RESEARCH & DEVELOPMENT

Use of Laboratory Testing to Predict Premature Failures in Asphalt

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16. **Abstract**

In last few months, North Carolina Department of Transportation (NCDOT) has encountered recently paved sections exhibiting early distress throughout the state which is a major concern. NCDOT conducted an internal investigation on the causes of early distresses. And this investigation did not yield any conclusive results, hence; NCDOT recognized the need for a more in-depth investigation.

To address these early distresses seen on various projects throughout the state, an investigation was performed to evaluate mixes from projects that have seen early distress, as well as mixes from projects that have not. Various mix design factors may be contributing to the early distresses, but it is largely unknown as to the relative magnitude of the contributions of these factors. These factors include but are not limited to – source aggregate properties, overall mix gradation, percentage of each stockpile used (natural sand content, screening content, coarse aggregate content, recycled asphalt pavement (RAP) content, recycled asphalt shingles (RAS) content), binder content, recycled binder content, virgin binder content, virgin binder grade, mixture voids in mineral aggregates (VMA) & voids filled with asphalt (VFA), and design gyration level.

In this study, four contractor mixes were replicated in the lab. Three mixes from three different contractors which vary in natural sand content, screening content, RAP content, RAS content, binder content, binder grade, & gyration level, were selected for testing. Additionally, a fourth mix was designed in the lab by substituting fine RAP for the RAS in the RAS mixture, changing to a PG 64-22 binder from PG 58-28 binder, and adjusting the binder content as required to meet the required volumetric properties. This study used component materials (aggregate, RAP, RAS, and binder) sampled from the contractor's stockpile.

These four mixes were then subjected to the following tests - Hamburg, IDEAL-CT (using Indirect Tensile Strength Testing), Semi-Circular Bend (SCB) Test, and Asphalt Pavement Analyzer (APA) Test. The results from these tests were examined to determine if variations of the various factors explain the results seen, or if they can be ruled out as a significant variable affecting the results.

The data from this study will provide a better understanding of the important variables (volumetric parameters) affecting the laboratory performance and eventually predict mixtures which might show early distresses in the field.

17. Key Words *Slippage Cracking, Premature Failure, Asphalt Pavements, Asphalt Concrete, IDEAL-CT, SCB, Hamburg, APA, Cracking, Rutting, Recycled Material*	18. Distribution Statement

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Executive Summary

In last few months, North Carolina Department of Transportation (NCDOT) has encountered recently paved sections exhibiting early distress throughout the state which is a major concern.

NCDOT conducted an internal investigation on the causes of early distresses. And this investigation did not yield any conclusive results, hence; NCDOT recognized the need for a more in-depth investigation.

To address these early distresses seen on various projects throughout the state, an investigation was performed to evaluate mixes from projects that have seen early distress, as well as mixes from projects that have not. Various mix design factors may be contributing to the early distresses, but it is largely unknown as to the relative magnitude of the contributions of these factors.

These factors include but are not limited to – source aggregate properties, overall mix gradation, percentage of each stockpile used (natural sand content, screening content, coarse aggregate content, recycled asphalt pavement (RAP) content, recycled asphalt shingles (RAS) content), binder content, recycled binder content, virgin binder content, virgin binder grade, mixture voids in mineral aggregates (VMA) & voids filled with asphalt (VFA), and design gyration level.

In this study, four contractor mixes were replicated in the lab. Three mixes from three different contractors which vary in natural sand content, screening content, RAP content, RAS content, binder content, binder grade, & gyration level, were selected for testing. Additionally, a fourth mix was designed in the lab by substituting fine RAP for the RAS in the RAS mixture, changing to a PG 64-22 binder from PG 58-28 binder, and adjusting the binder content as required to meet the required volumetric properties. This study used component materials (aggregate, RAP, RAS, and binder) sampled from the contractor's stockpile.

These four mixes were then subjected to the following tests - Hamburg, IDEAL-CT (using Indirect Tensile Strength Testing), Semi-Circular Bend (SCB) Test, and Asphalt Pavement Analyzer (APA) Test. The results from these tests were examined to determine if variations of the various factors explain the results seen, or if they can be ruled out as a significant variable affecting the results.

The goal of the study was to identify the volumetric parameters that affect the field performance or premature failure of asphalt mixtures. Since there was no field performance data available the study focused on identifying which volumetric parameters correlate well or poorly with the cracking and rutting performance indicators of the asphalt mixtures from the lab testing.

All four mixtures were ranked on their performance based on the main performance parameters from each lab test. Rut depth (mm) from APA test and Hamburg test was used to rank the mixture's rutting performance. IDEAL-CT Index from IDEAL-CT test and Flexibility Index from SCB test were used to rank the mixture's cracking performance.

All mixtures performed well in both the rutting tests – APA and Hamburg. Mix 3 performed the best in both tests and Mix 4 was worst. However, all four mixtures had rut depth below the maximum allowable rut depths. Mix 2 performed the best as per the IDEAL-CT test while mix 3

performed the worst. Mix 1 performed the best as per the SCB test. Mixes 2, 3, and 4 all had very low values to rank them.

% RBR and asphalt content in RAP seemed to be a good indicator to how the mix will perform in the rutting tests such as Hamburg and APA tests. % Screenings, % Sand, Sand Equivalent value, % RBR, % RAP in the mix, and RAP PG grade (high) seem to have a good correlation with the IDEAL-CT index. None of the volumetric parameters seem to have a good correlation with the Flexibility Index from SCB test.

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1. Introduction

In last few months, North Carolina Department of Transportation (NCDOT) has encountered recently paved sections exhibiting early distress throughout the state which is a major concern.

NCDOT conducted an internal investigation on the causes of early distresses. And this investigation did not yield any conclusive results, hence; NCDOT recognized the need for a more in-depth investigation.

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These factors include but are not limited to – source aggregate properties, overall mix gradation, percentage of each stockpile used (natural sand content, screening content, coarse aggregate content, recycled asphalt pavement (RAP) content, recycled asphalt shingles (RAS) content), binder content, recycled binder content, virgin binder content, virgin binder grade, mixture voids in mineral aggregates (VMA) & voids filled with asphalt (VFA), and design gyration level.

In this study, four contractor mixes were replicated in the lab. Three mixes from three different contractors which vary in natural sand content, screening content, RAP content, RAS content, binder content, binder grade, & gyration level, were selected for testing. Additionally, a fourth mix was designed in the lab by substituting fine RAP for the RAS in the RAS mixture, changing to a PG 64-22 binder from PG 58-28 binder, and adjusting the binder content as required to meet the required volumetric properties. This study used component materials (aggregate, RAP, RAS, and binder) sampled from the contractor's stockpile.

These four mixes were then subjected to the following tests - Hamburg, IDEAL-CT, SCB test, and APA Test. The results from these tests were examined to determine if variations of the various factors explain the results seen, or if they can be ruled out as a significant variable affecting the results.

1.1 Research Need Definition

There is a need to address early distresses in the field using a suitable and easily replicated laboratory test. Premature failures on newly constructed projects can cause undue delays to the traveling public and additional funds for repairs. If these distresses are being caused by certain parameters of asphalt mixtures, then identifying those parameters will help design mixes which are not susceptible to premature distresses in the field.

The results from this study can lead to developing guidelines or specifications to identify asphalt mixtures that are susceptible to early distresses.

1.2 Research Objectives

The main objective of the proposed study was to check the feasibility of using IDEAL-CT, SCB, Hamburg, and APA tests to identify asphalt mixtures which can be susceptible to premature distresses in the field. An additional objective was to identify various asphalt mixture parameters that can cause premature distresses in asphalt mixtures the field.

2. Research Tasks and Methodology

The research tasks mentioned below were done to fulfil the objectives of the study. These tasks were decided based on consultation and feedback from NCDOT.

Task 1. Material Acquisition and Characterization: Aggregate material and recycled material was obtained from the respective asphalt plants. Asphalt binder was collected from the respective asphalt terminals used by the asphalt plant. Additional material acquisition was done for another research study by Dr. Cassie Castorena at North Carolina State University.

The asphalt was chemically extracted and recovered from the recycled material. The recovered asphalt liquid was then PG graded. LA Abrasion testing was done on the coarse aggregates and source properties for the course and fine aggregates – coarse and fine aggregate specific gravity and sulfate soundness testing - were evaluated in the lab. The sand equivalency test was done on all the sand sources.

Task 2. IDEAL-CT: Indirect Tensile Strength (IDT) test was done on each mixture. IDEAL-CT analysis was done on the results to calculate the Cracking Test Index for all the four mixtures.

Task 3. Semi Circular Bend Test: Semi-Circular Bend (SCB) test was done on each mixture. Illinois Flexibility Index (I-FIT) analysis was done on the results to calculate the Flexibility Index for all the four mixtures.

Task 4. Hamburg Test: Hamburg wheel tracking testing was done on each mixture. Rut depth was measured, and stripping inflection point was estimated for each of the four mixtures.

Task 5. APA Specimens: Specimens were prepared for the Asphalt Pavement Analyzer (APA) Test for all the four mixtures. The samples were submitted to the NCDOT for rut testing using the APA.

Task 6. Analysis and Conclusions: Results from the above tests were used to do a regression analysis to identify the parameters or variables in the asphalt mixtures that might be causing early distresses.

Task 7. Final Report: The test results and findings from the proposed project are summarized in this report. Included are also possible parameter or variables in the asphalt mixtures that might be causing early distresses of asphalt mixtures in the field.

3. Material Characterization

Table 1 shows the tests performed on the materials to characterize the aggregates and asphalt materials used in this study.

Table 1. Tests done to characterize the aggregates and asphalt materials in this study

Test	Standard Test Method	Material Type
Specific Gravity	AASHTO T84, T85	Coarse and Fine Aggregate
LA Abrasion	ASTM C131	Coarse Aggregates
Soundness Test	AASHTO T104	Coarse and Fine Aggregate
Sand Equivalency	AASHTO T176	Sand
Asphalt Content – Chemical Extraction and Recovery	ASTM D2172, D5404	RAP and RAS
PG Grading	AASHTO M320	RAP and RAS

3.1 Specific Gravity

The specific gravity test was done on all the coarse and fine aggregate material sources. The specific gravity of coarse aggregates was done as per AASHTO T85, "Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate", and the specific gravity of fine aggregates was done as per AASHTO T84, "Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate." Table 2 shows the bulk specific gravity and the % absorption values for each of the material sources used in this study. All four mixes used the same source of 78Ms.

Table 2. Bulk Specific gravity and % absorption values for the material sources used in the study

Material Source	Bulk Specific Gravity	Absorption
78Ms	2.704	0.42%
Washed Screenings #1	2.718	0.17%
Washed Screenings #2	2.624	0.54%
Sand #1	2.610	0.52%
Sand #2	2.631	0.47%
Sand #3	2.596	0.51%

3.2 LA Abrasion Test

The LA Abrasion Test was done on the 78M aggregate source to determine the resistance to degradation of the coarse aggregates. The test was done as per ASTM C131, "Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine." Table 3 shows the LA Abrasion test results for the 78M material.

Table 3. LA Abrasion test results for the 78M material

Material Source	Loss by Abrasion
78Ms	21%

3.3 Soundness Test

The sulfate soundness test was done on all aggregate sources – 78Ms, Washed Screenings, and Sand. This test is done to check the soundness of aggregates when subjected to weathering action. This test was done as per AASHTO T104, "Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate." In this study Sodium Sulfate solution was used to do the soundness test and the test was run for 5 cycles. Table 4 shows the cumulative percentage loss values due to the soundness test for each of the material sources used in this study.

Table 4. Cumulative Percentage Loss values due to the soundness test for all material sources

Material Source	Cumulative Percentage Loss
78Ms	0.4%
Washed Screenings #1	1.1%
Washed Screenings #2	1.3%
Sand #1	1.5%
Sand #2	1.8%
Sand #3	1.6%

3.4 Sand Equivalency

Sand equivalency test was done on all the sand sources used in this study. This test is done to determine the relative proportions of fine dust or claylike material in soils or aggregates. This test was done as per AASHTO T176, "Standard Method of Test for Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test."

Table 5. Sand Equivalent readings for the three sand material sources used in the study

Material Source	Clay Reading	Sand Reading	Sand Equivalent
Sand 1	9.1	4.0	44%
Sand 2	4.8	4.4	92%
Sand 3	8.9	4.0	45%

3.5 Asphalt Recovery from Recycled Material

Asphalt liquid was chemically extracted and recovered from all the recycled materials used in this study. This was done for two purposes – to find out the asphalt content in the recycled material source, and to do PG grading on the asphalt from each of the sources. Asphalt was chemically extracted following ASTM D2172, "Standard Test Methods for Quantitative Extraction of Asphalt Binder from Asphalt Mixtures." The extracted asphalt was then recovered as per ASTM D5404, "Standard Practice for Recovery of Asphalt from Solution Using the Rotary Evaporator." The asphalt from all the RAP and one RAS sources was extracted and recovered. PG grading was done on this recovered asphalt as per AASHTO M320, "Standard Specification for Performance-Graded Asphalt Binder."

Table 6. Asphalt content and asphalt PG grades for all the recycled material used in the study

Recycled Material Source	Asphalt Content (Trimat)	Asphalt Content (Contractor)	PG Grade
RAP 1	4.1	4.4	PG 88-10
RAP 2	4.8	5.0	PG 76-16
RAP 3	5.5	4.7	PG 88-16
RAS	17.8	19.4	N/A

3.6 Mixture characterization

Optimum pills were made to verify air voids at design asphalt content. No changes were needed to be made to the original blend percentages or asphalt content for voids adjustments. The only changes that were required were due to the percentage of recycled binder contributed to the blends. Since we performed chemical extraction of the RAP, which is considered more accurate, we used these results for the calculation of virgin binder to be added. The average difference between our percent asphalt content and the contractors for the RAP material was 0.3% higher and for the RAS material was 1.6% higher. Results of our verifications are included in the Appendix.

