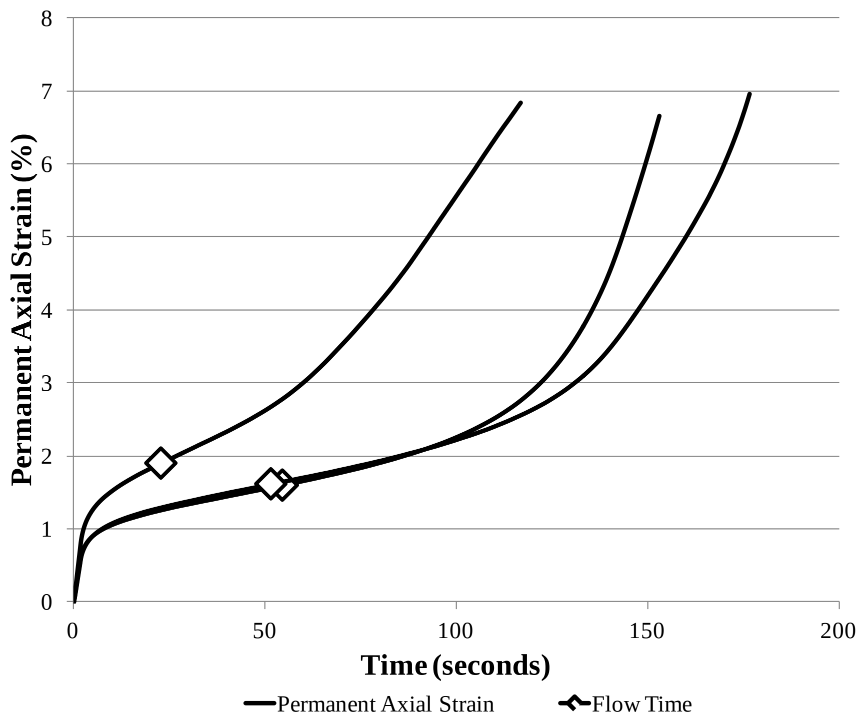

Figure B-23. Mixture NJ-00-5828 Static Creep Test Results

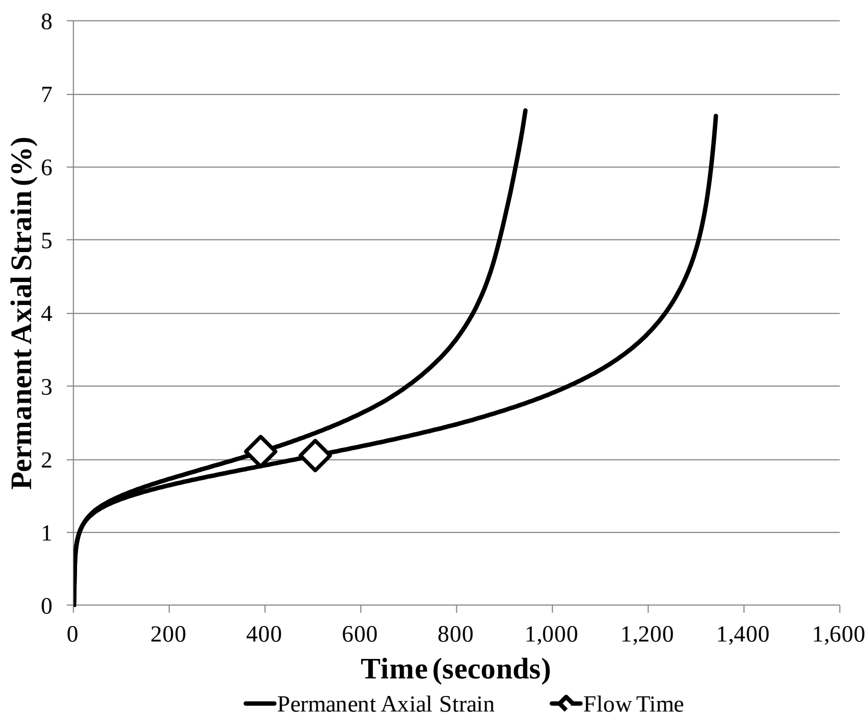

Figure B-24. Mixture NJ-00-7028 Static Creep Test Results

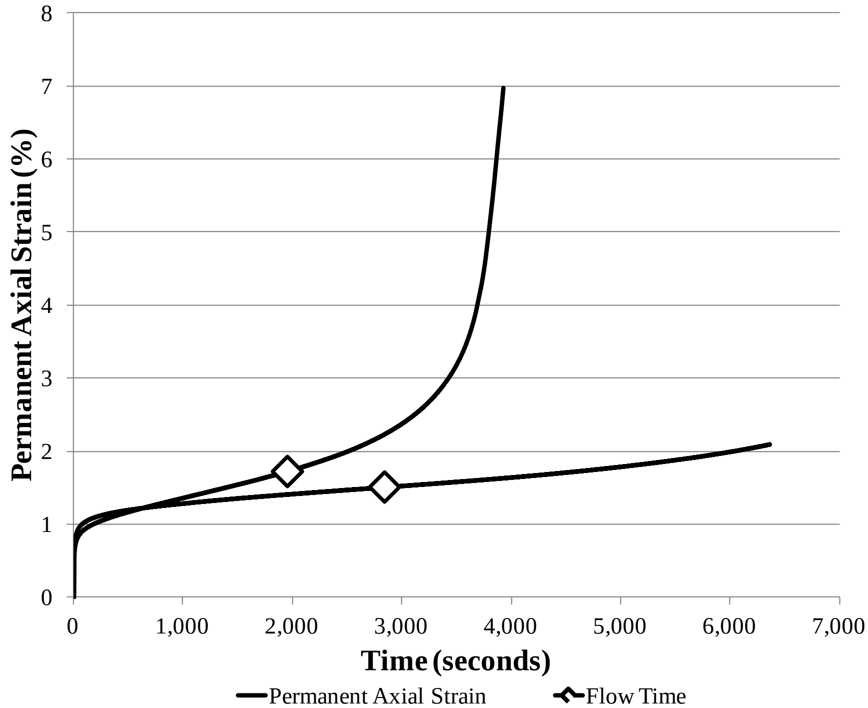

Figure B-25. Mixture NJ-00-7628 Static Creep Test Results

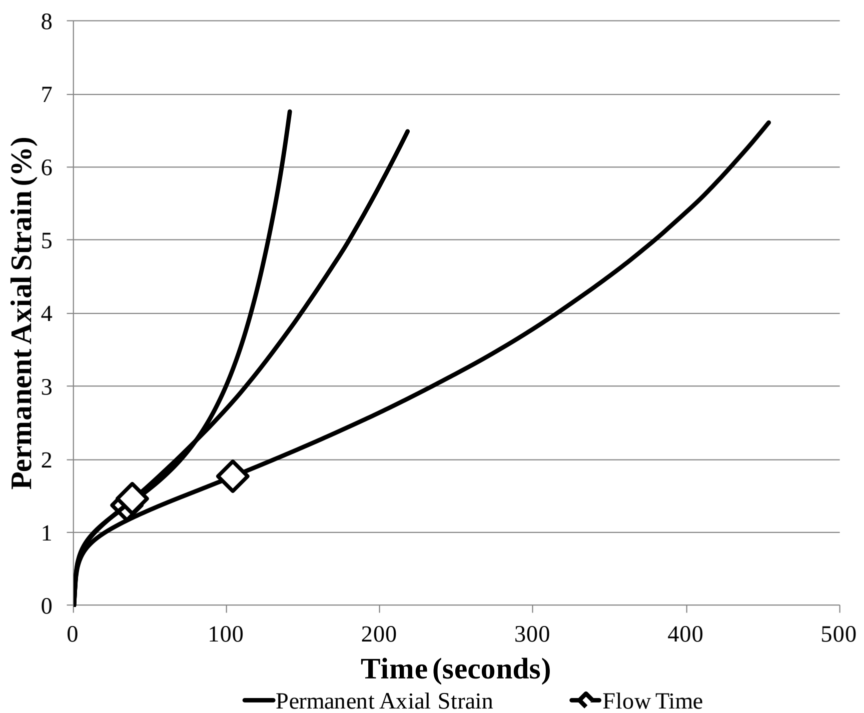

Figure B-26. Mixture NJ-00-6422 Static Creep Test Results

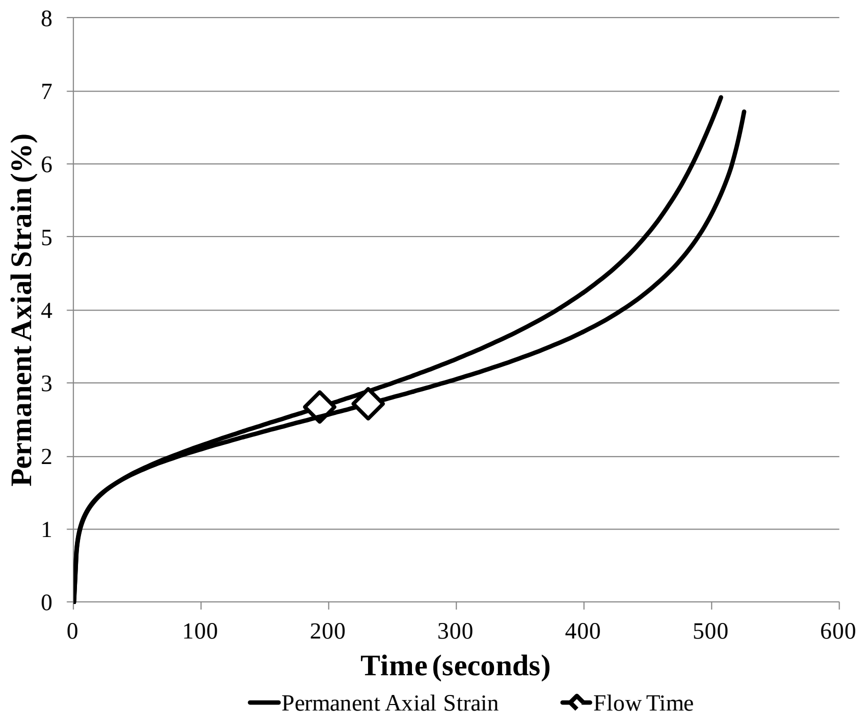

Figure B-27. Mixture NJ-00-7622 Static Creep Test Results

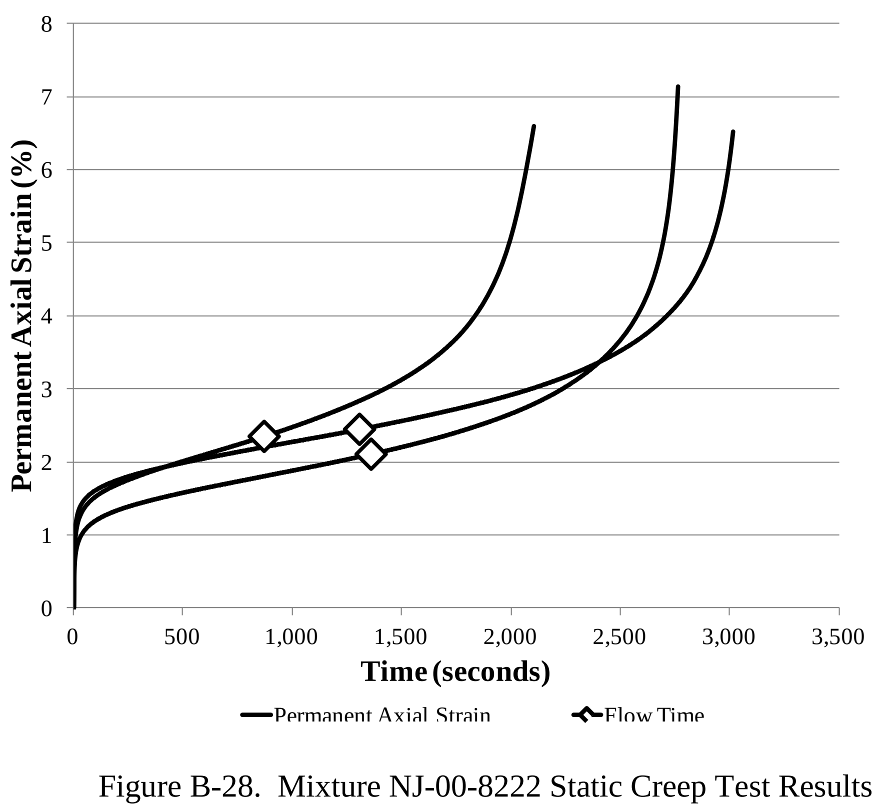

Figure B-28. Mixture NJ-00-8222 Static Creep Test Results

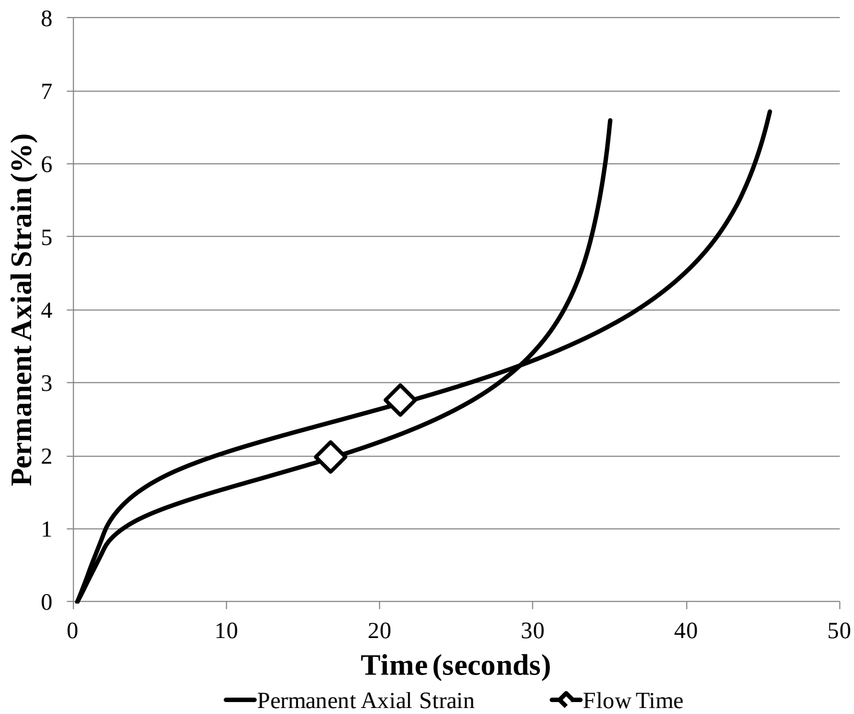

Figure B-29. Mixture NJ-15-5828 Static Creep Test Results

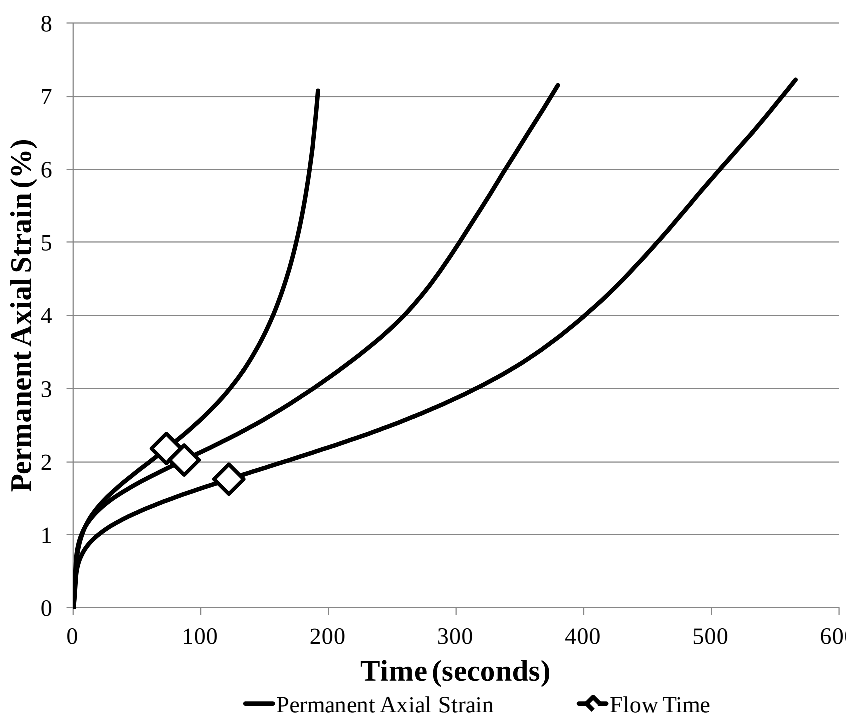

Figure B-30. Mixture NJ-15-7028 Static Creep Test Results