3.7 Material Composition

A total of four mixtures were tested in this study. Mix 1 and Mix 4 were from the same asphalt plant. Mix 1 was modified by replacing the RAS with RAP to create mix 4. All four mixtures use the same source of 78Ms. Mix 1, Mix 3, and Mix 4 use the same source for washed screenings (washed screenings 1) while Mix 2 uses washed screenings 2. Mix 1 and Mix 4 use Sand 1, Mix 2 uses Sand 2, and Mix 3 used Sand 3. Table 7 shows the percentage of each type of material in the asphalt mixtures. Tables 8 and 9 show the gradations for the material sources used in this study. Table 10 shows the lab gradations and the JMF gradations of the four mixtures used in the study.

Table 7. Proportion of each material source for all four mixes

Mixture No.	78M %	Screenings %	Sand %	RAP %	RAS %
Mix 1	24.0	16.0	31.0	25.0	4.0
Mix 2	26.0	28.0	25.0	21.0	0.0
Mix 3	23.0	12.0	35.0	30.0	0.0
Mix 4	20.0	16.0	34.0	29.0	0.0

Table 8. Gradations for the 78M and the recycled material sources used in this study

Sieves (mm)	% Passing				
	78 M	RAP 1	RAP 2	RAP 3	RAS
19.0	100.0	100.0	100.0	100.0	100.0
12.5	98.0	98.7	99.2	100.0	100.0
9.5	86.0	93.1	95.7	95.0	100.0
4.75	24.0	75.3	81.0	76.0	98.4
2.36	2.0	62.2	68.5	58.0	97.1
1.18	2.0	52.1	58.4	46.0	82.3
0.600	1.5	40.3	44.7	37.0	61.9
0.300	1.0	26.6	28.7	27.0	50.6
0.150	0.8	15.2	16.0	16.7	39.8
0.075	0.5	10.3	9.6	9.5	30.2

Table 9. Gradations for the Screenings and Sand material sources used in this study

Sieves (mm)	% Passing				
	Screenings 1	Screenings 2	Sand 1	Sand 2	Sand 3
19.0	100.0	100.0	100.0	100.0	100.0
12.5	100.0	100.0	100.0	100.0	100.0
9.5	100.0	100.0	100.0	100.0	99.0
4.75	97.0	97.0	98.0	99.0	99.0
2.36	77.0	74.0	94.0	96.0	81.0
1.18	47.0	53.0	82.0	87.0	62.0
0.600	31.0	38.0	54.0	62.0	49.0
0.300	19.0	27.0	24.0	18.0	20.0
0.150	11.8	18.0	8.0	2.5	14.0
0.075	8.9	11.9	5.4	1.0	4.1

Table 10. Lab and JMF gradations of all four mixes tested in the study

Sieves (mm)	%Passing							
	Mix 1		Mix 2		Mix 3		Mix 4	
	Lab	JMF	Lab	JMF	Lab	JMF	Lab	JMF
19.0	100	100	100	100	100	100	100	100
12.5	99	100	99	100	100	100	99	100
9.5	95	97	95	96	95	94	95	97
4.75	74	78	75	77	75	74	76	78
2.36	61	65	60	65	56	56	64	65
1.18	50	54	50	51	42	45	52	54
0.600	35	41	37	40	33	32	36	41
0.300	19	23	19	23	18	18	20	23
0.150	10	11	10	13	12	10	10	11
0.075	7.0	6.6	6.4	6.6	6.2	6.0	7.1	6.6

4. IDEAL-CT Testing

Indirect Tensile Asphalt Cracking Test (IDEAL-CT) test was done on all four mixtures to evaluate the cracking potential of the asphalt mixtures at intermediate temperatures. The IDEAL-CT test is like the indirect tensile strength test (ASTM D6931) in that it uses the same specimen geometry, loading rate, and the test temperature as the indirect tensile strength test. The load vs displacement curve is used to calculate the cracking test index (CT_{index}) to determine the rate of the growth rate of the crack in the specimen. IDEAL-CT analysis (ASTM D8225-19) is performed on the results from the IDT testing of the specimens to calculate the Cracking Test Index [1, 2].

Figure 1 shows a typical output for the IDT test.

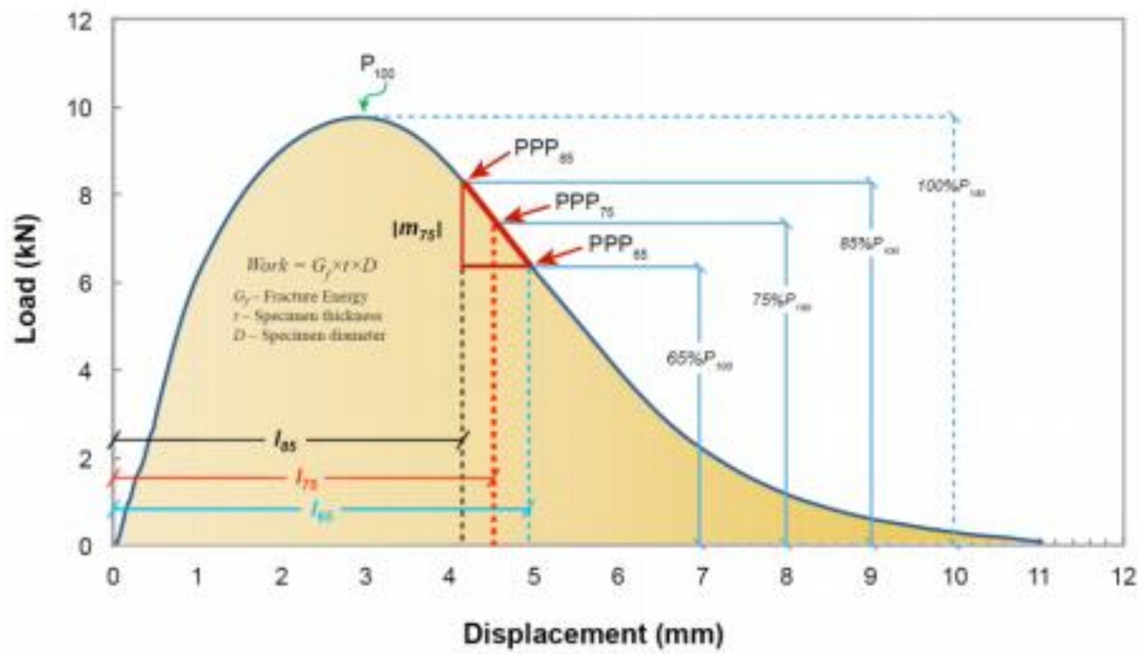

Figure 1. A typical output from the IDT test (Source – Zhou., F) [2]

4.1 IDEAL-CT Calculations

The cracking test index (CT_{index}) is calculated using the equation given below.

$$CT_{index} = (t/62) \times (G_f/|m_{75}|) \times (l_{75}/D)$$

t = thickness of specimen (mm), G_f = fracture energy, m_{75} = slope at 75% post peak load, l_{75} = displacement at 75% post peak load, D = diameter of the specimen (mm).

4.2 Specimen Preparation and Testing

Four specimens were prepared with 150 mm diameter and 62 mm tall with 7.0% ± 0.5% air voids. During the preparation of the specimens, the loose mixture was short term aged for 4 hours at 135 °C. Prior to testing, the specimens were conditioned at 25 °C for two hours and then were tested at a loading rate of 50mm/min on a Marshall Press.

4.3 Test Results

Table 11 shows the IDEAL-CT test results for all four mixtures. The higher the IDEAL-CT value, the more resistance to cracking the mixture has. From the results we can see that mix 2 has the highest IDEAL-CT value while mix 3 has the lowest. Mix 1 and 4 have similar IDEAL-CT values. These two are similar mixtures with mix 4 being prepared by replacing the RAS in mix 1 with RAP. Figure 2 shows the variation of Energy to Peak and the peak load for the four mixes used in the study. Figure 3 shows the variation of IDEAL-CT parameter for the four mixes.

The NCDOT does not have any criterion or recommendation for the IDEAL-CT test currently.

Table 11. IDEAL-CT test results for all the four mixtures used in this study

Mixtures	Peak Load (kN)	IDT (kPa)	Total Energy (Joules)	Energy to Peak (Joules)	IDEAL-CT
Mix 1	18.1	1238.7	85.4	42.6	55.3
Mix 2	14.8	1013.0	78.5	35.4	78.7
Mix 3	25.7	1759.3	93.4	48.4	22.5
Mix 4	20.5	1406.5	93.0	45.5	49.6

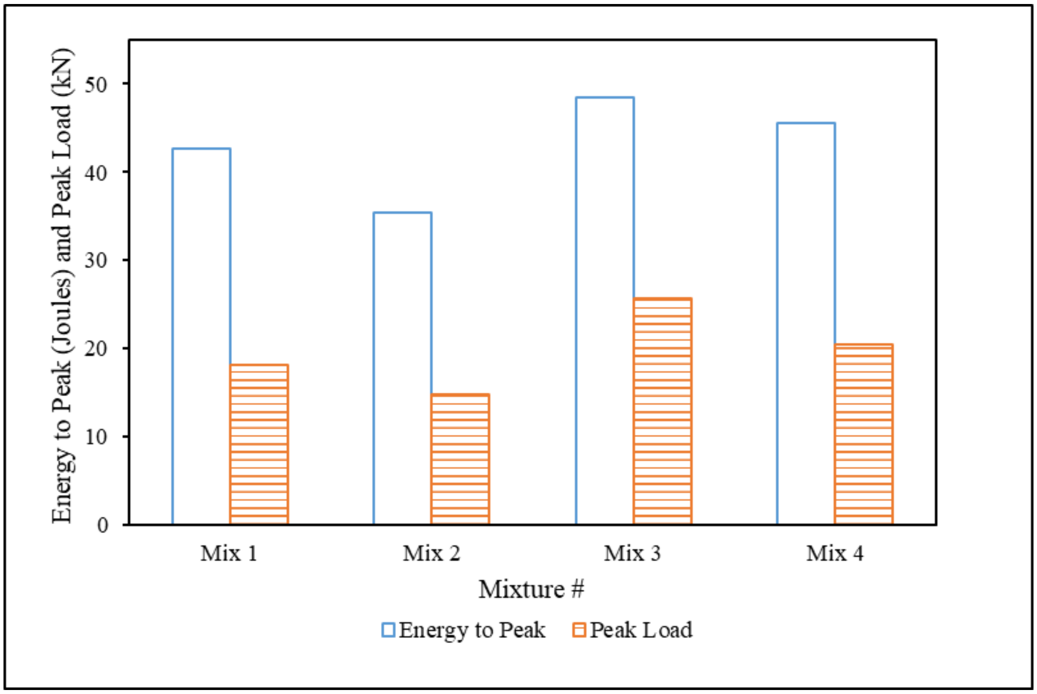

Figure 2. Variation of Energy to Peak and Peak Load for the four Mixes

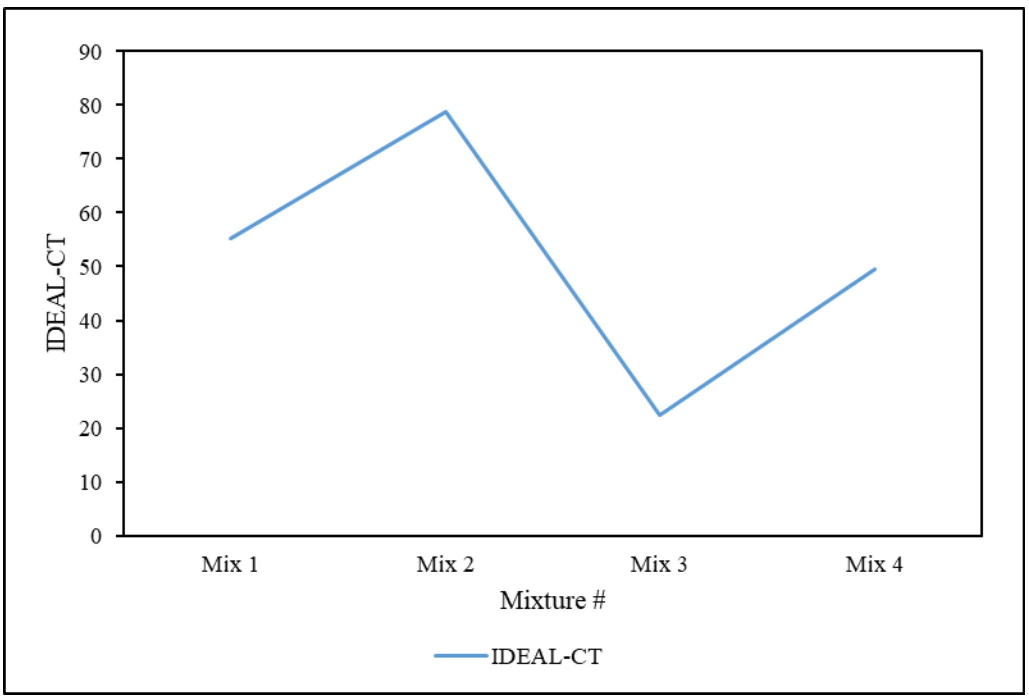

Figure 3. Variation of IDEAL-CT for the four Mixes

5. Semi – Circular Bend (SCB) Test

Semi-Circular Bend (SCB) with Illinois Flexibility test (I-FIT) was done on all four mixtures to characterize the flexibility of the mixture. Four samples were made for each mixture for Evaluation of Asphalt Mixture Cracking Resistance using the Semi-Circular Bend Test (SCB) at Intermediate Temperatures (ASTM D8044) [3].

The Illinois Flexibility Index Test (I-FIT) protocol (FHWA-ICT-15-017) developed by the Illinois Center for Transportation was followed on the semi-circular bend test specimens to calculate the Flexibility Index [4].