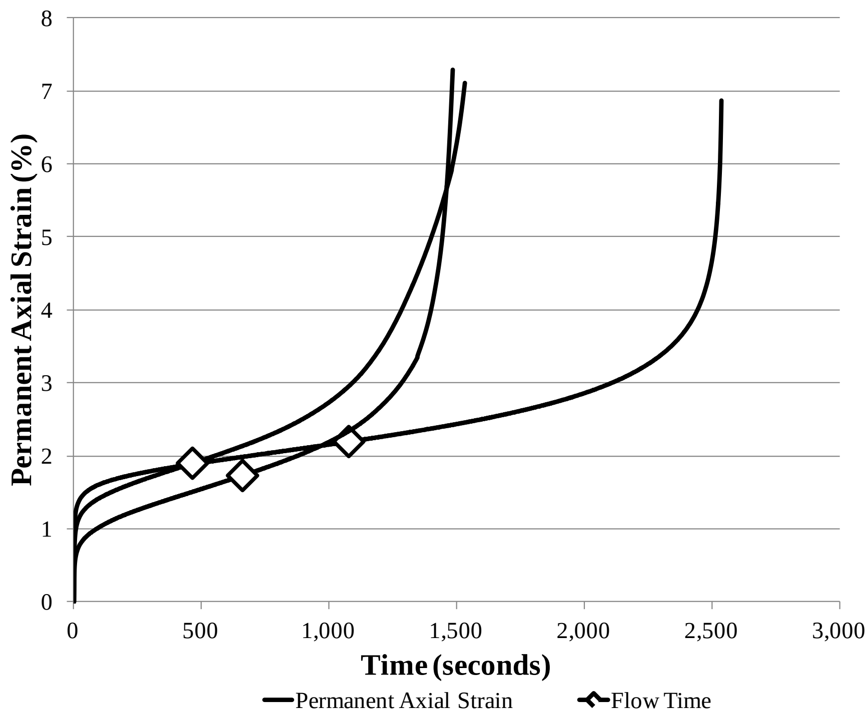

Figure B-31. Mixture NJ-15-7628 Static Creep Test Results

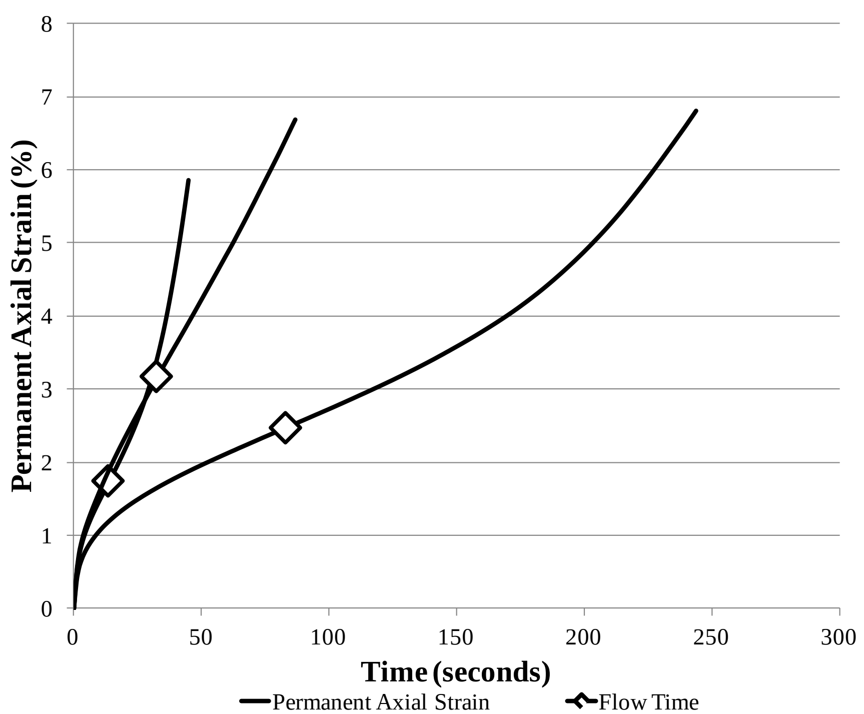

Figure B-32. Mixture NJ-15-6422 Static Creep Test Results

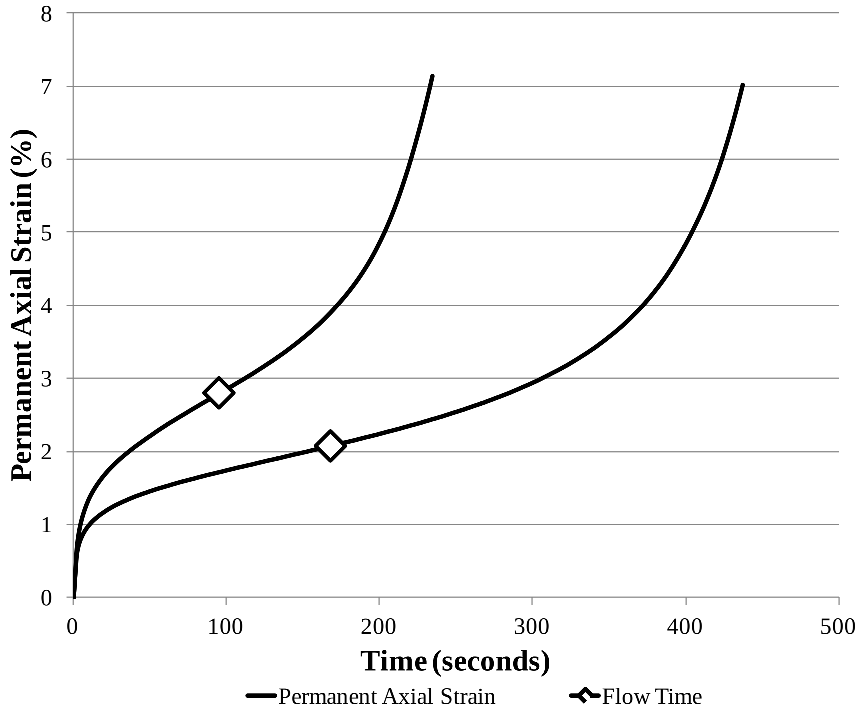

Figure B-33. Mixture NJ-15-7622 Static Creep Test Results

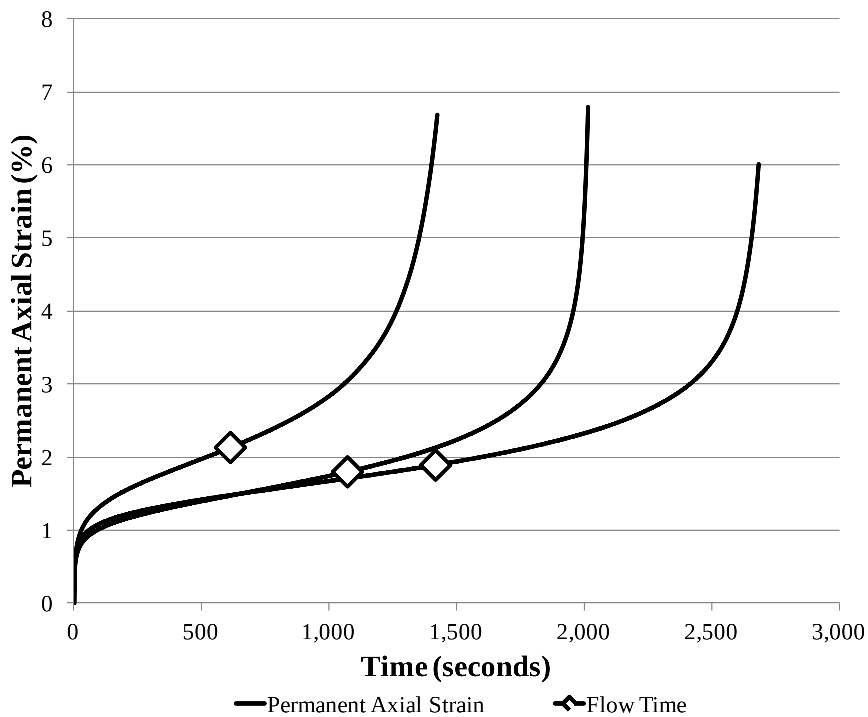

Figure B-34. Mixture NJ-15-8222 Static Creep Test Results

APPENDIX C—ASPHALT PAVEMENT ANALYZER TEST RESULTS

Figures C-1 through C-36 show the asphalt pavement analyzer (APA) test results for all specimens tested using each mixture type. The mixtures are designated by source origin (Arkansas (AR), Massachusetts (MA), New Jersey (NJ) or Mississippi (MS)), followed by the percentage of natural sand, and the binder grade used in the mixture.