5.1 Illinois Flexibility Index Test (I-FIT)

The I-FIT test protocol uses the intermediate-temperature SCB test to calculate the cracking potential of asphalt concrete at intermediate temperatures. The specimen geometry shown in Figure 4 is identical to the specimen geometry of SCB test specimen (ASTM D8044). The test setup uses an LVDT to measure the vertical displacement. The specimen is loaded at a rate of 0.5 mm/min and the test is done at 25° C.

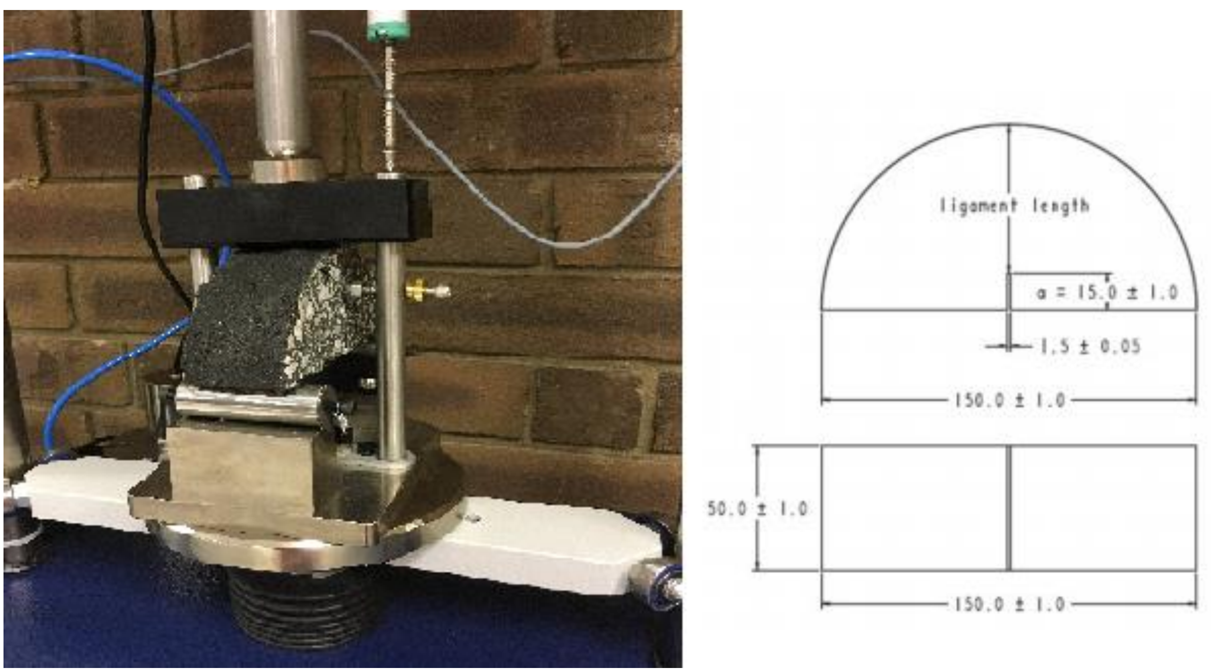

Figure 4. SCB Test setup with specimen geometry (Source – FHWA-ICT-15-017) [4]

The semi-circular disc specimen is simply-supported and loaded at the midpoint (opposite side of the 15 mm notch). The notch controls the crack propagation during the test.

Figure 5 shows a typical outcome of the SCB test. From this test the following parameters can be obtained –

- Fracture Energy (G_f) which is the Work of Fracture (W_f) (i.e. area under the curve)
- Peak Load (P_{max})
- Critical displacement (u_1)
- Displacement at the peak load (u_0)
- Displacement at the end of test (u_{final})
- Slope at inflection point (m)

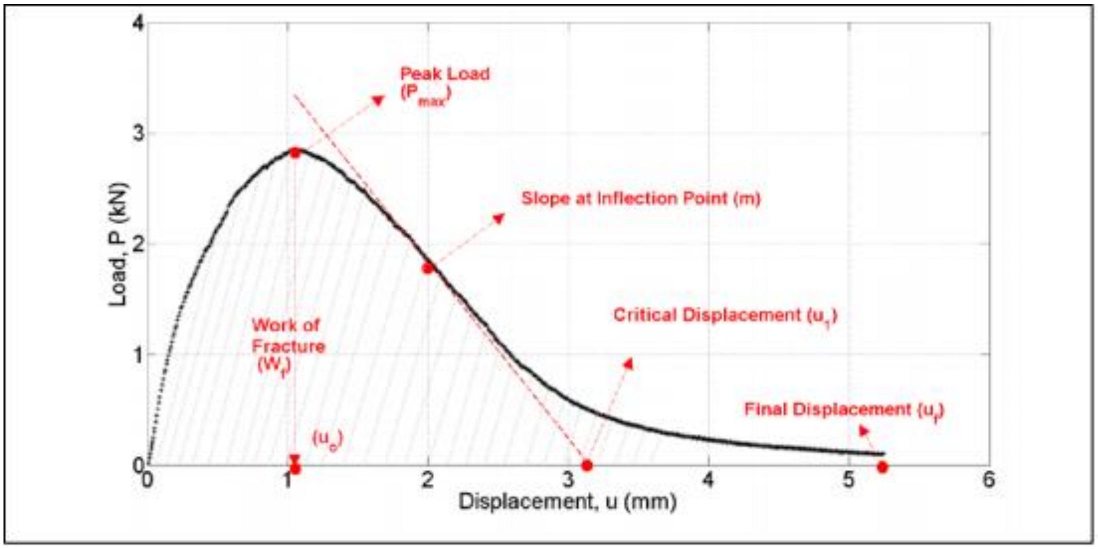

Figure 5. Typical outcome of the SCB Test (Source – FHWA-ICT-15-017) [4]

Flexibility Index (FI) is calculated by using the following equation

$$FI = 0.01x[G_f/abs(m)]$$

The higher the Flexibility Index, the more flexible the asphalt mixture is and the more resistant the mix is to fatigue cracking.

5.2 Specimen Preparation

Four semi-circular disk specimens were prepared with a 15mm notch in the middle of each specimen for each mix. During the preparation of the specimens, the loose mixture was short term aged for 4 hours at 135 °C. All the specimens had air void content of 7 ± 0.5 %. The specimens were loaded at a rate of 50 mm/min using a 10kN load head. The specimens were tested at 25 °C.

The I-FIT software provided by the Illinois Center for Transportation was used to estimate the slope, fracture energy and calculate the Flexibility Index.

5.3 Test Results

Table 12 shows the SCB test results for all four mixtures. The higher the Flexibility Index value, the more resistance to cracking the mixture is. From the results we can see that mix 1 has the highest Flexibility Index value. Mixtures 2, 3, and 4 all have very low flexibility index values. Figure 6 shows the variation of Fracture Energy and Flexibility Index for the four mixes used in the study.

The NCDOT does not have any criterion or recommendation for the SCB test currently.

Table 12. SCB Test results for the four mixtures used in this study

Mixtures	Peak Load (kN)	Strength (kPa)	Fracture Energy (J/m^2)	Flexibility Index
Mix 1	3.8	513.7	1780.6	3.8
Mix 2	5.5	564.3	1281.6	0.4
Mix 3	6.2	420.6	1084.7	0.1
Mix 4	5.6	568.8	1424.9	0.1

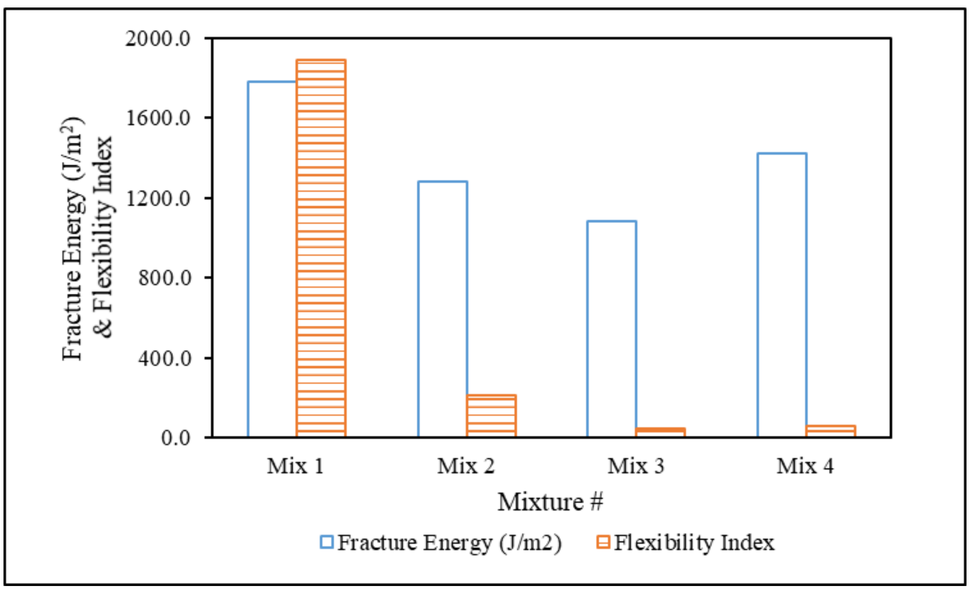

Figure 6. Variation of Fracture Energy and Flexibility Index for the four Mixes

*Note – Flexibility Index values are multiplied by 500 when plotted in the graph to scale up so that the variation in values are visible next to the Fracture Energy values.

6. Hamburg Test

Hamburg Wheel Test was done on all four asphalt mixtures to test the rut resistance of the mixtures used in the study. The test was performed as per the AASHTO T324 test standard. [5] Four samples were used as per the standard.

6.1 Specimen Preparation

The specimens were 62 mm tall and 150 mm in diameter with 7.0% ± 0.5% air voids. During the preparation of the specimens, the loose mixture was short term aged for 4 hours at 135 °C. The Hamburg Wheel Test is run in water at 50 °C or 122 °F for 20,000 passes unless the rut depth reaches 15 mm with a wheel pass rate of 50 passes per minute.

6.2 Results

Table 13 shows the Hamburg Test results for the four mixtures used in this study. Mix 3 had the least rut depth and hence it is the most rut resistant. Mix 4 is the least rut resistant since it has the most rut depth. The NCDOT does not have a criterion for the Hamburg Test currently. However, for surface mixtures a few states that use the Hamburg Test use a maximum of 12.5 mm rut depth at 20,000 passes [6, 7].

Table 13. Hamburg Test results for the four mixtures used in this study

Mixtures	**Rut Depth (mm)**		
	Left	**Right**	**Average**
Mix 1	4.6	3.6	4.1
Mix 2	4.1	4.7	4.4
Mix 3	2.4	2.4	2.4
Mix 4	4.9	6.0	5.5

7. APA Test

Asphalt Pavement Analyzer (APA) Test was done on all four asphalt mixtures to test the rut resistance of the mixtures used in the study. The test was performed as per the AASHTO T340 test standard [8]. Four samples were used as per the standard.

7.1 Specimen Preparation

Six specimens per mix, each 75 mm tall and 150 mm in diameter were prepared. During the preparation of the specimens, the loose mixture was short term aged for 4 hours at 135 °C. The specimens were targeted to an air void content of 4.0±0.5%. The rate of wheel passes is 60 cycles per minute. The test is run for 8000 cycles. The test was run in air at 64 °C or 149 °F by the Materials and Test Unit of NCDOT.

7.2 Results

Table 14 shows the APA Test results for the four mixtures used in this study. Mix 3 had the least rut depth and hence it is the most rut resistant. Mix 4 is the least rut resistant since it has the most rut depth. The rut dept of all the mixtures were below the maximum rut depth of 6.5 mm for a 9.5C mixture as per NCDOT's QMS manual [9].

Table 14. APA Test results for the four mixtures used in this study

Mixtures	**Rut Depth (mm)**			
	Left	**Center**	**Right**	**Average**
Mix 1	5.7	4.2	5.4	5.1
Mix 2	6.0	4.4	4.3	4.9
Mix 3	2.7	3.1	3.2	3.0
Mix 4	6.1	5.6	5.3	5.7

8. Discussion

Four mixes were tested in this study to determine suitable lab tests or parameters to predict premature failure of asphalt mixtures in the field.

8.1 Aggregate Testing

These tests include source properties tests on the aggregate stockpiles used and testing the asphalt from the recycled material. The absorption values for all the sources except Washed Screenings #1 were around 0.5%. The absorption of Washed Screenings #1 was 0.17%. The LA Abrasion values and cumulative percentage loss from the soundness test were within limits. Sand 1 and 3 had a sand equivalent value of 44% and 45% respectively. This indicates that they have low sand to clay ratio. Sand 2 had a sand equivalent value of 92% indicating a high sand to clay ratio. Sand 2 is hence much cleaner than Sand 1 and 3. The asphalt content from chemical extraction of RAP 1 and RAP 2 source at Trimat was 0.3% and 0.2% lower than the asphalt content from the JMF. For RAP 3 however, the asphalt content from chemical extraction was 0.8% higher at Trimat and for the RAS the asphalt content was 1.6% lower at Trimat. RAP 1 and 3 had the same high PG grade of 88 °C, and RAP 2 had a high PG grade of 76 °C. The high PG grade for RAP was not able to be measured as the temperature went beyond the DSR limit of 154 °C.

The mixtures replicated in the lab at Trimat had similar aggregate gradation to that of the mixture's JMF or that of the mix during field production.

An additional ignition oven test was done on Mix 3 to find the asphalt content of the mix to ensure the asphalt content of the mix produced at Trimat was same as the JMF asphalt content. This was done as the asphalt content in the RAP 3 at Trimat was 0.8% higher than the asphalt content of RAP 3 in the JMF and the mix had 30% RAP in it. The asphalt content from the ignition oven test was 5.8% compared to the JMF asphalt content of 5.7%.

8.2 Cracking Test

Two tests were done on the asphalt mixtures to predict the resistance of the mixtures to cracking at intermediate temperatures – IDEAL CT and SCB test with I-Fit analysis. Figure 7 shows the comparison of the results from both the cracking tests for all the four mixtures. The IDEAL-CT test gives a wider range of Cracking Index results while the SCB test with I-Fit analysis has a small range of Flexibility Index values. NCDOT does not have any specifications for Cracking Index or Flexibility Index values. From the results, mix 2 is more resistant to cracking as per the IDEAL-CT Index while mix 1 is more resistant to cracking as per the Flexibility Index.

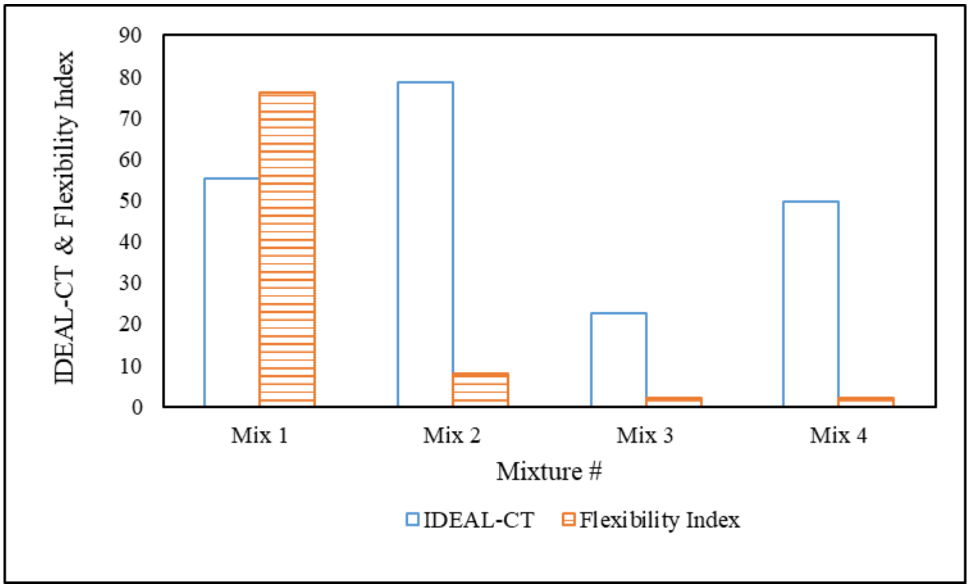

Figure 7. Variation of IDEAL-CT and Flexibility Index value for the four mixtures

*Note – Flexibility Index values are multiplied by 20 when plotted in the graph to scale up so that the variation in values are visible next to the IDEAL-CT values.

8.3 Rut Test

Two tests were done on the asphalt mixtures to predict the resistance of the mixtures to rutting – Hamburg and APA tests. Figure 8 shows the comparison of the results from both the rut tests for all the four mixtures. Both the tests have similar results. Mix 3 is the most rut resistant (lowest rut depth) and Mix 4 is the least rut resistant (highest rut depth) as per both the tests. All the mixes were RS9.5C which have an APA rut depth limit of 6.5 mm and Hamburg limit of 12.5 mm. All four mixes had rut depths under the limits for both tests.

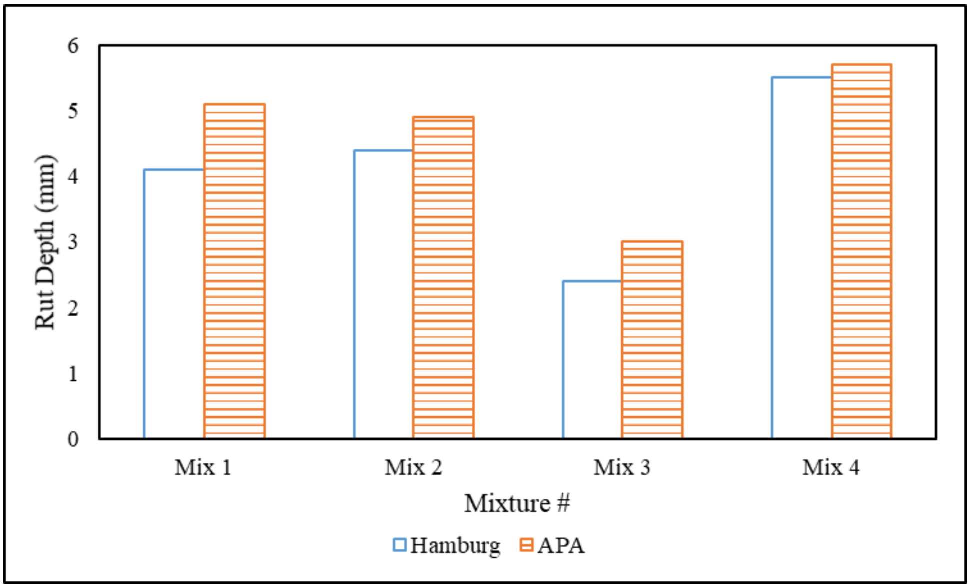

Figure 8. Variation of rut depths from Hamburg and APA test for the four mixtures

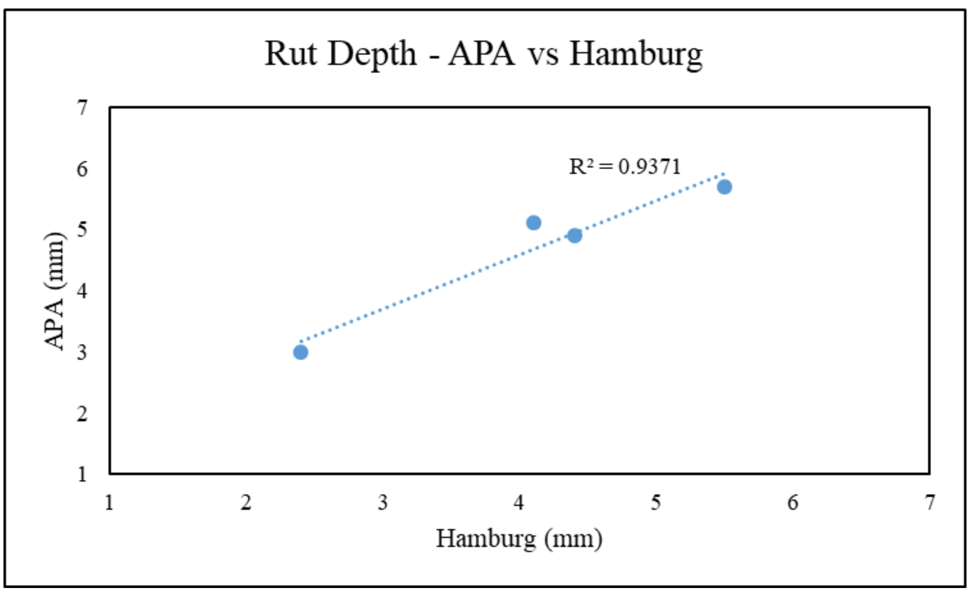

Figure 9. Correlation of rut depths for the four mixtures from APA and Hamburg Tests

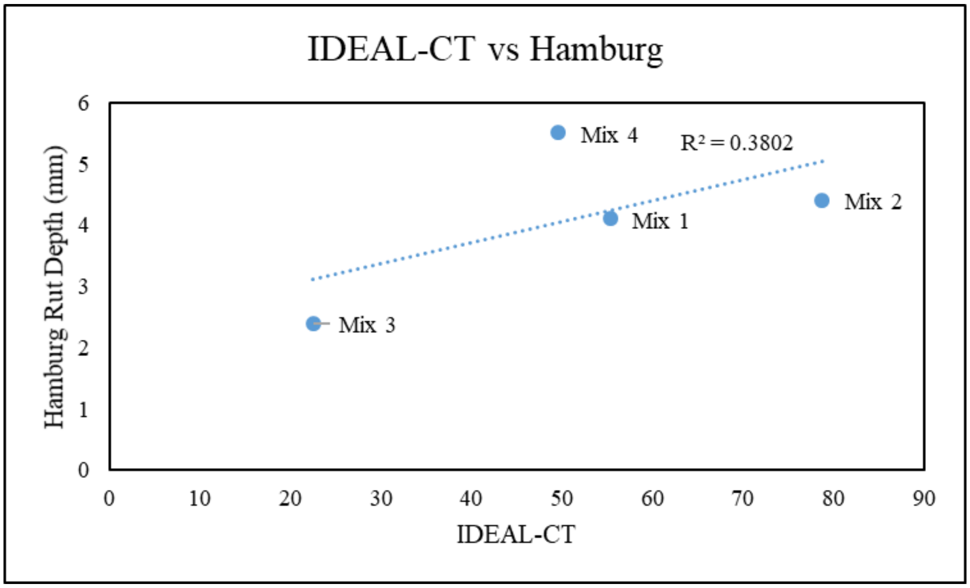

Figure 10. Plot of IDEAL-CT value versus Hamburg Rut Depth for all four mixes

9. Statistical Analysis

The four mixes tested in the study all were RS9.5C mixes. Even though they were all RS9.5C mixes they still differed in the fine aggregate sources, amount of asphalt being contributed from recycled material, amount of sand and screenings, as well as total asphalt content.

To test the effect of volumetric properties on the performance of the mixtures a statistical analysis was done to check the correlation between various performance parameters and volumetric properties. Table 15 shows the volumetric/aggregate properties and performance parameters that were tested for correlation. The correlation analysis was done assuming the performance predictors as the dependent parameter (y).

Table 15. Volumetric/Aggregate Properties and Performance Predictors used for Statistical Analysis

Volumetric /Aggregate Properties	Performance Predictors
% 78M	Rut Depth (APA)
% Screenings	Rut Depth (Hamburg)
% Sand	IDEAL-CT
Sand Equivalent	Flexibility Index
% RBR	Total Energy (IDEAL)
% RAP	Energy to Peak (IDEAL)
RAP AC content (lab)	Fracture Energy (SCB)
RAP PG Grade (High)	

9.1 Results

Regression analysis was done to find out the correlation between the volumetric properties and the performance predictors. R^2 value was found for each combination of Volumetric Property and performance predictor. This analysis was done in two parts. In the first part the regression analysis was done using the testing data from all four mixtures used in this study. In the second regression analysis the data from Mix 1 (which has RAS) was eliminated. This was done to see if the presence of RAS impacts the correlation of the parameters. The results are presented in two tables for each part – one table has performance predictors related to the cracking test and the second table has performance predictors related to the rutting test.

Tables 16 and 17 show the R^2 values for correlation between volumetric properties and performance indicators using data from all four mixtures. Tables 18 and 19 show the R^2 values for correlation between volumetric properties and performance indicators using data from three mixtures.

Table 16. R^2 values for correlation between volumetric properties and cracking test performance indicators using data from all four mixtures

Volumetric Properties	Performance Predictors				
	IDEAL-CT	Flexibility Index	Total Energy (IDEAL-CT)	Energy to Peak (IDEAL-CT)	Fracture Energy (SCB)
% 78M	(+)0.28	(+)0.07	**(-)0.74**	**(-)0.54**	**(-)**0.00
% Screenings	(+)**0.85**	**(-)**0.01	**(-)0.81**	**(-)0.94**	**(-)**0.00
% Sand	**(-)0.84**	**(-)**0.01	(+)**0.97**	(+)**0.98**	**(-)**0.01
Sand Equivalent	(+)**0.60**	**(-)**0.07	**(-)0.72**	**(-)0.81**	**(-)**0.07
% RBR	**(-)0.65**	(+)0.17	(+)0.31	(+)0.56	(+)0.01
% RAP	**(-)0.84**	**(-)**0.08	(+)**0.99**	(+)**0.96**	**(-)**0.07
RAP AC content (Trimat)	**(-)**0.22	**(-)**0.27	(+)0.02	(+)0.04	**(-)**0.74
RAP PG Grade (High)	**(-)0.62**	(+)0.07	(+)**0.73**	(+)**0.82**	(+)0.06

Table 17. R^2 values for correlation between volumetric properties and rutting test performance indicators using data from all four mixtures

Volumetric Properties	Performance Predictors	
	Rut Depth (APA)	Rut Depth (Hamburg)
% 78M	**(-)**0.05	**(-)**0.12
% Screenings	(+)0.15	(+)0.15
% Sand	**(-)**0.10	**(-)**0.06
Sand Equivalent	(+)0.01	(+)0.02
% RBR	**(-)0.36**	**(-)0.49**
% RAP	**(-)**0.13	**(-)**0.07
RAP AC content (Trimat)	**(-)0.87**	**(-)0.71**
RAP PG Grade (High)	**(-)**0.02	**(-)**0.02

From the results it can be seen that % RBR and RAP asphalt content can be good rutting performance predictors. % Screenings, % Sand, Sand Equivalent value, % RBR, % RAP in the mix, and RAP PG grade (high) seem to have a good correlation with the IDEAL-CT Index. None of the indicators seems to have a good correlation with Flexibility Index when the data from all four mixtures is being used. However, the correlation improves significantly when only three mixes are used. This increase can be attributed to very low Flexibility Index values.

As a general trend, the correlation seems to get better when data from only mixtures without RAS are used as compared to the data from all four mixtures. However, reducing the number of data points from 4 to 3 also might increase the correlation in general.