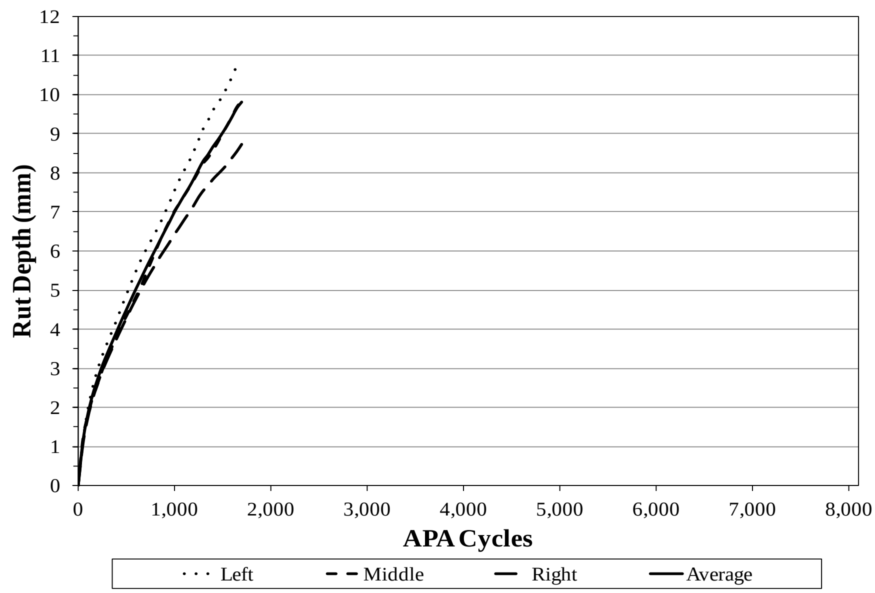

Figure C-1. Mixture AR-10-5828 APA Test Results

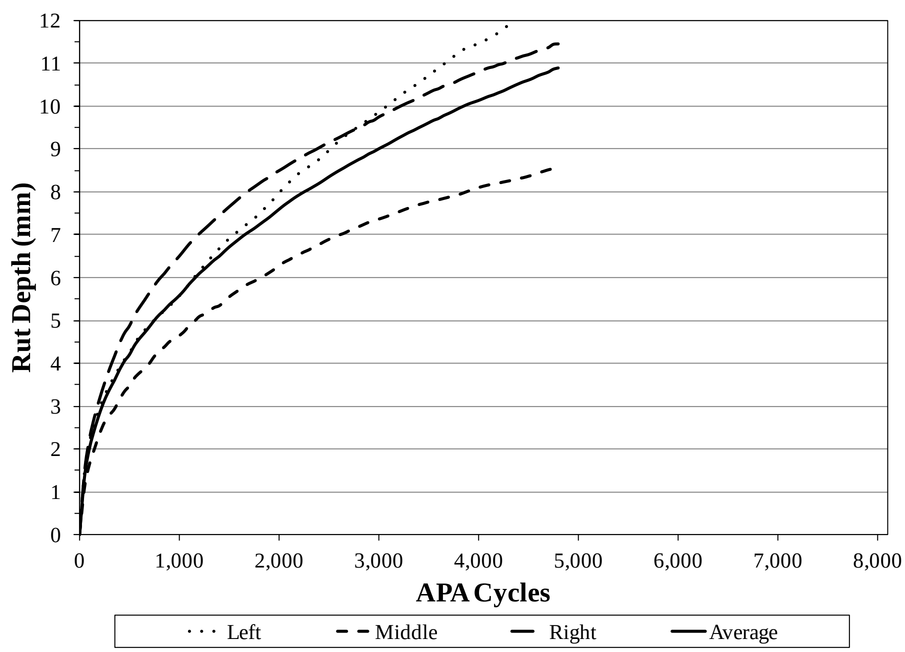

Figure C-2. Mixture AR-10-7028 APA Test Results

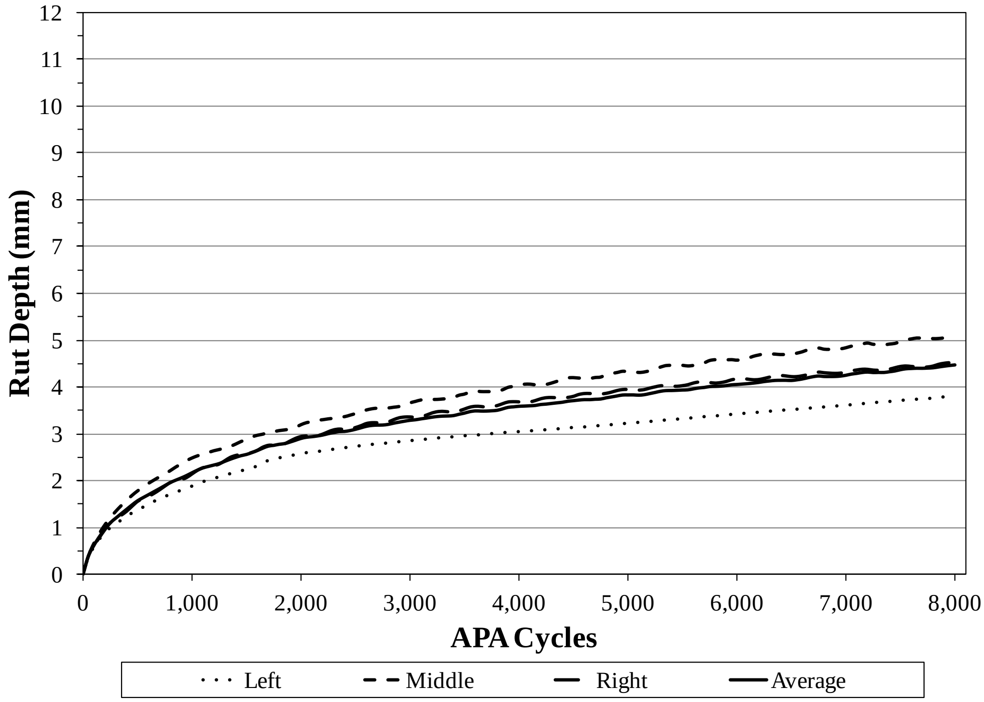

Figure C-3. Mixture AR-10-7628 APA Test Results

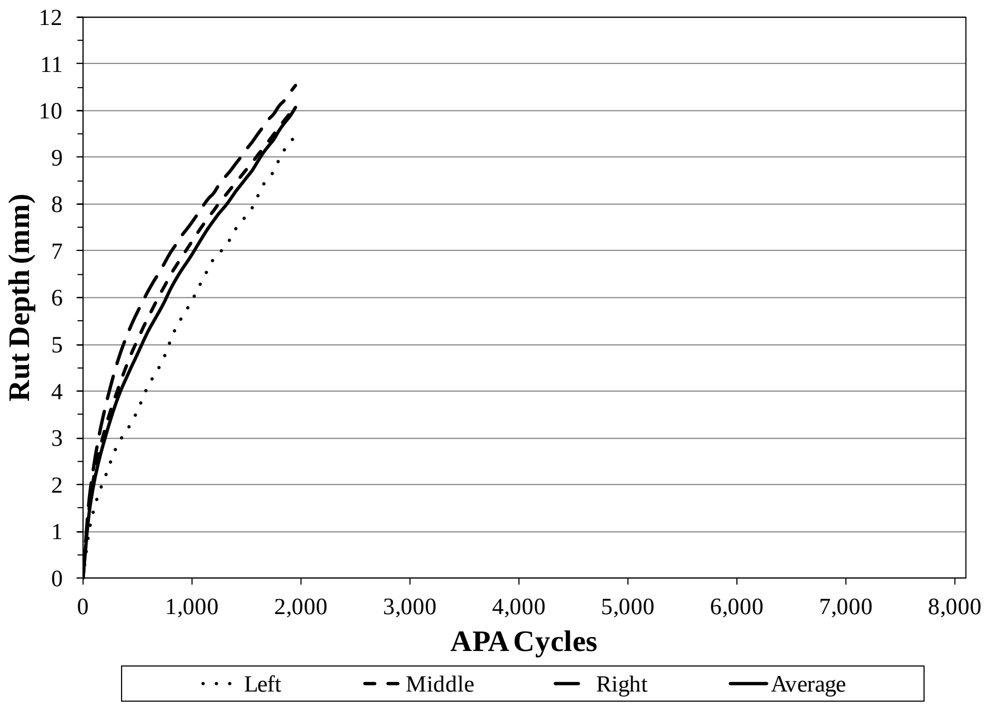

Figure C-4. Mixture AR-10-6422 APA Test Results

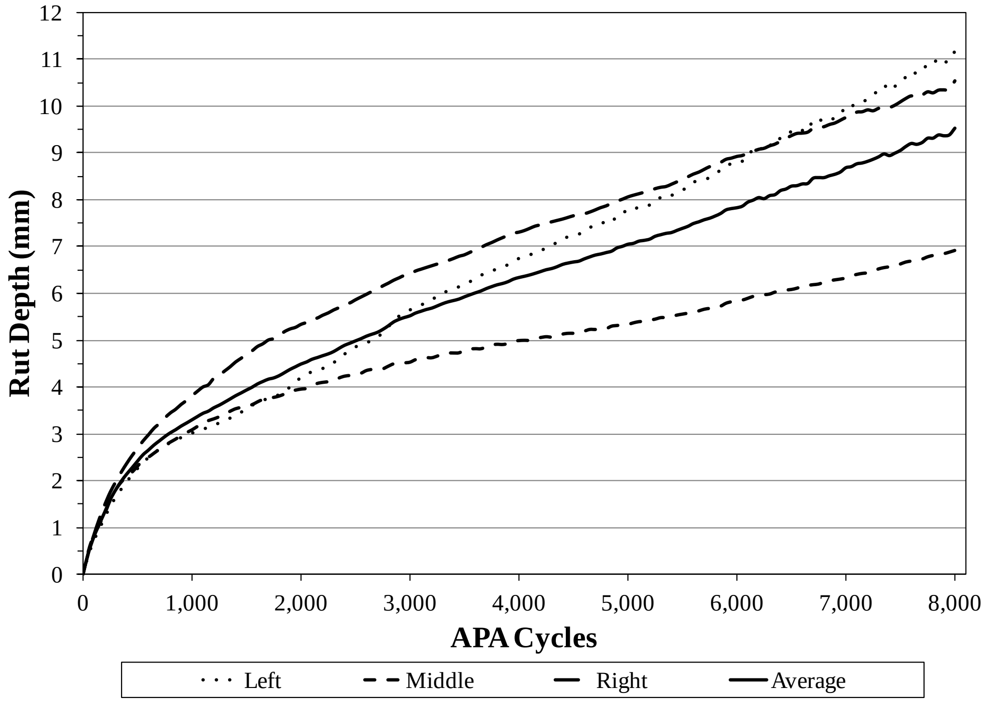

Figure C-5. Mixture AR-10-7622 APA Test Results

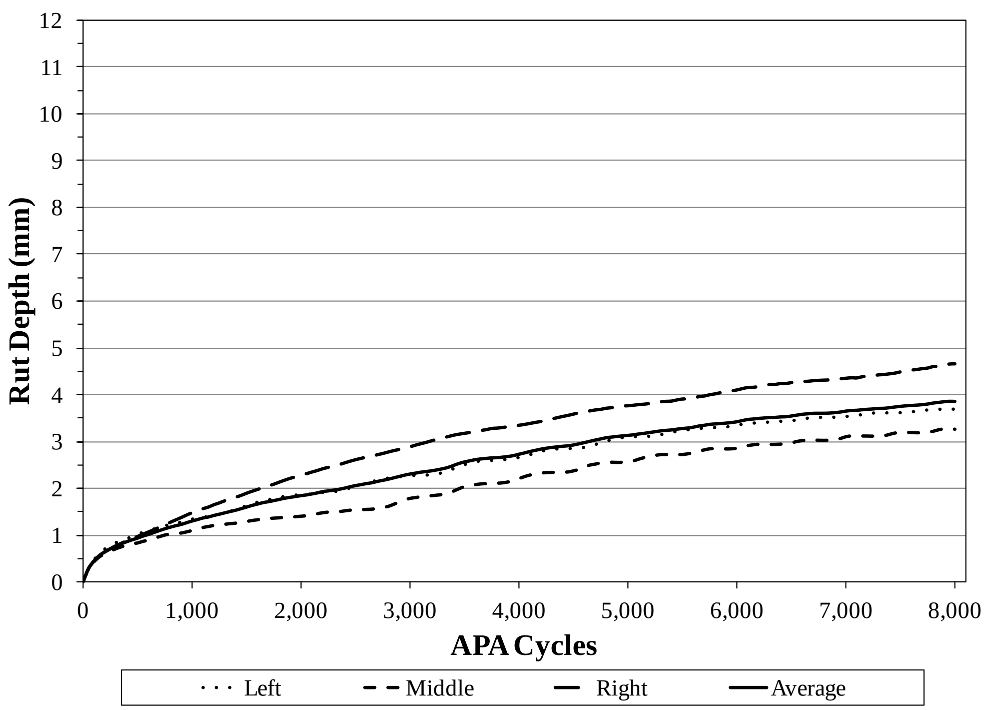

Figure C-6. Mixture AR-10-8222 APA Test Results