Table 18. R^2 values for correlation between volumetric properties and <u>cracking test performance</u> indicators using data from three mixtures

Volumetric Properties	**Performance Predictors**				
	IDEAL-CT	Flexibility Index	Total Energy (IDEAL-CT)	Energy to Peak (IDEAL-CT)	Fracture Energy (SCB)
% 78M	(+)0.27	(+)**0.75**	**(-)0.73**	**(-)0.55**	**(-)**0.18
% Screenings	(+)**0.93**	(+)**0.94**	**(-)0.95**	**(-)1.00**	(+)0.11
% Sand	**(-)0.84**	**(-)0.99**	(+)**1.00**	(+)**0.98**	**(-)**0.03
Sand Equivalent	(+)**0.75**	(+)**1.00**	**(-)1.00**	**(-)0.95**	(+)0.01
% RBR	**(-)0.95**	**(-)0.55**	(+)**0.57**	(+)**0.75**	(+)**0.54**
% RAP	**(-)0.85**	**(-)0.99**	(+)**0.99**	(+)**0.99**	**(-)**0.04
RAP AC content (Trimat)	**(-)**0.23	(+)0.00	(+)0.00	(+)0.05	**(-)0.99**
RAP PG Grade (High)	**(-)0.77**	**(-)1.00**	(+)**1.00**	(+)**0.95**	**(-)**0.01

Table 19. R^2 values for correlation between volumetric properties and <u>rutting test performance</u> indicators using data from three mixtures

Volumetric Properties	**Performance Predictors**	
	Rut Depth (APA)	Rut Depth (Hamburg)
% 78M	**(-)**0.08	**(-)**0.12
% Screenings	(+)0.21	(+)0.16
% Sand	**(-)**0.10	**(-)**0.06
Sand Equivalent	(+)0.04	(+)0.02
% RBR	**(-)0.68**	**(-)0.62**
% RAP	**(-)**0.11	**(-)**0.07
RAP AC content (Trimat)	**(-)0.95**	**(-)0.97**
RAP PG Grade (High)	**(-)**0.05	**(-)**0.03

10. Conclusions

This research study was done to identify the lab test parameters that can predict the premature failure of asphalt mixtures in the field. Eventually the goal of the study was to identify the volumetric parameters that affect the field performance or premature failure of asphalt mixtures. However, since there was no field performance data available the study focused on identifying which volumetric parameters correlate well or poorly with the performance predictors of the asphalt mixtures from the lab testing.

Using the results from the study all four mixtures can be ranked on their performance based on the main performance parameters from each lab test. Rut depth (mm) from APA test and Hamburg test was used to rank the mixture's rutting performance. IDEAL-CT Index from IDEAL-CT test and Flexibility Index from SCB test were used to rank the mixture's cracking performance. Table 20 shows the ranking of the mixtures.

Table 20. Ranking of the four mixtures based on the four performance tests

Mixture	**Performance Test**			
	APA	**Hamburg**	**IDEAL-CT**	**SCB**
Mix 1	3	2	2	1
Mix 2	2	3	1	2
Mix 3	1	1	4	3
Mix 4	4	4	3	3

The conclusions from the study are –

1. All mixtures performed well in both the rutting tests – APA and Hamburg. Mix 3 performed the best in both tests and Mix 4 was worst. However, all four mixtures had rut depth below the maximum allowable rut depths.
2. There were no available standard recommendations for IDEAL-CT and SCB tests for conditions like North Carolina, so, the results for these mixtures were not compared to any limiting values. Mix 2 performed the best as per the IDEAL-CT test while mix 3 performed the worst. Mix 1 performed the best as per the SCB test. Mixes 2, 3, and 4 all had very low values to rank them.
3. The IDEAL-CT test results had a wider range of results as compared to SCB test.
4. The sample preparation for the IDEAL-CT test is less intensive than the SCB test.
5. % RBR and asphalt content in RAP seemed to be a good indicator to how the mix will perform in the rutting tests such as Hamburg and APA tests.
6. % Screenings, % Sand, Sand Equivalent value, % RBR, % RAP in the mix, and RAP PG grade (high) seem to have a good correlation with the IDEAL-CT index. However, more testing needs to be done to confirm this correlation. None of the volumetric parameters seem to have a good correlation with the Flexibility Index from SCB test.
7. These lab performance predictors need to be correlated to the field performance and identify the performance predictors which can predict premature failure in the field.

8. The correlation between the field performance and laboratory performance predictors can identify which volumetric properties/mixture parameters need to be changed to improve the field performance of the mixtures.
9. Other mixture performance parameters such as moisture sensitivity can also be tested to see if that contributes to the premature failure of the mixtures in the field.
10. From the study IDEAL-CT test seems to be a better test in understanding the cracking behavior of the asphalt mixtures.

10. 1 Recommendations for Future Studies

1. Moisture Sensitivity of the mixtures can be tested.
2. Change the volumetric properties of the mixtures to identify changing which property affects the laboratory performance predictors the most.
3. Use of additives to improve the performance of the mixtures.
4. Further IDEAL-CT testing needs to be done on mixes all over North Carolina and compared to their field performance to come up with guidelines for preventing premature cracking in asphalt mixtures.

References

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8. AASHTO T340, "Standard Method of Test for Determining Rutting Susceptibility of Hot Mix Asphalt (HMA) Using the Asphalt Pavement Analyzer (APA)," *American Association of State Highway and Transportation Officials (AASHTO)*, Washington, D.C., 2010.
9. Mix Design Criteria (Table 610-3), *Asphalt Quality Management System Manual*, North Carolina Department of Transportation (NCDOT), pp. 4-9.

APPENDIX

Trimat Materials Testing, Inc.

Asphalt Content of Hot-Mix Asphalt by Extraction Method and Gradation

ASTM D 2172 / ASTM D 5444

Project #:	18-1278	Report Date:	1/21/2019
Project Name:	NCDOT Slippage Cracking	Test Date(s):	1/18/2019
Client Name:		Received Date:	
Client Address:			

References:

ASTM D5444/T30: *Mechanical Size Analysis of Extracted Aggregate*
ASTM C117/T11: *Test Method for Materials Finer then 75-µm (No. 200) Sieve in Mineral Aggregates by Washing*
ASTM D979/T168: *Practice for Sampling Bituminous Paving Materials*
ASTM D2172/T164: *Quantitative Extraction of Bitumen From Bituminous Paving Mixtures*

Lab #:	Material Description: RAP 1	Sample Date:	
Source:	Sample #:	Sample Type:	

Percent Asphalt by Extraction Method "A"

Mass of Bituminous Material Sample:	A	3111.0	0.1g
Mass of Mineral Aggregate:	B	2976.2	0.1g
Mass of Mineral Matter: C = (E-D) + (G-F)	C	8.71	0.01g
New Filter Wt.:	D	23.04	0.01g
Spun Filter Wt.:	E	24.75	0.01g
Empty Tube Wt.:	F	455.09	0.01g
Spun Tube Wt.:	G	462.09	0.01g
Total Mass of Aggregate: H = (B + C)	H	2984.9	0.1g
Bitumen Content:			
% A/C = ((A - H) / A) x 100	%A/C	4.05%	0.1%

Calculations:

* % Retained = (Cumulative Wt. Retained) / H * 100

** % Pass = 100 - % Retained

ε: Percent Passing shall be reported to the nearest whole number (1.0%) except the 0.075mm (No. 200) sieve shall be reported to the nearest 0.1%.

Gradation of Recovered Aggregate after Wash

Dry Wgt After Wash 2702.2 Pan Wgt less than 0.2% of Dry After Wash? Y

Sieve	Cumulative Wgt Retained	% Retained.*	% Pass**,ε	Spec.
3/4"	0.0			
1/2"	39.5	1.3	98.7	
3/8"	207.5	7.0	93.0	
#4	737.1	24.7	75.3	
#8	1129.0	37.8	62.2	
#16	1430.8	47.9	52.1	
#30	1784.0	59.8	40.2	
#50	2192.0	73.4	26.6	
#100	2531.6	84.8	15.2	
#200	2679.9	89.8	10.2	
pan	2701.7			

Shake Duration: 10 Sieving Sufficient? Y

Remarks:

Technician:

Printed Name *Certification #* *Signature*

Trimat Materials Testing, Inc.

Asphalt Content of Hot-Mix Asphalt by Extraction Method and Gradation

ASTM D 2172 / ASTM D 5444

Project #:	18-1278	Report Date:	1/21/2019
Project Name:		Test Date(s):	1/18/2019
Client Name:		Received Date:	
Client Address:			

References:

ASTM D5444/T30: *Mechanical Size Analysis of Extracted Aggregate*
ASTM C117/T11: *Test Method for Materials Finer then 75-µm (No. 200) Sieve in Mineral Aggregates by Washing*
ASTM D979/T168: *Practice for Sampling Bituminous Paving Materials*
ASTM D2172/T164: *Quantitative Extraction of Bitumen From Bituminous Paving Mixtures*

Lab #:		Material Description:	RAP 2	Sample Date:	
Source:		Sample #:		Sample Type:	

Percent Asphalt by Extraction Method "A"

Mass of Bituminous Material Sample:	A	3028.1	0.1g
Mass of Mineral Aggregate:	B	2869.4	0.1g
Mass of Mineral Matter: C = (E-D) + (G-F)	C	12.89	0.01g
New Filter Wt.:	D	23.74	0.01g
Spun Filter Wt.:	E	25.11	0.01g
Empty Tube Wt.:	F	485.58	0.01g
Spun Tube Wt.:	G	497.10	0.01g
Total Mass of Aggregate: H = (B + C)	H	2882.3	0.1g
Bitumen Content: % A/C = ((A - H) / A) x 100	%A/C	4.82%	0.1%

Calculations:

* % Retained = (Cumulative Wt. Retained) / H * 100

** % Pass = 100 - % Retained

ε: Percent Passing shall be reported to the nearest whole number (1.0%) except the 0.075mm (No. 200) sieve shall be reported to the nearest 0.1%.

Gradation of Recovered Aggregate after Wash

Dry Wgt After Wash 2691.2 Pan Wgt less than 0.2% of Dry After Wash? Y

Sieve	Cumulative Wgt Retained	% Retained.*	% Pass**,ε	Spec.
3/4"	0.0			
1/2"	28.5	1.0	99.0	
3/8"	191.2	6.6	93.4	
#4	647.4	22.5	77.5	
#8	978.2	33.9	66.1	
#16	1260.0	43.7	56.3	
#30	1639.1	56.9	43.1	
#50	2134.9	74.1	25.9	
#100	2484.1	86.2	13.8	
#200	2648.6	91.9	8.1	
pan	2689.8			

Shake Duration: 10 Sieving Sufficient? Y

Remarks:

Technician:

Printed Name *Certification #* *Signature*

Trimat Materials Testing, Inc.

Asphalt Content of Hot-Mix Asphalt by Extraction Method and Gradation

ASTM D 2172 / ASTM D 5444

Project #: 18-1278	Report Date: 1/21/2019
Project Name: NCDOT Slippage	Test Date(s): 1/18/2019
Client Name:	Received Date:
Client Address:	

References:

ASTM D5444/T30: *Mechanical Size Analysis of Extracted Aggregate*
ASTM C117/T11: *Test Method for Materials Finer then 75-µm (No. 200) Sieve in Mineral Aggregates by Washing*
ASTM D979/T168: *Practice for Sampling Bituminous Paving Materials*
ASTM D2172/T164: *Quantitative Extraction of Bitumen From Bituminous Paving Mixtures*

Lab #:	Material Description: RAP 3	Sample Date:
Source:	Sample #:	Sample Type:

Percent Asphalt by Extraction Method "A"

Mass of Bituminous Material Sample:	A	3013.2	0.1g
Mass of Mineral Aggregate:	B	2835.0	0.1g
Mass of Mineral Matter: C = (E-D) + (G-F)	C	13.03	0.01g
New Filter Wt.:	D	23.52	0.01g
Spun Filter Wt.:	E	25.48	0.01g
Empty Tube Wt.:	F	483.99	0.01g
Spun Tube Wt.:	G	495.06	0.01g
Total Mass of Aggregate: H = (B + C)	H	2848.0	0.1g
Bitumen Content: % A/C = ((A - H) / A) x 100	%A/C	5.48%	0.1%

Calculations:

* % Retained = (Cumulative Wt. Retained) / H * 100

** % Pass = 100 - % Retained

ε: Percent Passing shall be reported to the nearest whole number (1.0%) except the 0.075mm (No. 200) sieve shall be reported to the nearest 0.1%.

Gradation of Recovered Aggregate after Wash

Dry Wgt After Wash: 2547.8

Pan Wgt less than 0.2% of Dry After Wash? Y

Sieve	Cumulative Wgt Retained	% Retained.*	% Pass**,ε	Spec.
3/4"	0.0			
1/2"	30.8	1.1	98.9	
3/8"	113.3	4.0	96.0	
#4	562.7	19.8	80.2	
#8	1016.2	35.7	64.3	
#16	1417.5	49.8	50.2	
#30	1820.6	63.9	36.1	
#50	2206.2	77.5	22.5	
#100	2427.5	85.2	14.8	
#200	2531.0	88.9	11.1	
pan	2547			

Shake Duration: 10 Sieving Sufficient? Y

Remarks:

Technician:

Printed Name *Certification #* *Signature*

Trimat Materials Testing, Inc.