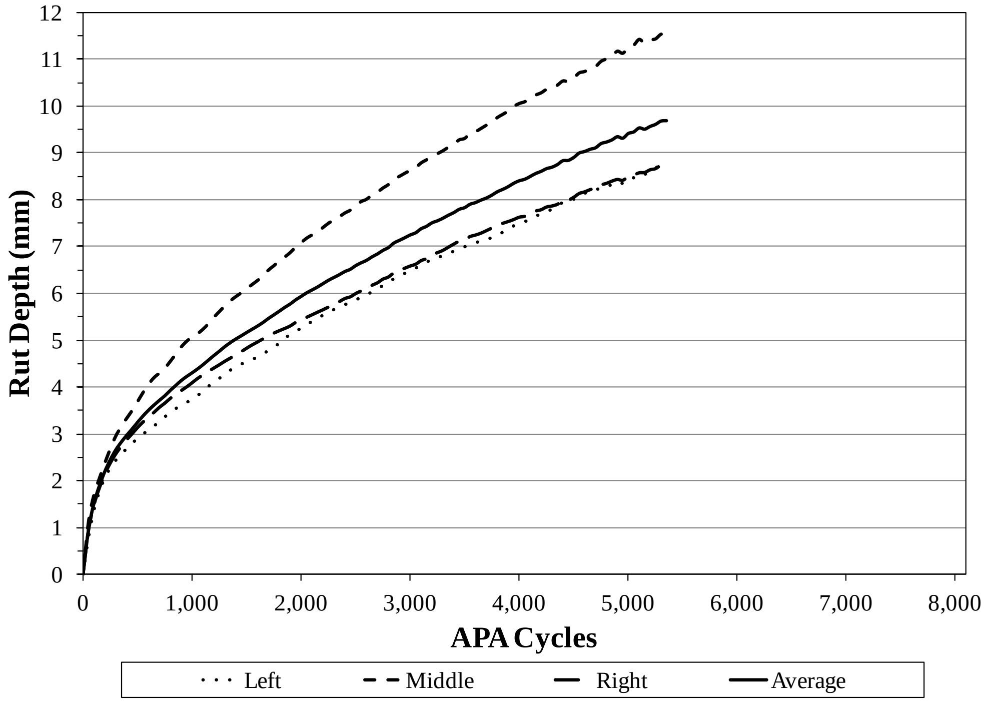

Figure C-7. Mixture MA-00-5828 APA Test Results

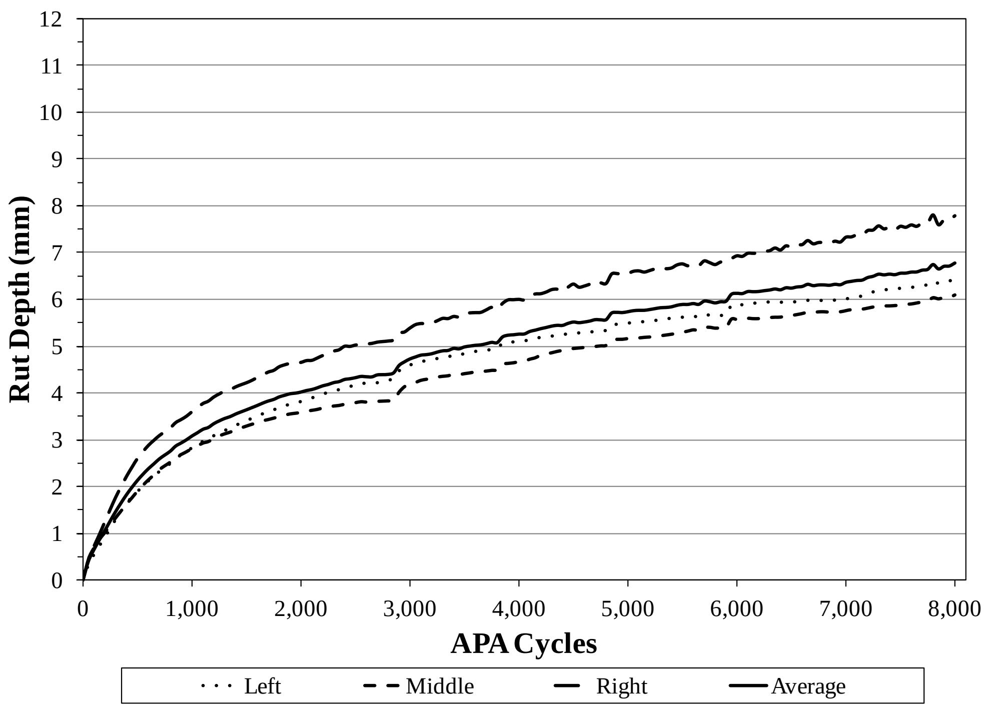

Figure C-8. Mixture MA-00-7028 APA Test Results

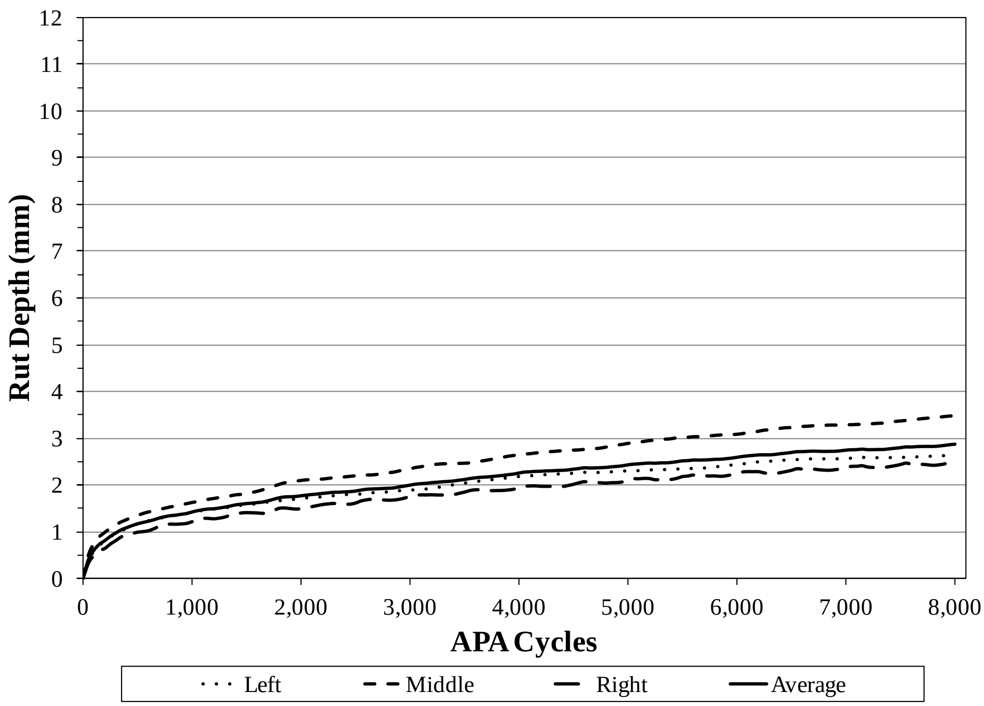

Figure C-9. Mixture MA-00-7628 APA Test Results

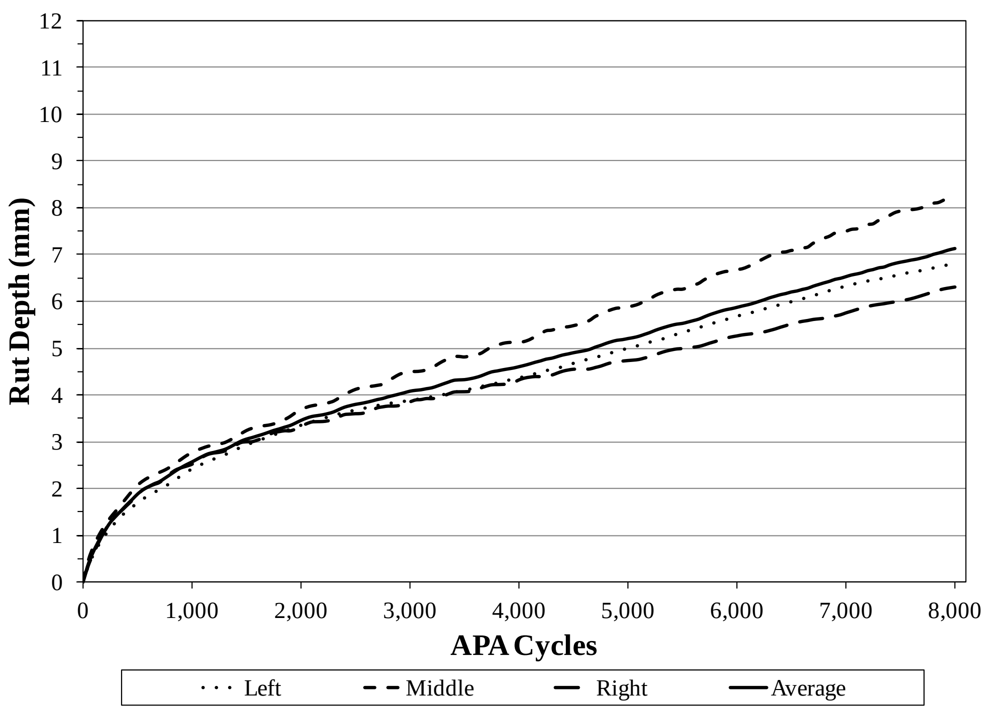

Figure C-10. Mixture MA-00-6422 APA Test Results

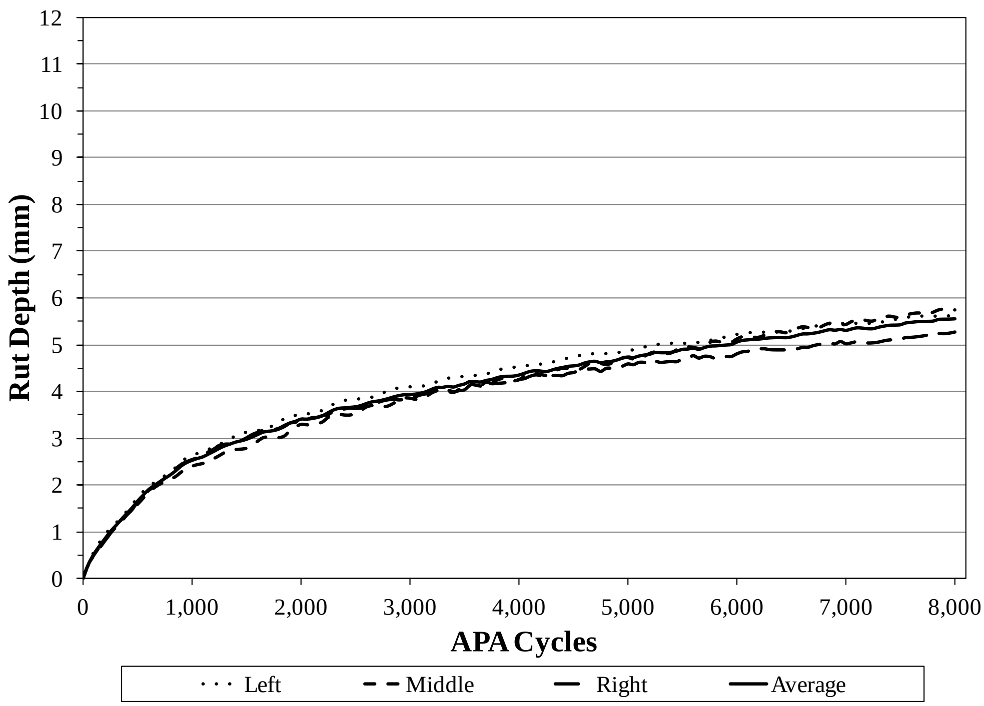

Figure C-11. Mixture MA-00-7622 APA Test Results

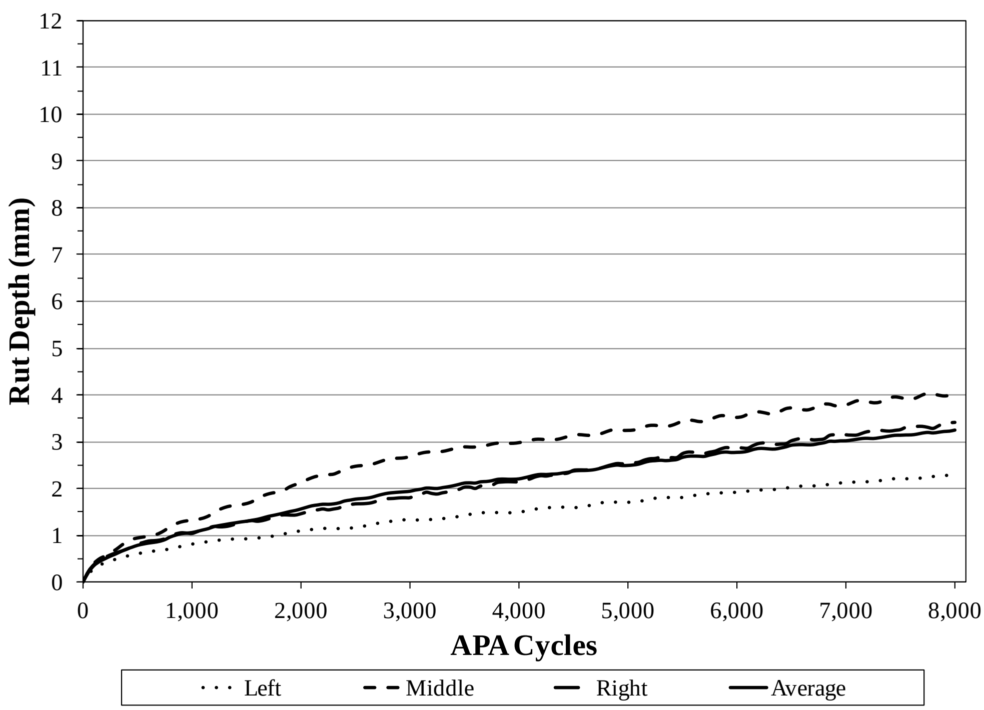

Figure C-12. Mixture MA-00-8222 APA Test Results

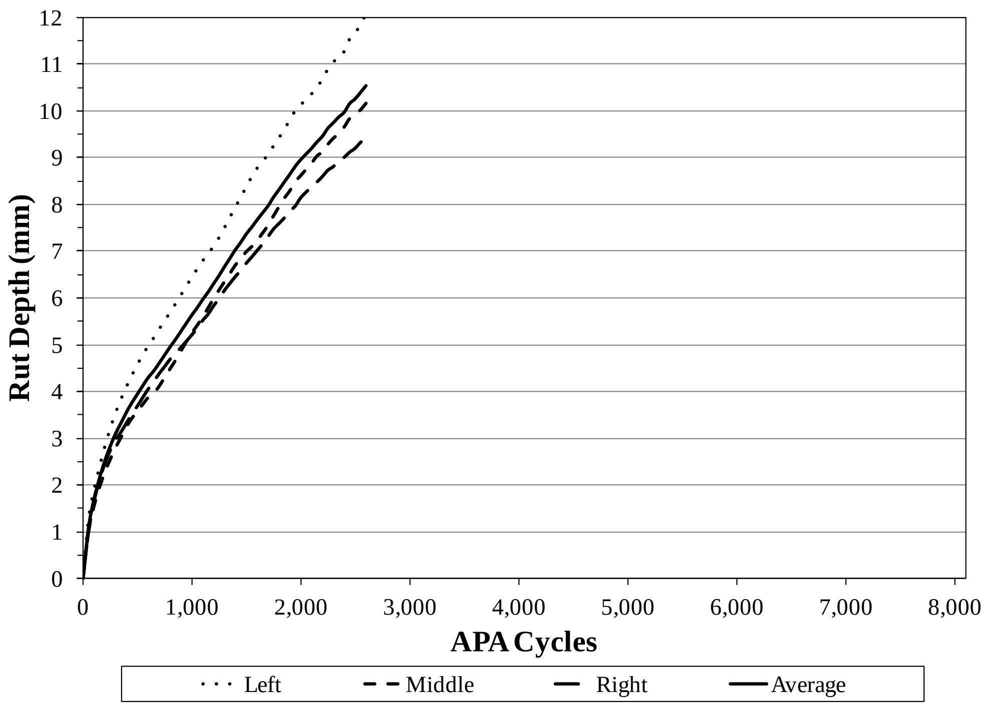

Figure C-13. Mixture MS-07-5828 APA Test Results

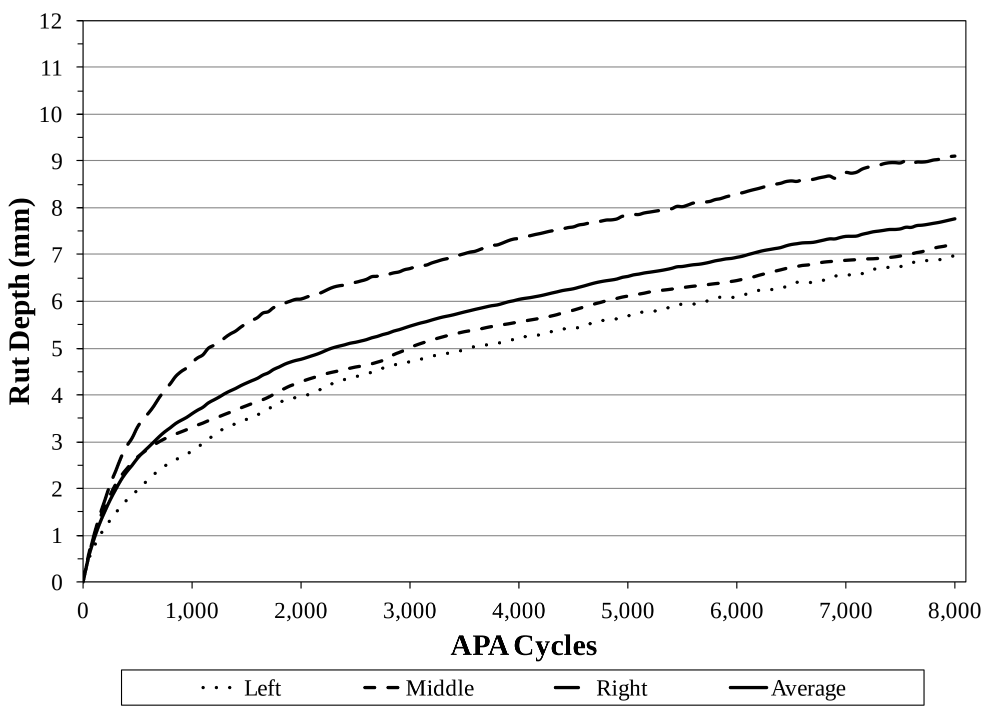

Figure C-14. Mixture MS-07-7028 APA Test Results

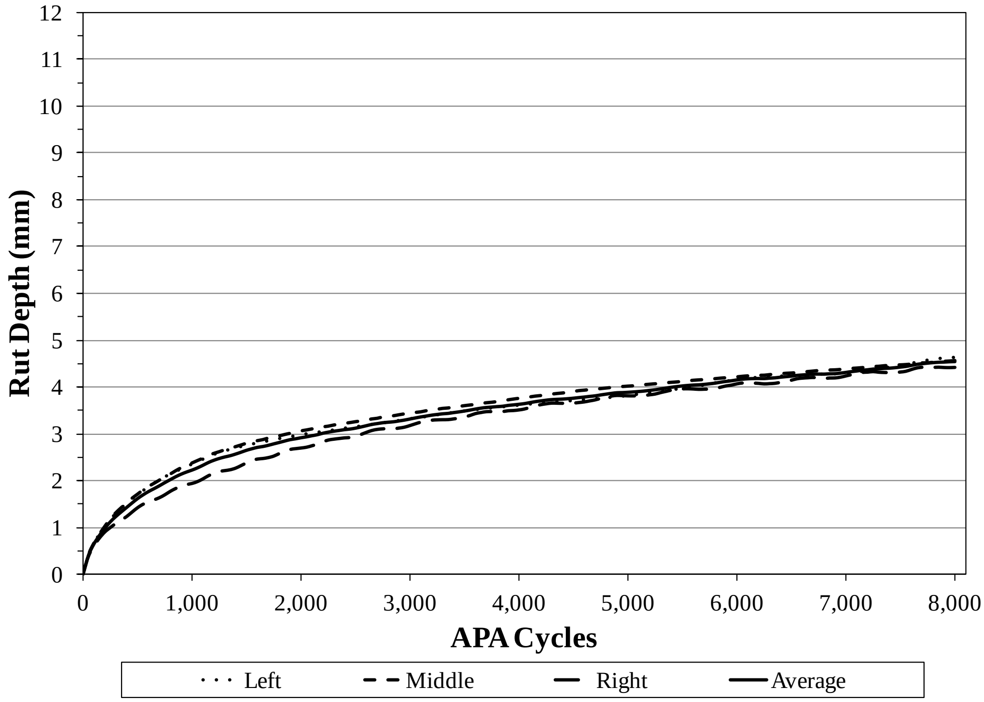

Figure C-15. Mixture MS-07-7628 APA Test Results

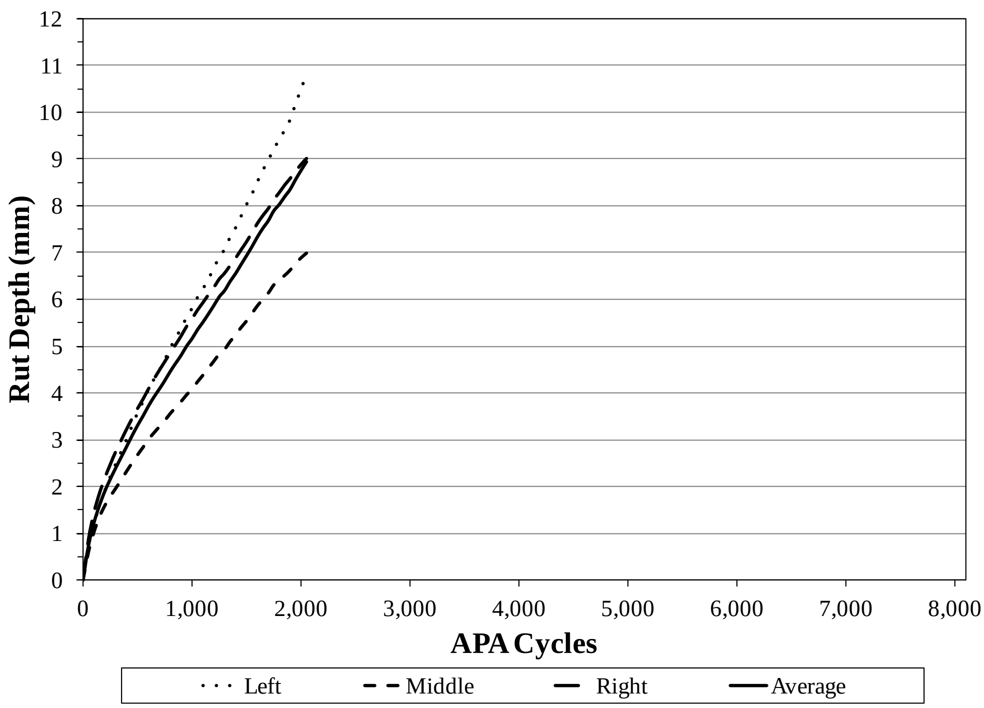

Figure C-16. Mixture MS-07-6422 APA Test Results

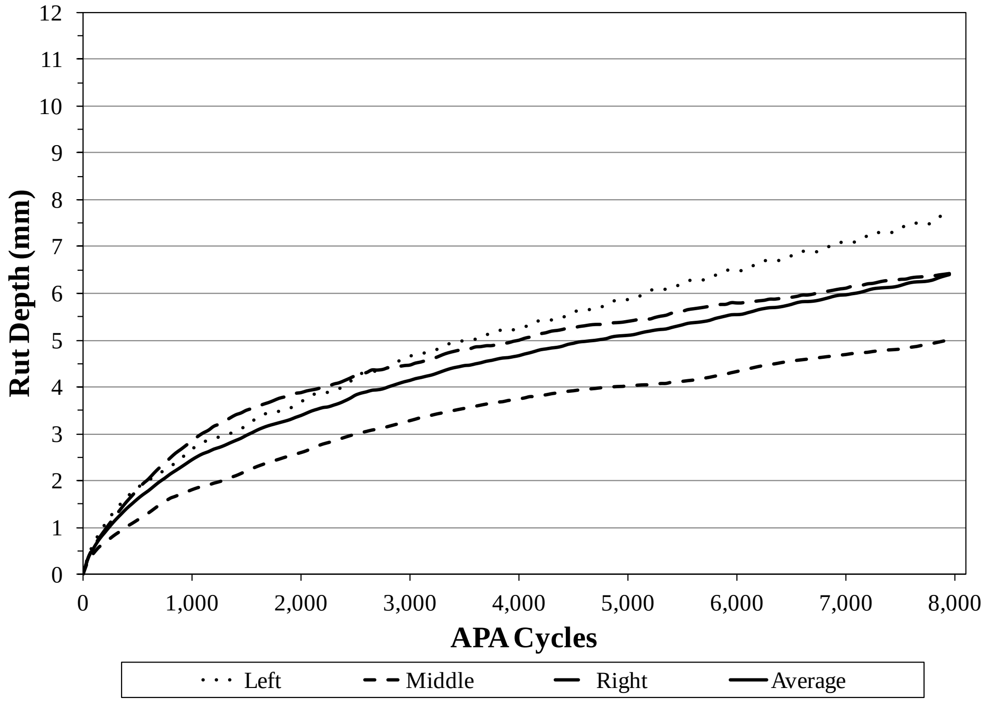

Figure C-17. Mixture MS-07-7622 APA Test Results

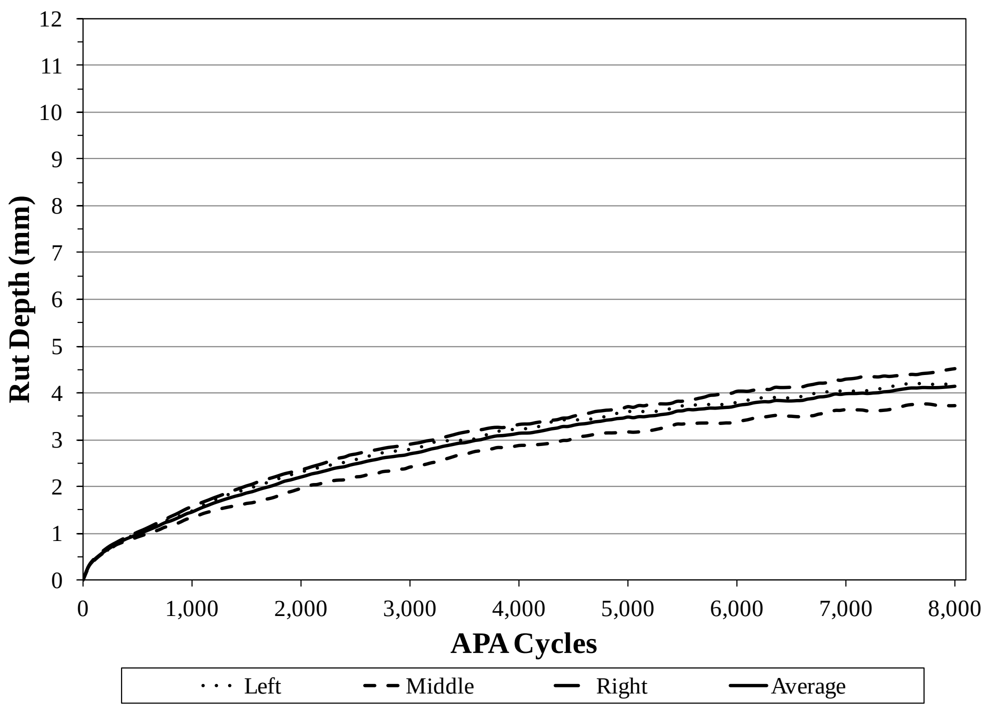

Figure C-18. Mixture MS-07-8222 APA Test Results