Asphalt Content of Hot-Mix Asphalt by Extraction Method and Gradation

ASTM D 2172 / ASTM D 5444

Project #:	18-1278	Report Date:	2/6/2019
Project Name:	NCDOT Slippage	Test Date(s):	2/1/2019
Client Name:		Received Date:	
Client Address:			

References:

ASTM D5444/T30: *Mechanical Size Analysis of Extracted Aggregate*
ASTM C117/T11: *Test Method for Materials Finer then 75-μm (No. 200) Sieve in Mineral Aggregates by Washing*
ASTM D979/T168: *Practice for Sampling Bituminous Paving Materials*
ASTM D2172/T164: *Quantitative Extraction of Bitumen From Bituminous Paving Mixtures*

Lab #:		Material Description:	RAS	Sample Date:	
Source:		Sample #:		Sample Type:	

Percent Asphalt by Extraction Method "A"

Mass of Bituminous Material Sample:	A	1052.1	0.1g
Mass of Mineral Aggregate:	B	860.2	0.1g
Mass of Mineral Matter: C = (E-D) + (G-F)	C	4.60	0.01g
New Filter Wt.:	D	23.11	0.01g
Spun Filter Wt.:	E	26.04	0.01g
Empty Tube Wt.:	F	460.05	0.01g
Spun Tube Wt.:	G	461.72	0.01g
Total Mass of Aggregate: H = (B + C)	H	864.8	0.1g
Bitumen Content: % A/C = ((A - H) / A) x 100	%A/C	17.80%	0.1%

Calculations:

* % Retained = (Cumulative Wt. Retained) / H * 100

** % Pass = 100 - % Retained

ε: Percent Passing shall be reported to the nearest whole number (1.0%) except the 0.075mm (No. 200) sieve shall be reported to the nearest 0.1%.

Gradation of Recovered Aggregate after Wash

Dry Wgt After Wash 642.3 Pan Wgt less than 0.2% of Dry After Wash? Y

Sieve	Cumulative Wgt Retained	% Retained.*	% Pass**,ε	Spec.
3/4"	0.0			
1/2"	0.0			
3/8"	0.0			
#4	13.8	1.6	98.4	
#8	25.3	2.9	97.1	
#16	152.7	17.7	82.3	
#30	329.1	38.1	61.9	
#50	427.1	49.4	50.6	
#100	520.7	60.2	39.8	
#200	603.4	69.8	30.2	
pan	640.3			

Shake Duration: 10 Sieving Sufficient? Y

Remarks:

Technician:

Printed Name *Certification #* *Signature*

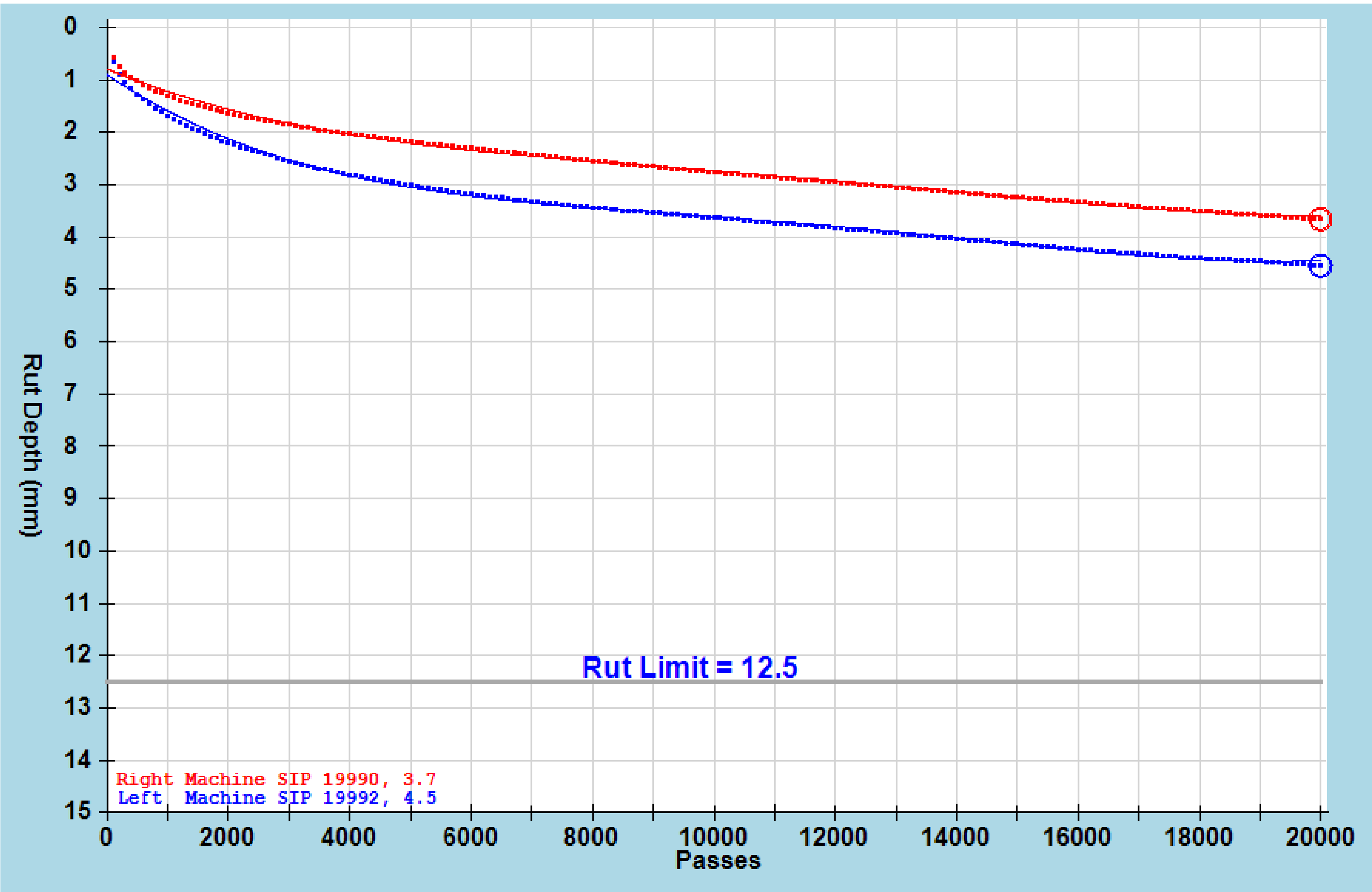
TRIMAT MATERIALS TESTING, INC.

HWT-Report AASHTO T-324

Project: 18-1278 **Mix:** 1 [redacted] **Date Sampled:** **Technician:** AK

	Left	Right
Date Tested:	03/06/2019	03/06/2019
Passes Per Minute:	52	52
Water Temperature:	50.0 °C	50.0 °C
Rut Depth Limit (mm):	12.5	12.5
Target Passes to Failure:	20000	20000
Final Rut Depth:	4.55 mm	3.66 mm
Total Passes:	20000	20000
Passes to Failure:	20000	20000
Rut Depth Pass/Fail:	PASS	PASS
Creep Slope:	-5.514E-05	-6.415E-06
Stripping Slope:	-5.522E-05	-6.464E-06
Stripping Inflection Point:	19992	19990

Left			Right			Difference
Pass	Rut Depth	Temp.	Pass	Rut Depth	Temp	ABS (R-L)
1000	1.68	49.9	1000	1.30	49.9	0.38
2000	2.20	49.9	2000	1.63	49.9	0.57
3000	2.54	50.0	3000	1.85	50.0	0.69
4000	2.81	49.8	4000	2.03	49.8	0.78
5000	3.01	49.9	5000	2.17	49.9	0.84
6000	3.18	50.0	6000	2.30	50.0	0.88
7000	3.32	50.0	7000	2.43	50.0	0.89
8000	3.43	49.9	8000	2.54	49.9	0.89
9000	3.53	50.0	9000	2.65	50.0	0.88
10000	3.63	49.9	10000	2.76	49.9	0.87
11000	3.73	49.9	11000	2.86	49.9	0.87
12000	3.82	49.9	12000	2.95	49.9	0.87
13000	3.93	49.9	13000	3.05	49.9	0.88
14000	4.04	49.9	14000	3.16	49.9	0.88
15000	4.14	49.9	15000	3.25	49.9	0.89
16000	4.24	49.9	16000	3.34	49.9	0.90
17000	4.32	49.9	17000	3.42	49.9	0.90
18000	4.40	49.8	18000	3.50	49.8	0.90
19000	4.46	50.0	19000	3.58	50.0	0.88
20000	4.55	49.8	20000	3.66	49.8	0.89



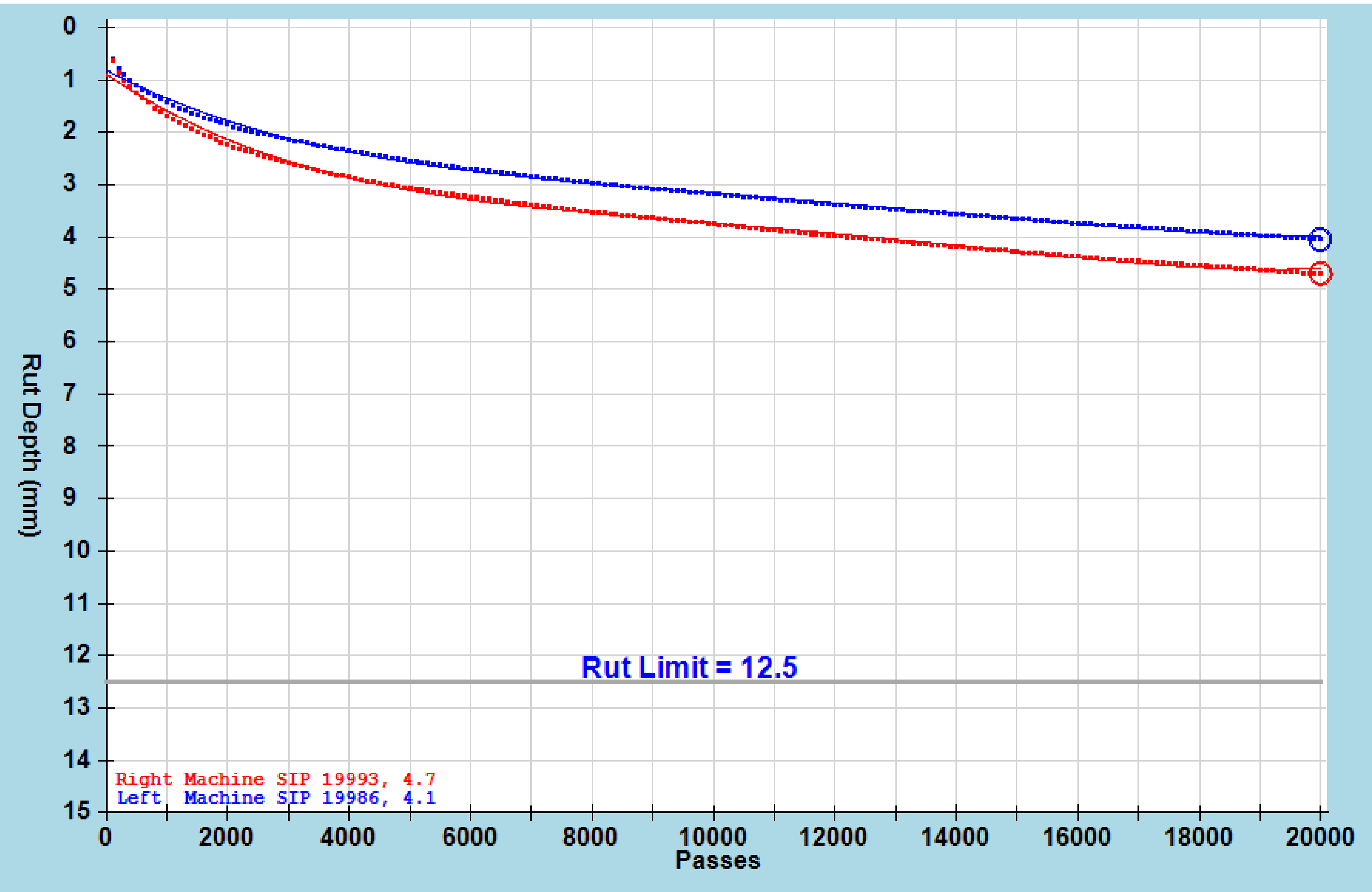
TRIMAT MATERIALS TESTING, INC.

HWT-Report AASHTO T-324

Project: 18-1278 **Mix:** 2 [redacted] **Date Sampled:** **Technician:** AK

	Left	Right
Date Tested:	03/07/2019	03/07/2019
Passes Per Minute:	52	52
Water Temperature:	50.0 °C	50.0 °C
Rut Depth Limit (mm):	12.5	12.5
Target Passes to Failure:	20000	20000
Final Rut Depth:	4.05 mm	4.70 mm
Total Passes:	20000	20000
Passes to Failure:	20000	20000
Rut Depth Pass/Fail:	PASS	PASS
Creep Slope:	-1.022E-05	-5.624E-05
Stripping Slope:	-1.027E-05	-5.632E-05
Stripping Inflection Point:	19986	19993

Left			Right			Difference
Pass	Rut Depth	Temp.	Pass	Rut Depth	Temp	ABS (R-L)
1000	1.44	50.0	1000	1.68	50.0	0.24
2000	1.85	49.9	2000	2.23	49.9	0.38
3000	2.14	49.9	3000	2.59	49.9	0.45
4000	2.35	50.0	4000	2.86	50.0	0.51
5000	2.54	50.0	5000	3.07	50.0	0.53
6000	2.70	49.9	6000	3.24	49.9	0.54
7000	2.84	49.8	7000	3.38	49.8	0.54
8000	2.97	50.0	8000	3.52	50.0	0.55
9000	3.08	49.9	9000	3.63	49.9	0.55
10000	3.18	49.9	10000	3.75	49.9	0.57
11000	3.28	50.0	11000	3.87	50.0	0.59
12000	3.38	49.9	12000	3.98	49.9	0.60
13000	3.47	49.9	13000	4.08	49.9	0.61
14000	3.56	49.9	14000	4.19	49.9	0.63
15000	3.65	49.8	15000	4.29	49.8	0.64
16000	3.73	49.8	16000	4.37	49.8	0.64
17000	3.81	50.0	17000	4.46	50.0	0.65
18000	3.89	49.9	18000	4.54	49.9	0.65
19000	3.97	49.9	19000	4.62	49.9	0.65
20000	4.05	49.9	20000	4.70	49.9	0.65