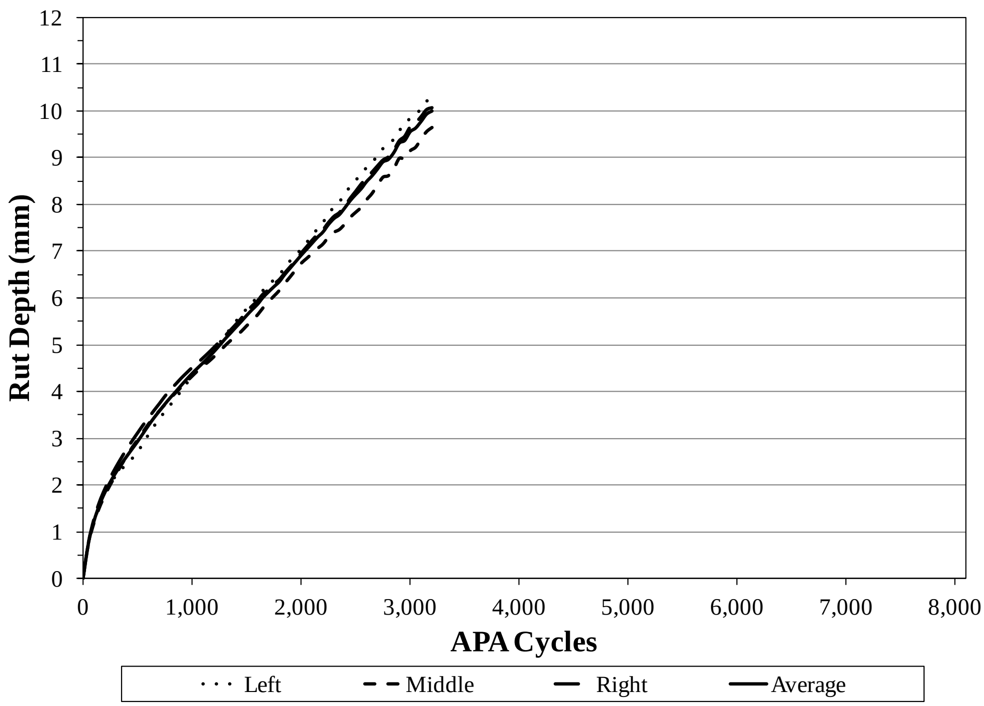

Figure C-19. Mixture MS-15-5828 APA Test Results

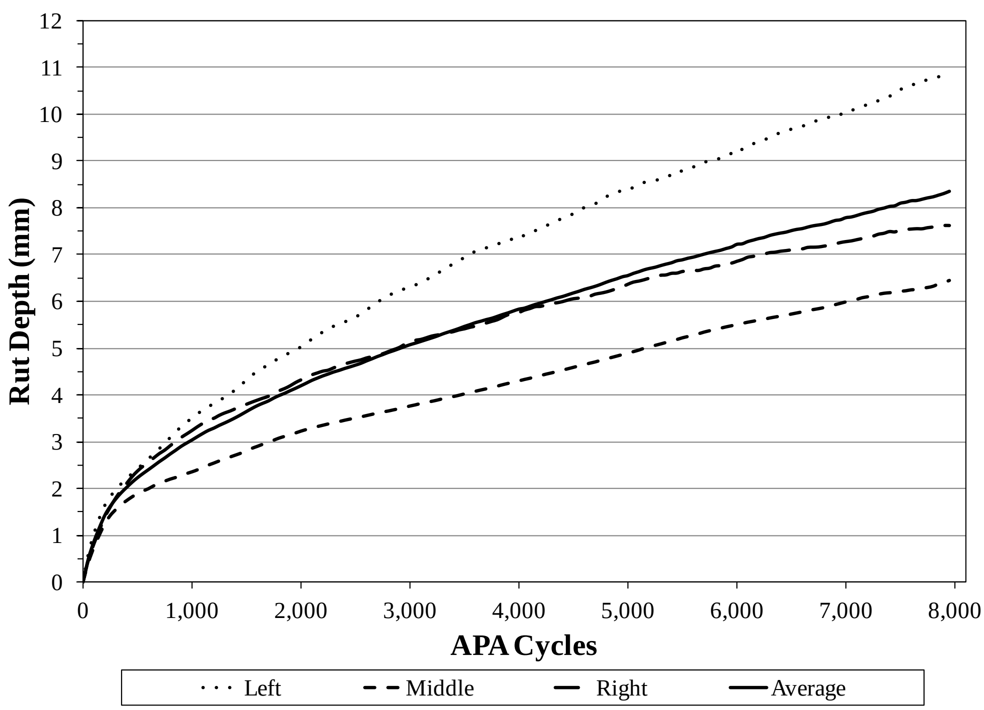

Figure C-20. Mixture MS-15-7028 APA Test Results

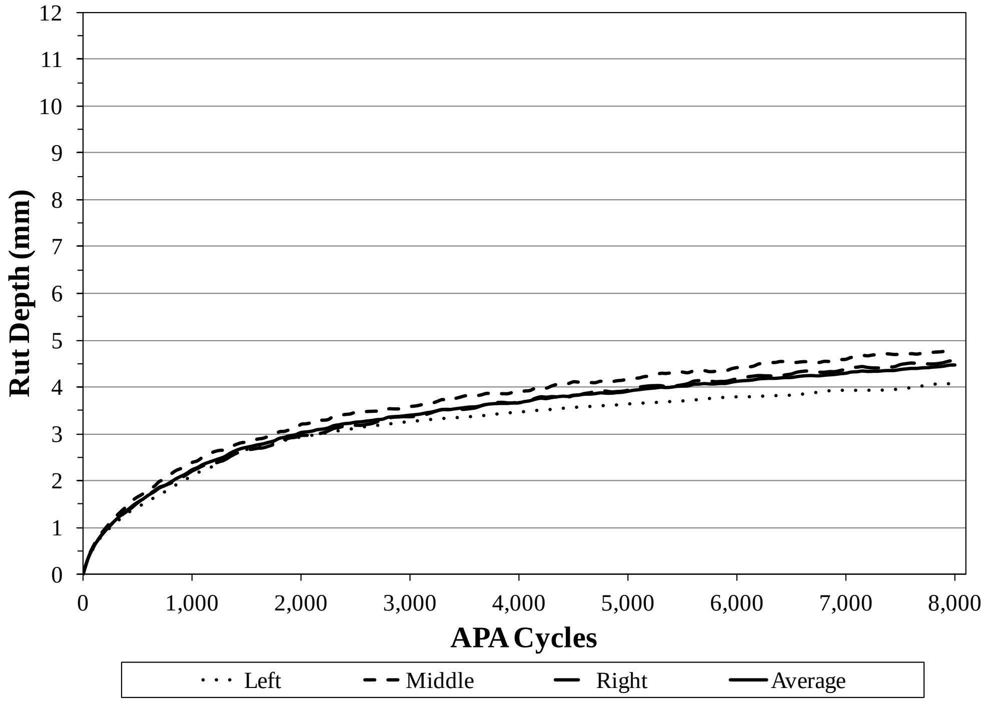

Figure C-21. Mixture MS-15-7628 APA Test Results

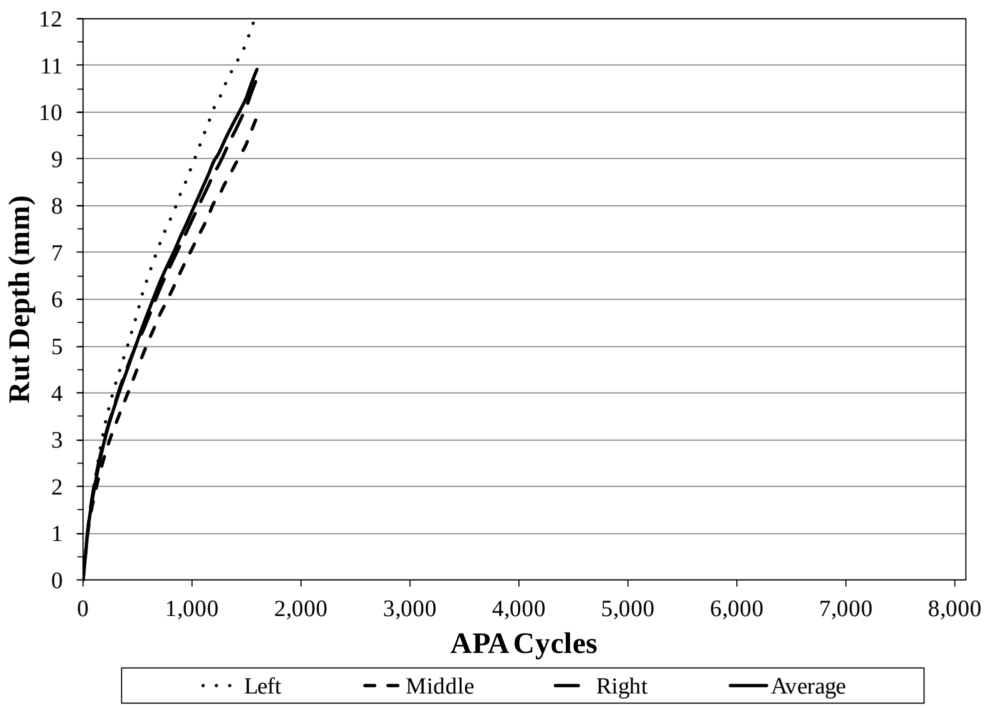

Figure C-22. Mixture MS-15-6422 APA Test Results

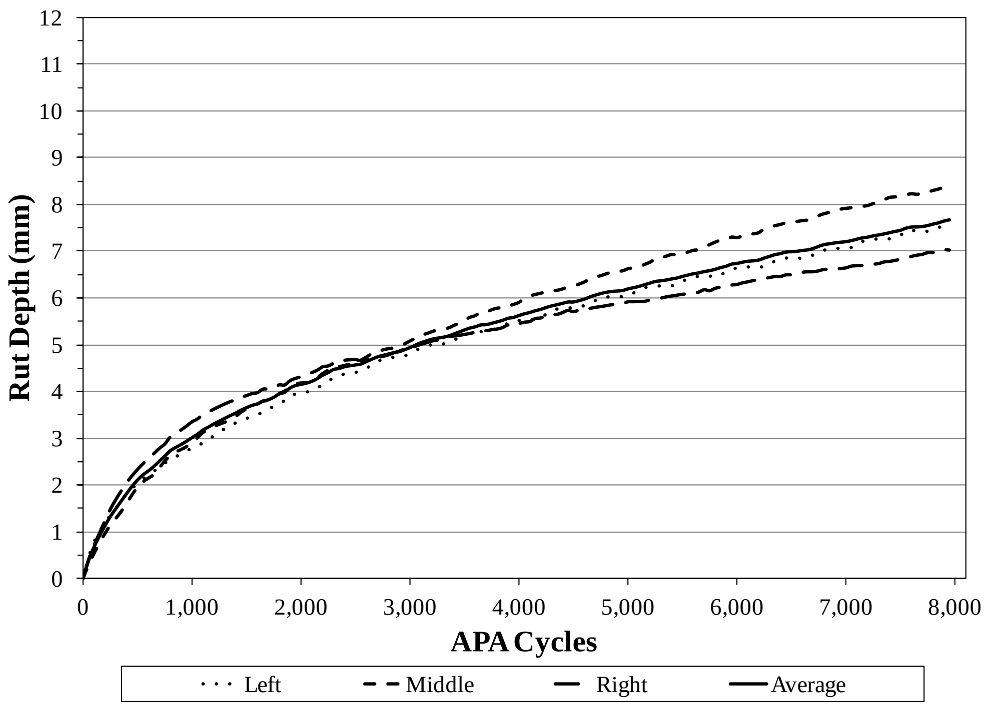

Figure C-23. Mixture MS-15-7622 APA Test Results

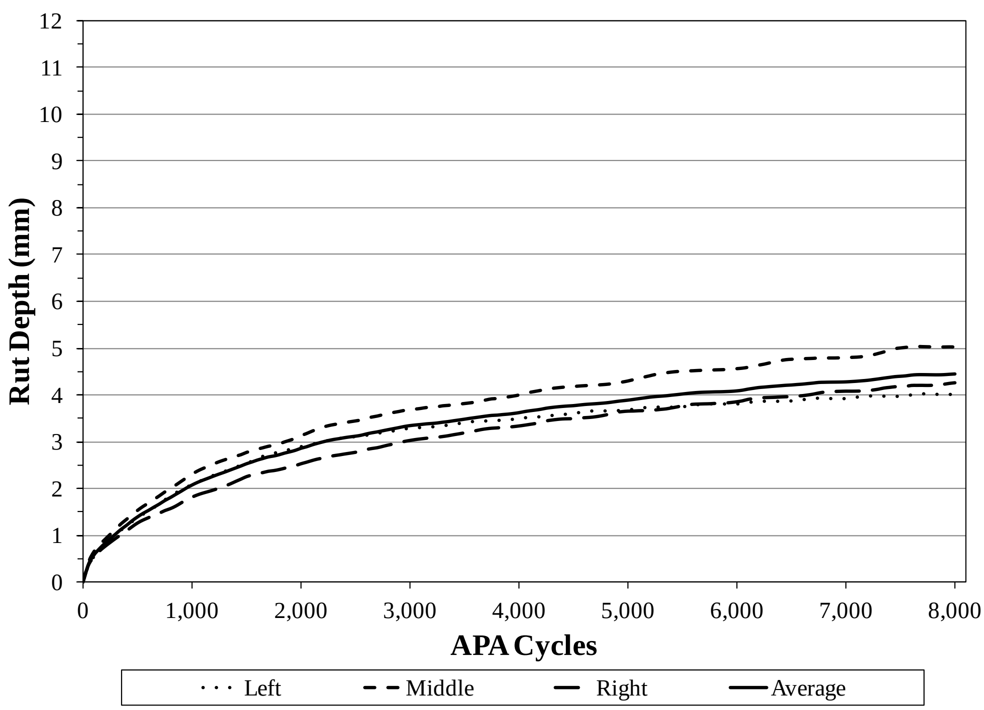

Figure C-24. Mixture MS-15-8222 APA Test Results

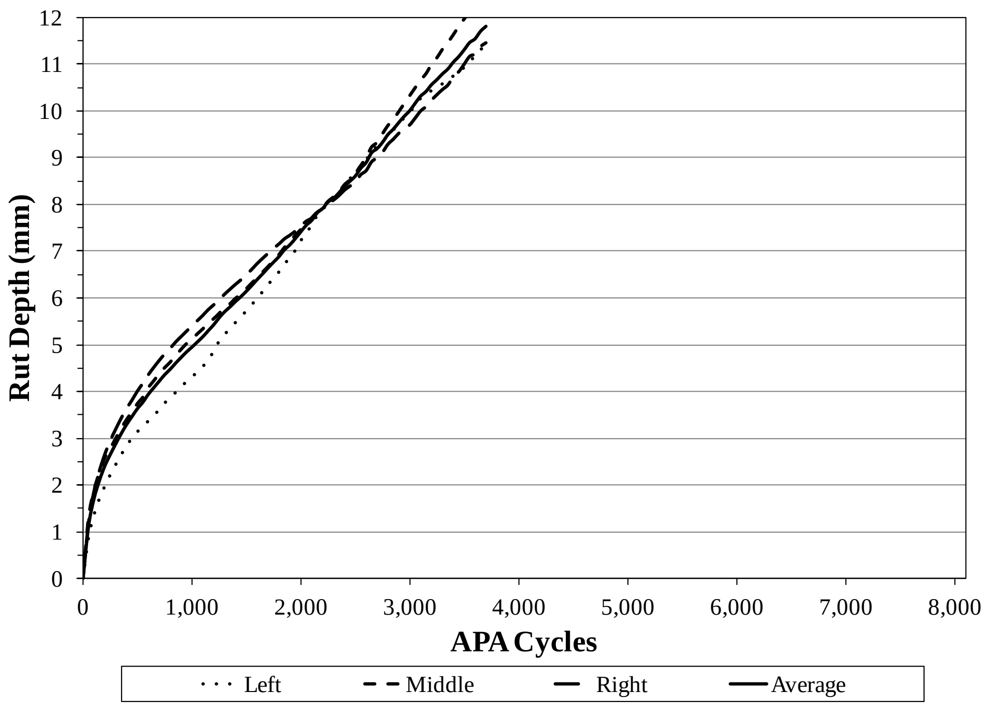

Figure C-25. Mixture NJ-00-5828 APA Test Results

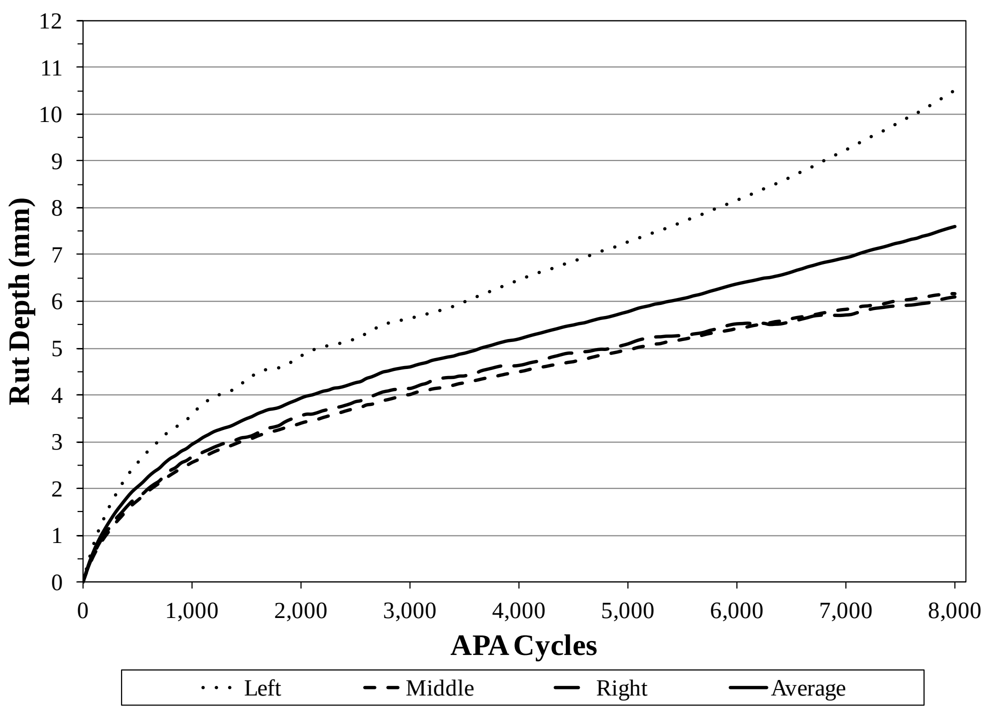

Figure C-26. Mixture NJ-00-7028 APA Test Results

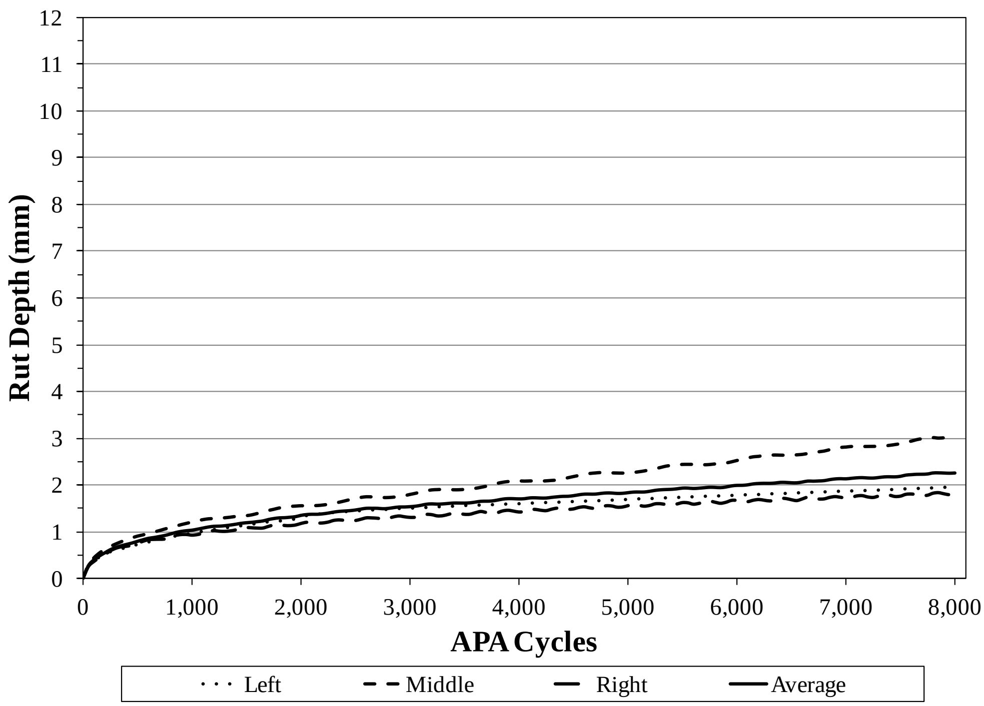

Figure C-27. Mixture NJ-00-7628 APA Test Results

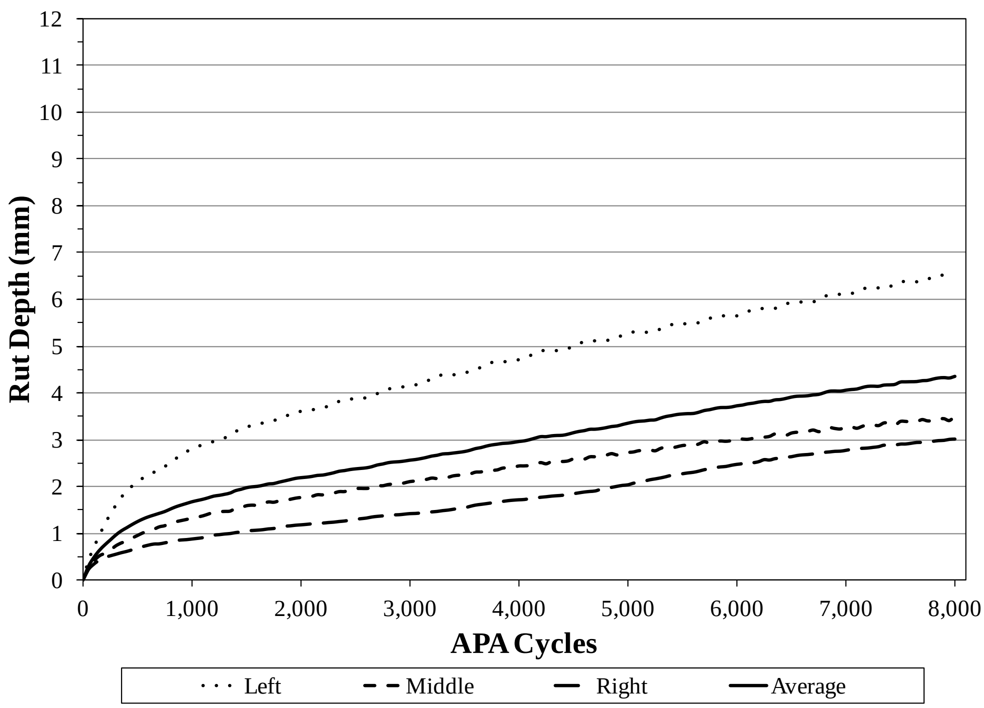

Figure C-28. Mixture NJ-00-6422 APA Test Results

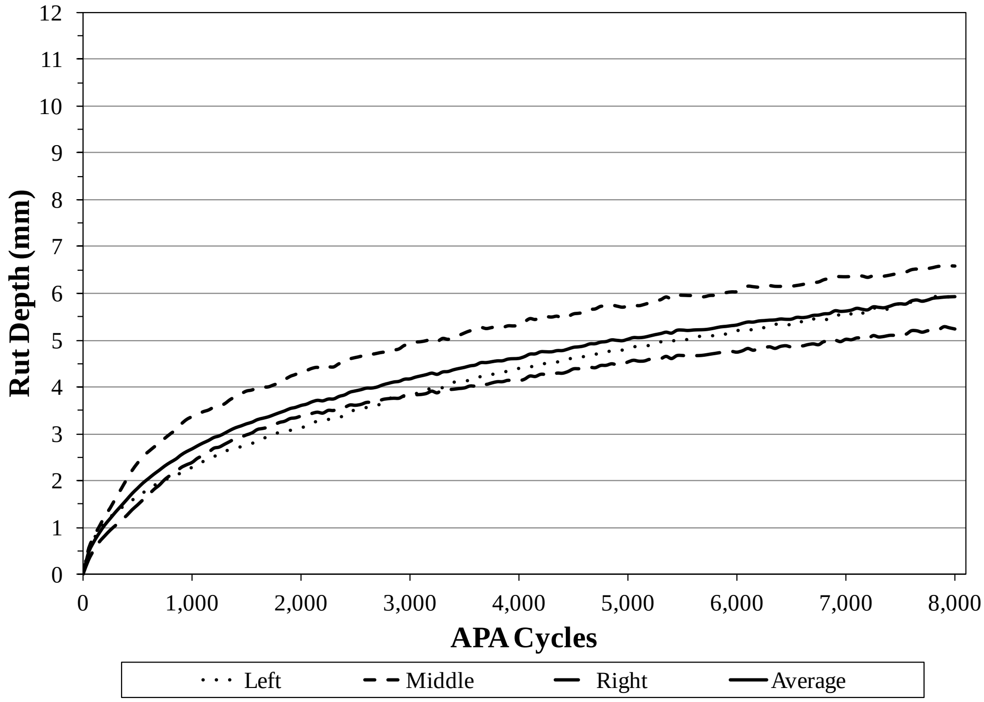

Figure C-29. Mixture NJ-00-7622 APA Test Results

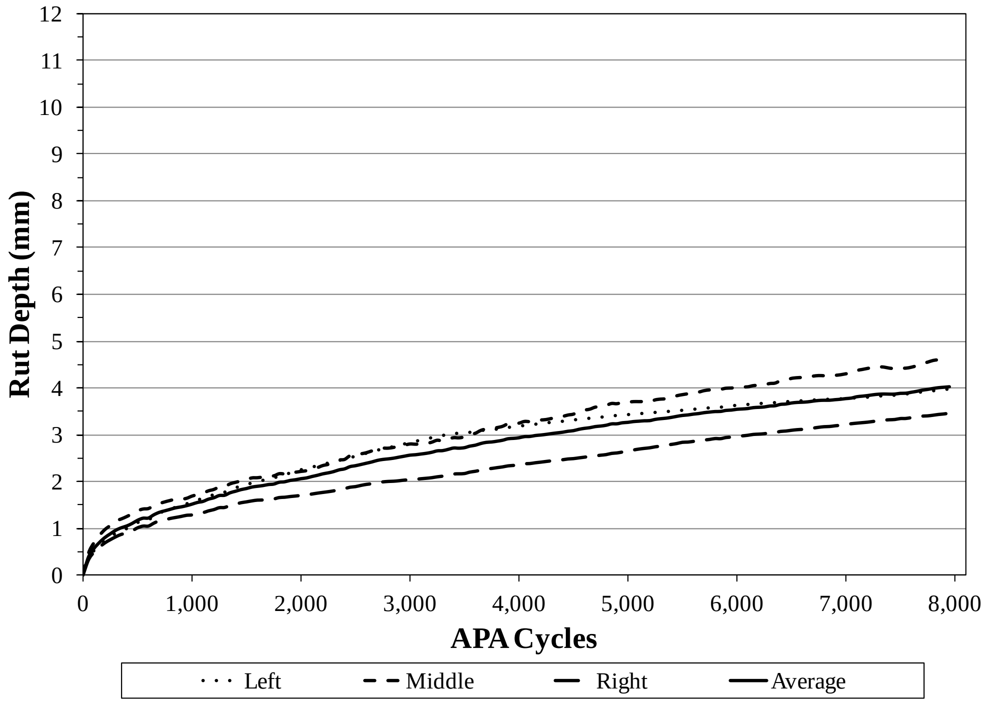

Figure C-30. Mixture NJ-00-8222 APA Test Results