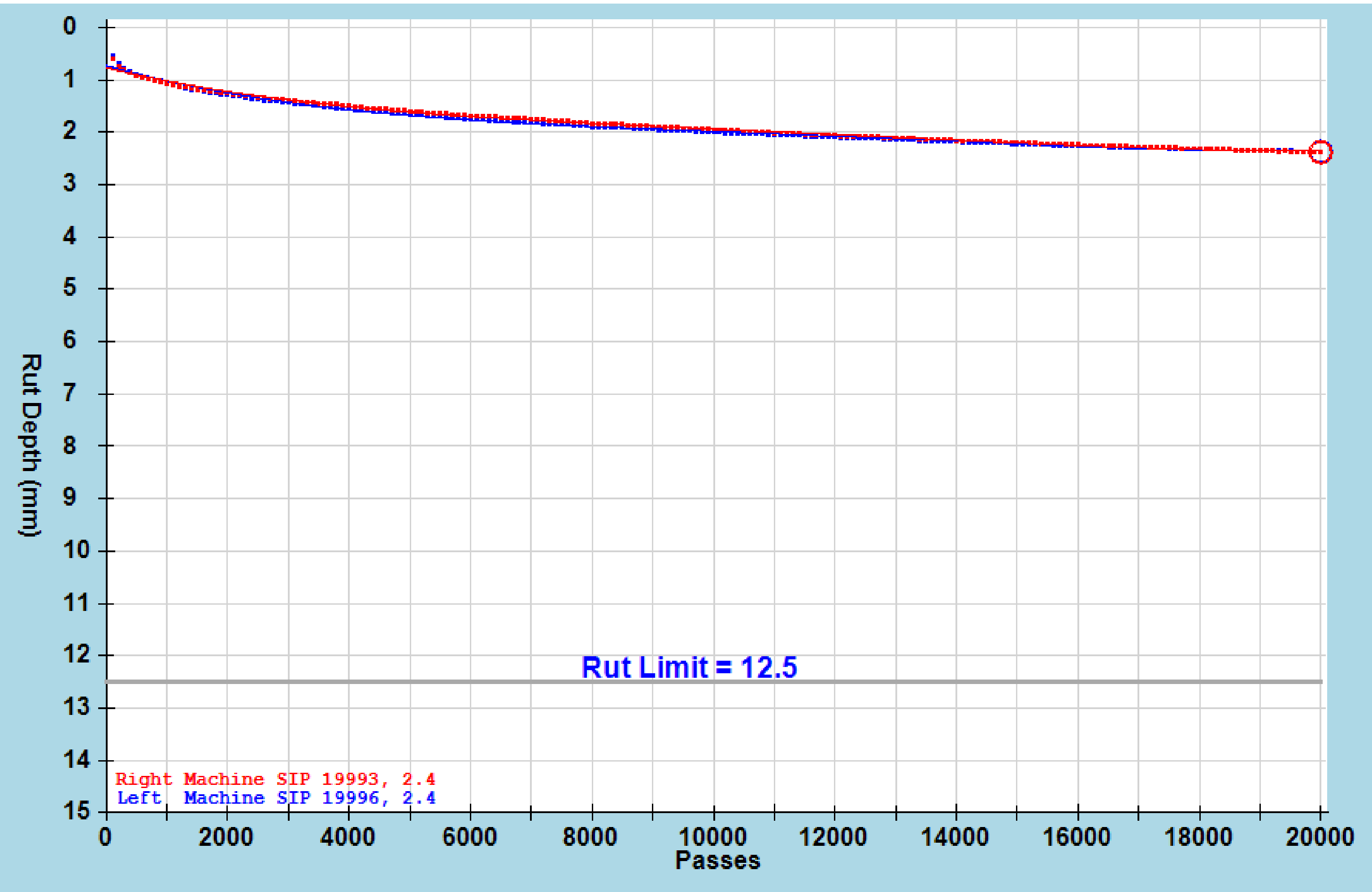
TRIMAT MATERIALS TESTING, INC.

HWT-Report AASHTO T-324

Project: 18-1278 **Mix:** [redacted] **Date Sampled:** **Technician:** AK

	Left	Right
Date Tested:	03/08/2019	03/08/2019
Passes Per Minute:	52	52
Water Temperature:	50.0 °C	50.0 °C
Rut Depth Limit (mm):	12.5	12.5
Target Passes to Failure:	20000	20000
Final Rut Depth:	2.38 mm	2.38 mm
Total Passes:	20000	20000
Passes to Failure:	20000	20000
Rut Depth Pass/Fail:	PASS	PASS
Creep Slope:	-2.552E-05	-1.35E-05
Stripping Slope:	-2.555E-05	-1.353E-05
Stripping Inflection Point:	19996	19993

Left			Right			Difference
Pass	Rut Depth	Temp.	Pass	Rut Depth	Temp	ABS (R-L)
1000	1.08	50.0	1000	1.07	50.0	0.01
2000	1.29	49.9	2000	1.26	49.9	0.03
3000	1.43	50.0	3000	1.39	50.0	0.04
4000	1.55	50.0	4000	1.50	50.0	0.05
5000	1.66	49.8	5000	1.59	49.8	0.07
6000	1.75	50.0	6000	1.68	50.0	0.07
7000	1.82	49.9	7000	1.74	49.9	0.08
8000	1.89	49.8	8000	1.83	49.8	0.06
9000	1.94	50.1	9000	1.89	50.1	0.05
10000	1.99	49.9	10000	1.95	49.9	0.04
11000	2.05	50.0	11000	2.01	50.0	0.04
12000	2.09	50.0	12000	2.06	50.0	0.03
13000	2.14	49.9	13000	2.11	49.9	0.03
14000	2.18	49.9	14000	2.16	49.9	0.02
15000	2.22	49.9	15000	2.20	49.9	0.02
16000	2.26	50.0	16000	2.24	50.0	0.02
17000	2.29	49.8	17000	2.28	49.8	0.01
18000	2.32	49.9	18000	2.32	49.9	0.00
19000	2.35	50.0	19000	2.35	50.0	0.00
20000	2.38	49.9	20000	2.38	49.9	0.00

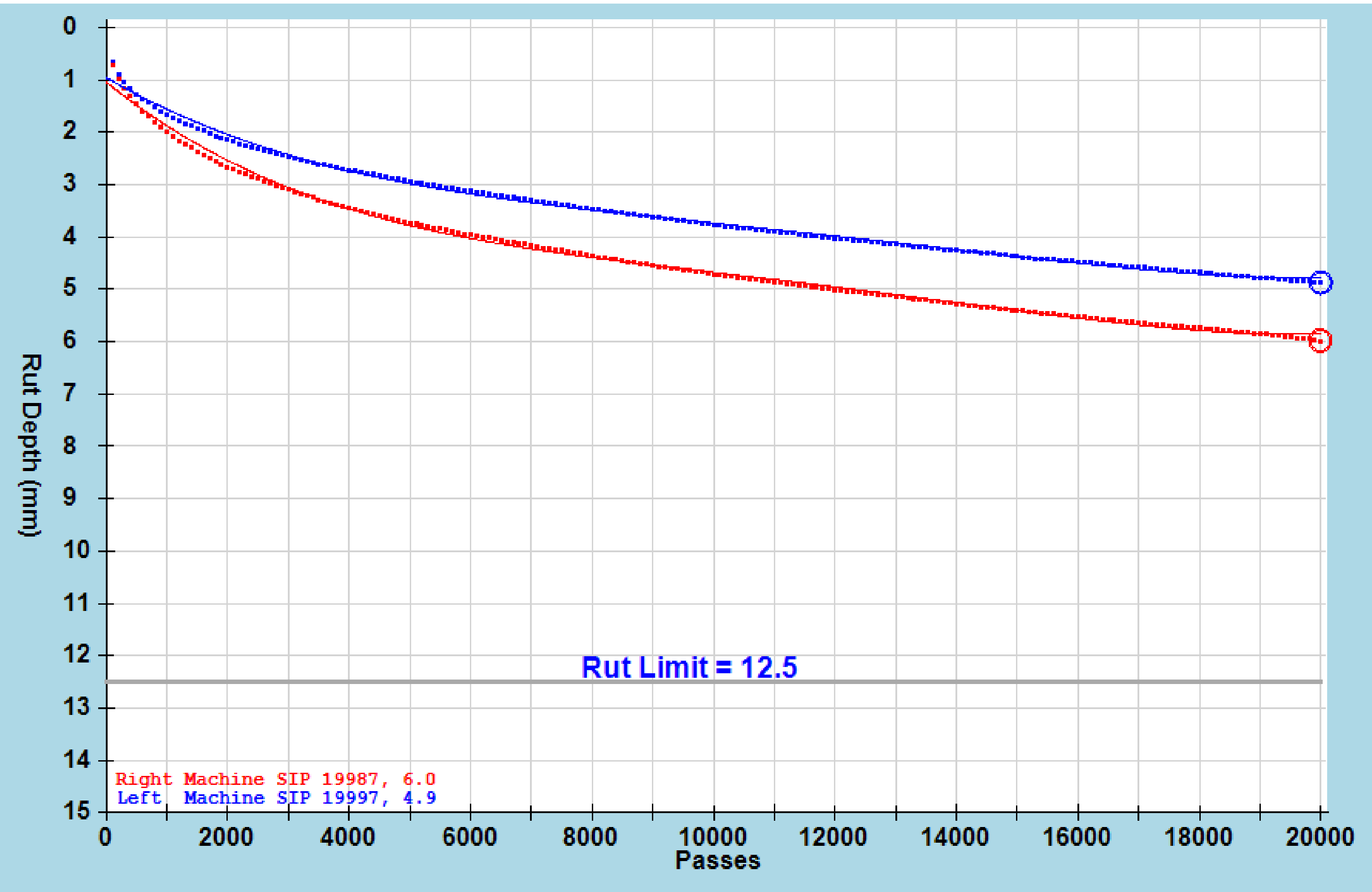


HWT-Report AASHTO T-324

Project: 18-1278 **Mix:** Mix 4 **Date Sampled:** **Technician:** AK

	Left	Right
Date Tested:	03/07/2019	03/07/2019
Passes Per Minute:	52	52
Water Temperature:	50.0 °C	50.0 °C
Rut Depth Limit (mm):	12.5	12.5
Target Passes to Failure:	20000	20000
Final Rut Depth:	4.87 mm	5.99 mm
Total Passes:	20000	20000
Passes to Failure:	20000	20000
Rut Depth Pass/Fail:	PASS	PASS
Creep Slope:	-1.105E-05	-3.291E-05
Stripping Slope:	-1.111E-05	-3.299E-05
Stripping Inflection Point:	19997	19987

Left			Right			Difference
Pass	Rut Depth	Temp.	Pass	Rut Depth	Temp	ABS (R-L)
1000	1.65	50.0	1000	1.99	50.0	0.34
2000	2.15	49.9	2000	2.66	49.9	0.51
3000	2.46	50.0	3000	3.10	50.0	0.64
4000	2.72	49.9	4000	3.45	49.9	0.73
5000	2.94	49.9	5000	3.73	49.9	0.79
6000	3.13	49.9	6000	3.96	49.9	0.83
7000	3.30	50.0	7000	4.17	50.0	0.87
8000	3.46	50.0	8000	4.36	50.0	0.90
9000	3.61	50.0	9000	4.54	50.0	0.93
10000	3.76	49.9	10000	4.71	49.9	0.95
11000	3.90	50.0	11000	4.86	50.0	0.96
12000	4.03	50.0	12000	5.01	50.0	0.98
13000	4.14	50.0	13000	5.14	50.0	1.00
14000	4.26	50.0	14000	5.28	50.0	1.02
15000	4.37	50.0	15000	5.40	50.0	1.03
16000	4.47	50.0	16000	5.51	50.0	1.04
17000	4.57	49.9	17000	5.63	49.9	1.06
18000	4.67	50.0	18000	5.74	50.0	1.07
19000	4.78	49.9	19000	5.85	49.9	1.07
20000	4.87	49.9	20000	5.99	49.9	1.12



InstroTek Inc.