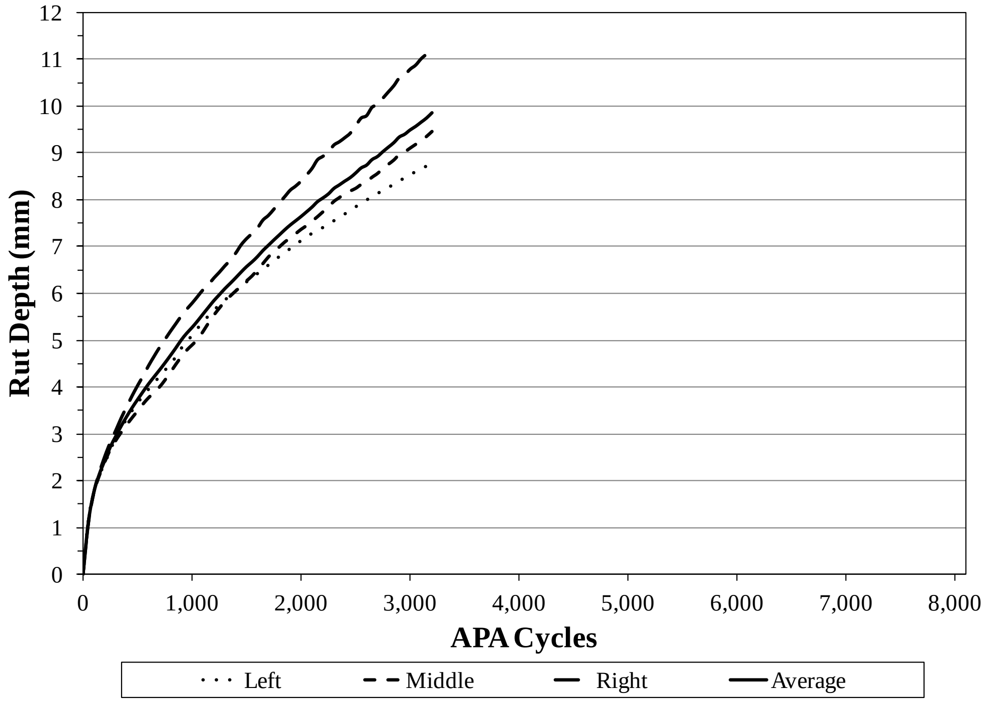

Figure C-31. Mixture NJ-15-5828 APA Test Results

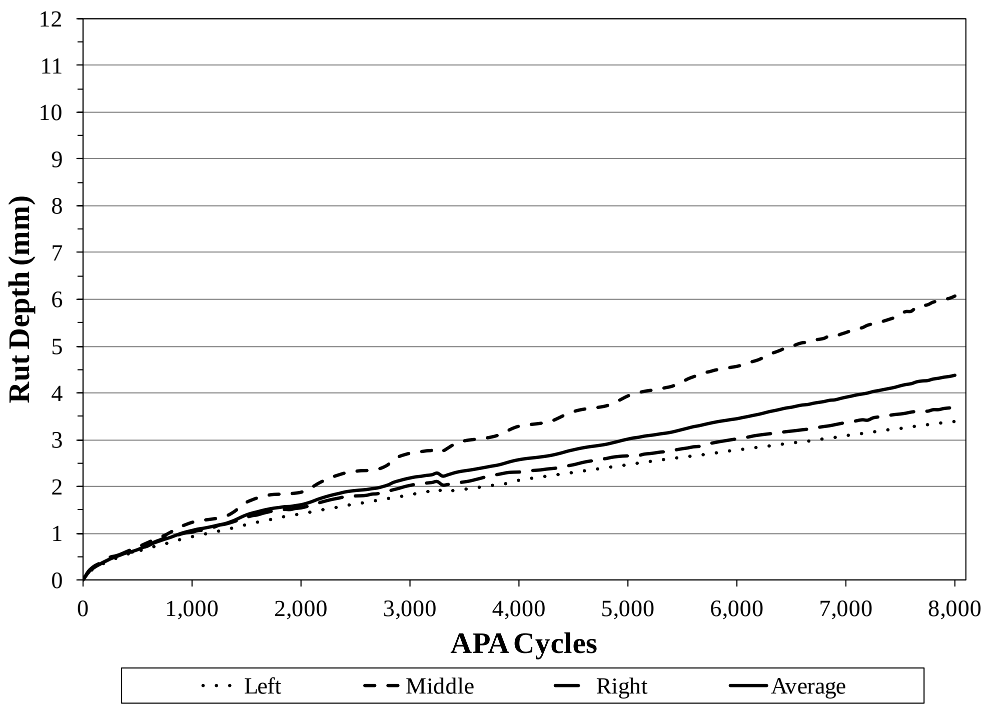

Figure C-32. Mixture NJ-15-7028 APA Test Results

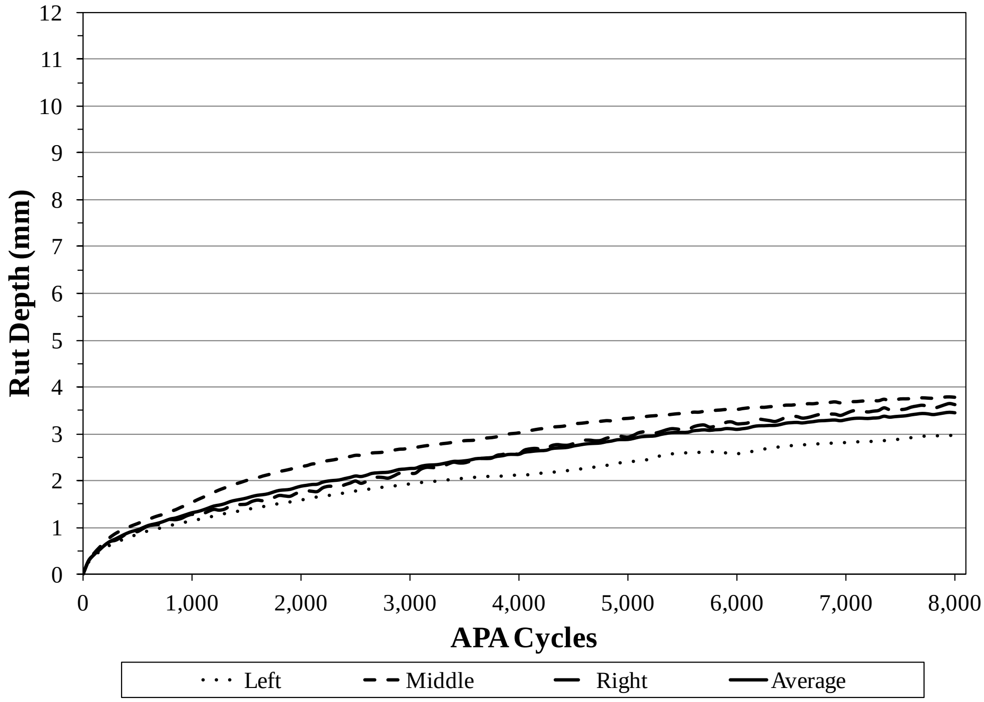

Figure C-33. Mixture NJ-15-7628 APA Test Results

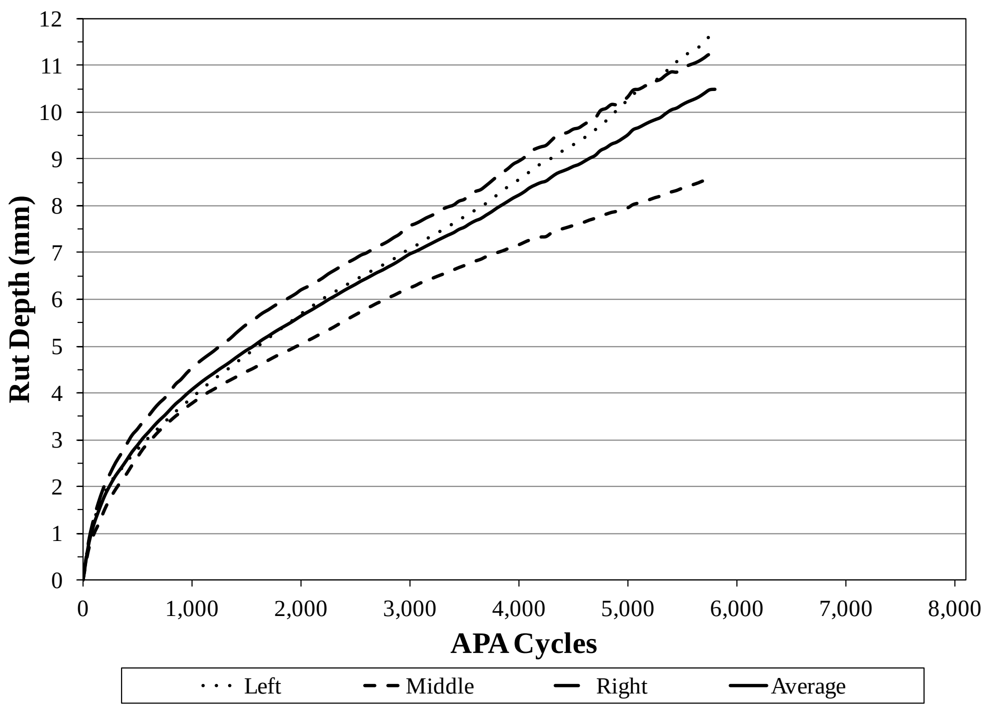

Figure C-34. Mixture NJ-15-6422 APA Test Results

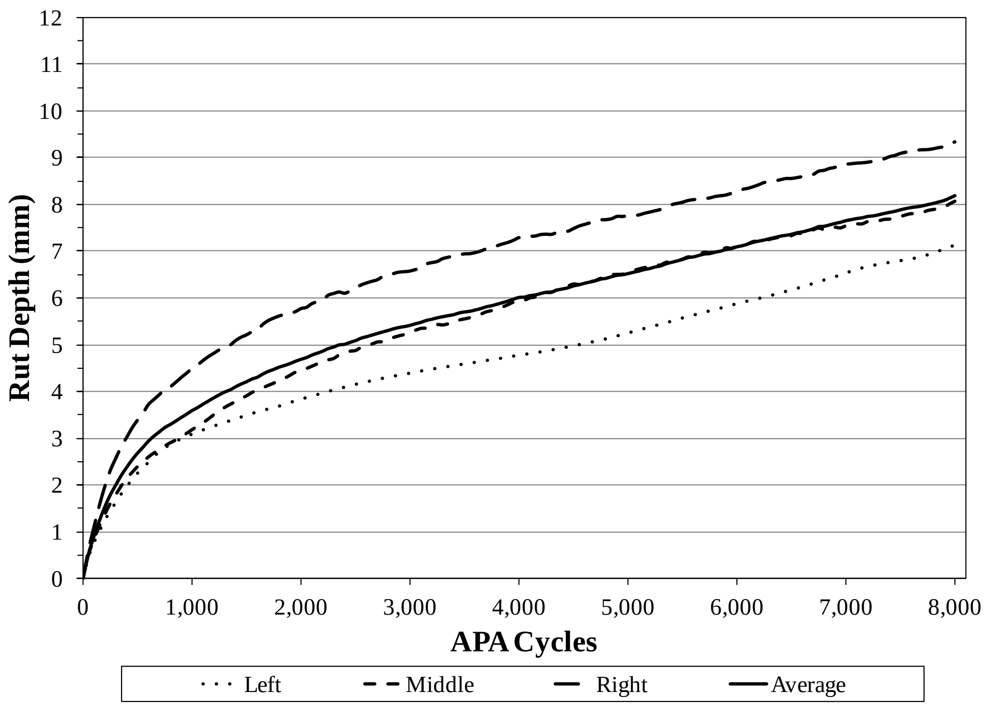

Figure C-35. Mixture NJ-15-7622 APA Test Results

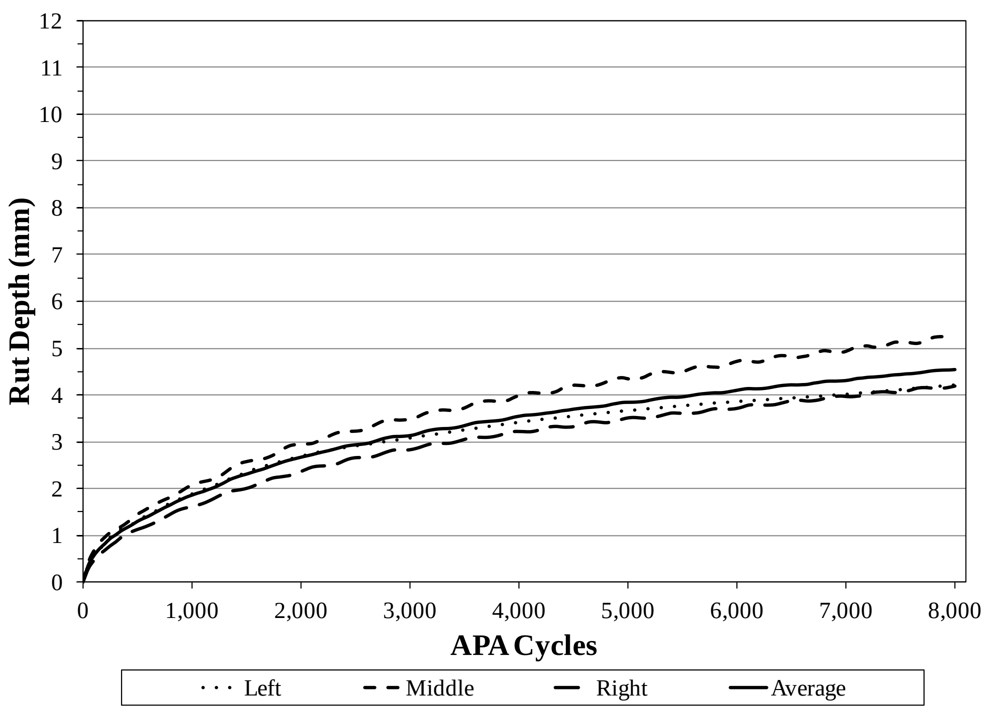

Figure C-36. Mixture NJ-15-8222 APA Test Results