Load Report

Project ID:	Specimen ID: Mix 1 - 1
Date / Time: 04/04/19 11:22	Stability (Peak Load): **18.76 kN**
Specimen Diameter: **150.00 mm**	IDT Strength: **1284 kPa (186.2 PSI)**
Specimen Thickness: **62.00 mm**	Peak Displacement: **3.49 mm**
Starting Load: 0.05 kN	Flow (0.01 inch units): **13.7**
Stopping Load: 0.1 kN	Total Energy: **84.86 Joules**
Max Specific Gravity: 2.435	Energy to Peak: **40.99 Joules**
% Voids: 7.3	Temperature: 22 °C
% AC: %	IDEAL-CT Index: **48.245**

Project ID:	Specimen ID: Mix 1 - 2
Date / Time: 04/04/19 11:20	Stability (Peak Load): **17.5 kN**
Specimen Diameter: **150.00 mm**	IDT Strength: **1196.7 kPa (173.6 PSI)**
Specimen Thickness: **62.00 mm**	Peak Displacement: **4.16 mm**
Starting Load: 0 kN	Flow (0.01 inch units): **16.4**
Stopping Load: 0.1 kN	Total Energy: **83.9 Joules**
Max Specific Gravity: 2.435	Energy to Peak: **42.69 Joules**
% Voids: 7.0	Temperature: 22 °C
% AC: %	IDEAL-CT Index: **50.434**

Project ID:	Specimen ID: Mix 1 - 3
Date / Time: 04/04/19 11:10	Stability (Peak Load): **18.4 kN**
Specimen Diameter: **150.00 mm**	IDT Strength: **1260.1 kPa (182.8 PSI)**
Specimen Thickness: **62.00 mm**	Peak Displacement: **3.98 mm**
Starting Load: 0 kN	Flow (0.01 inch units): **16**
Stopping Load: 0.1 kN	Total Energy: **85.05 Joules**
Max Specific Gravity: 2.435	Energy to Peak: **42.73 Joules**
% Voids: 7.2	Temperature: 22 °C
% AC: %	IDEAL-CT Index: **49.806**

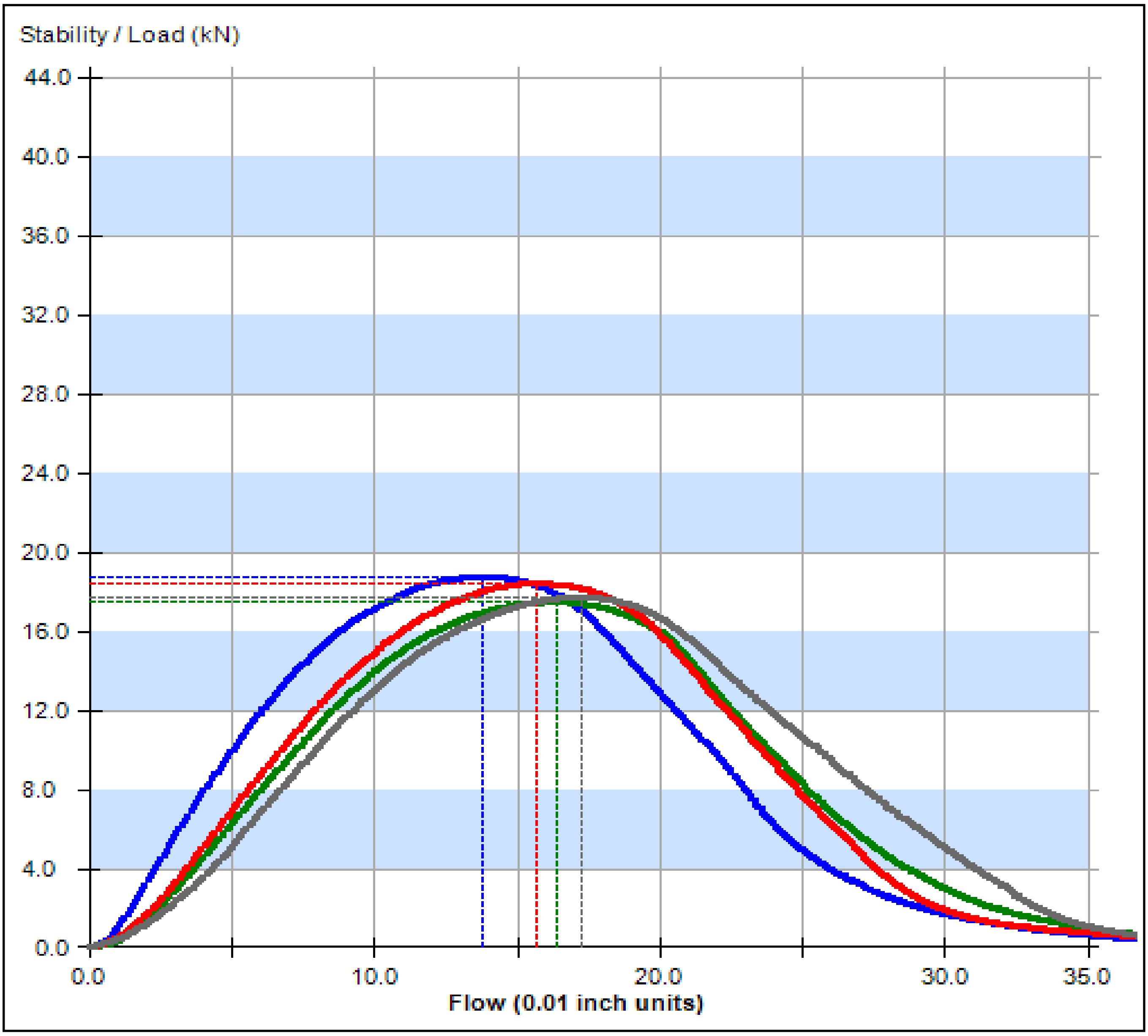
Project ID:	Specimen ID: Mix 1 - 4
Date / Time: 04/04/19 10:57	Stability (Peak Load): **17.7 kN**
Specimen Diameter: **150.00 mm**	IDT Strength: **1213.9 kPa (176.1 PSI)**
Specimen Thickness: **62.00 mm**	Peak Displacement: **4.37 mm**
Starting Load: 0.1 kN	Flow (0.01 inch units): **17.2**
Stopping Load: 0.1 kN	Total Energy: **87.81 Joules**
Max Specific Gravity: 2.435	Energy to Peak: **43.98 Joules**
% Voids: 7.5	Temperature: 22 °C
% AC: %	IDEAL-CT Index: **72.61**

Technician:

Signature: ______________________________

InstroTek Inc.

Load Report



In order of peak load (High to Low):

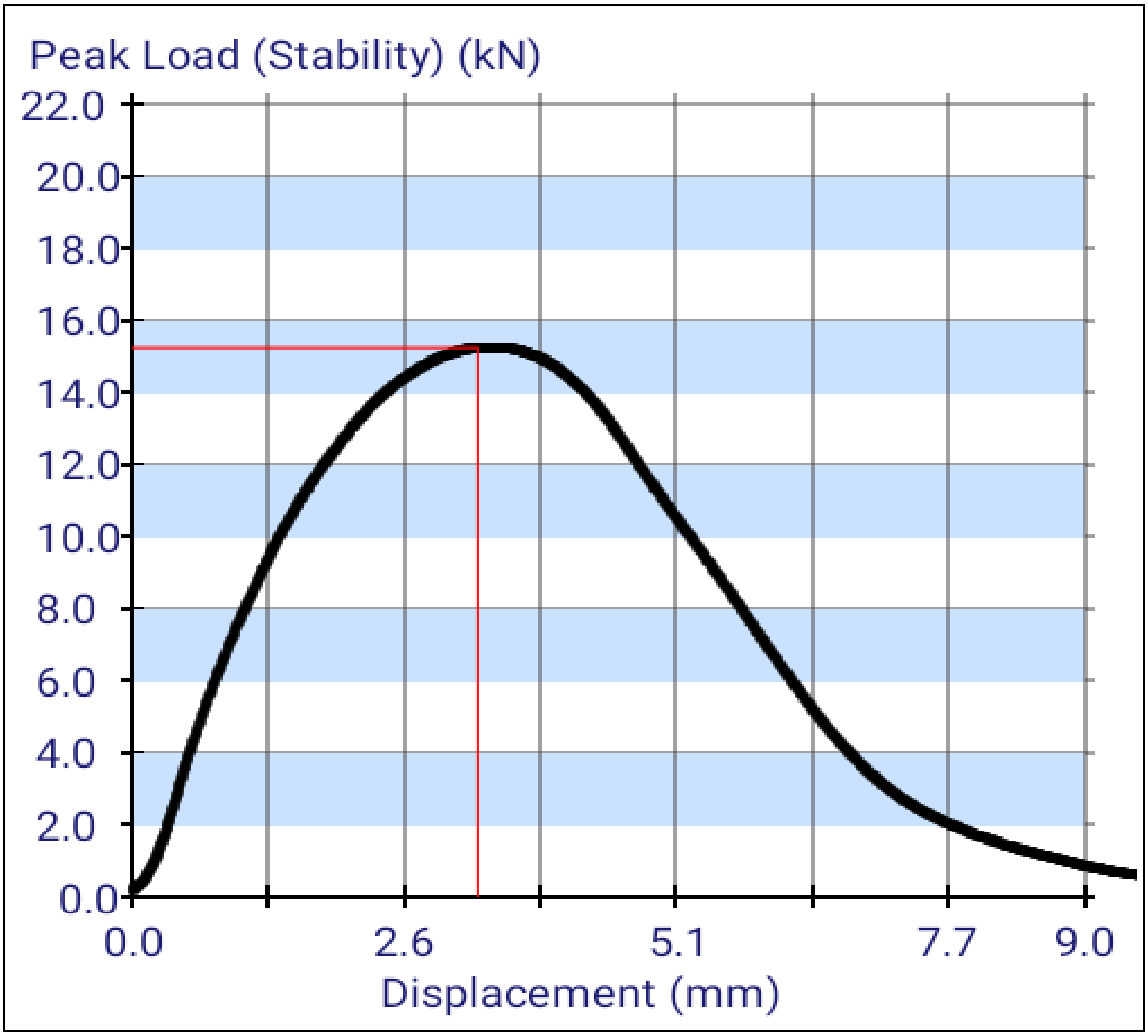
[redacted]

Technician:

Signature: ______________________________

Load Report

InstroTek Inc.



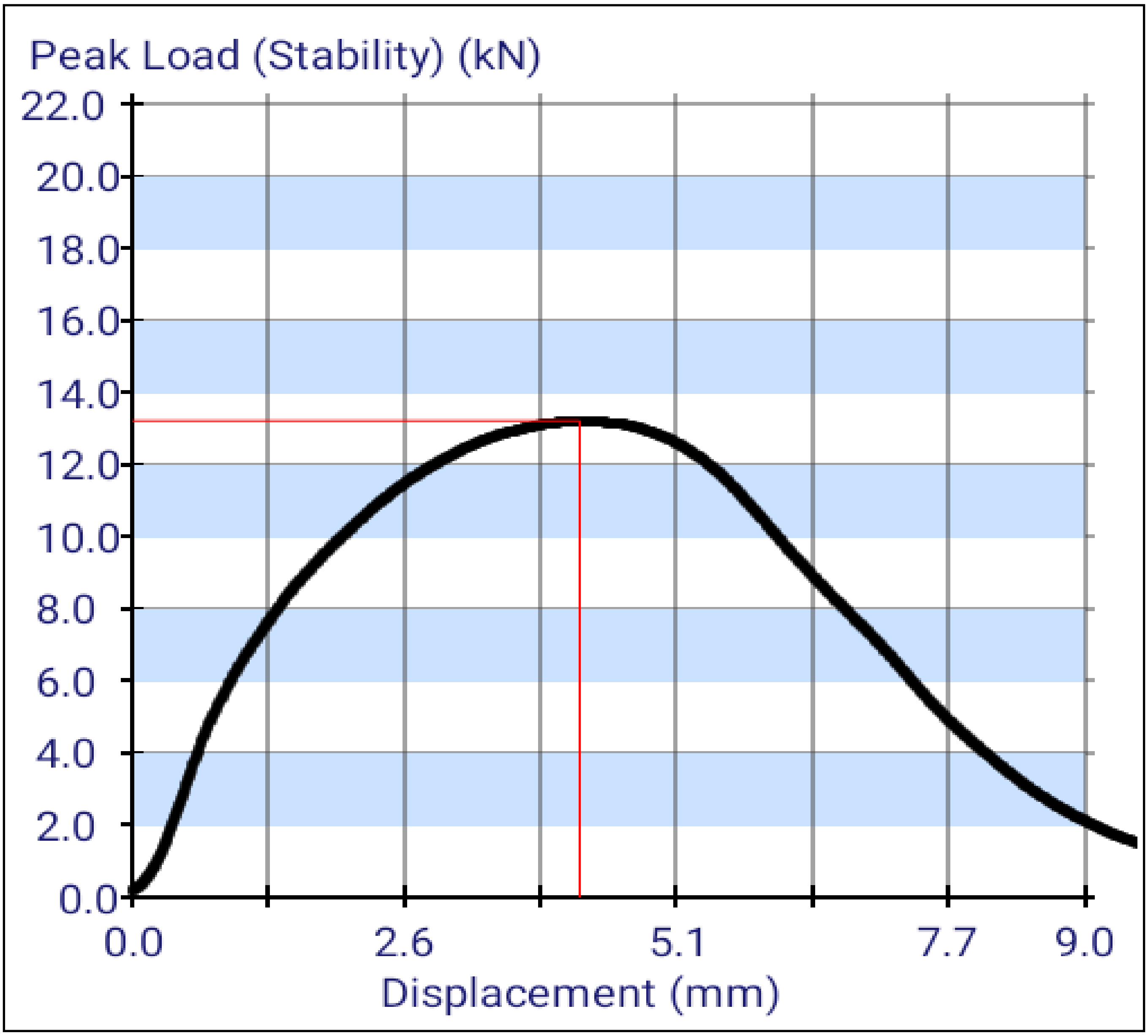
Project ID: 18-1298	Sample ID: Mix 2 - 1
Date / Time: 02/28/19 13:23	Peak Load (Stability): **15.24 kN**
Sample Diameter: **150 mm**	IDT Strength: **1,043 kPa (151.3 PSI)**
Sample Thickness: **62 mm**	Peak Displacement: **3.27 mm**
Starting Load: 0.20 kN	Flow (0.01 inch units): **12.9**
Stopping Load: 0.1%	Total Energy: **75.23 Joules**
Max Specific Gravity:	Energy to Peak: **32.24 Joules**
Voids:	Temperature: 25
% AC: %	IDEAL-CT Index: **63.861**
Displacement at 75%: 4.9 mm	Post-Peak Slope 75%: -4163.6 N/mm

Technician: AK

Signature: ____________________

Load Report

InstroTek Inc.



Project ID: 18-1298	**Sample ID:** Mix 2 - 2
Date / Time: 02/28/19 13:25	Peak Load (Stability): **13.21 kN**
Sample Diameter: **150 mm**	IDT Strength: **904 kPa (131.2 PSI)**
Sample Thickness: **62 mm**	Peak Displacement: **4.23 mm**
Starting Load: 0.20 kN	Flow (0.01 inch units): **16.6**
Stopping Load: 0.1%	Total Energy: **81.08 Joules**
Max Specific Gravity:	Energy to Peak: **38.53 Joules**
Voids:	Temperature: 25
% AC: %	IDEAL-CT Index: **109.369**
Displacement at 75%: 6.1 mm	Post-Peak Slope 75%: -3260.1 N/mm

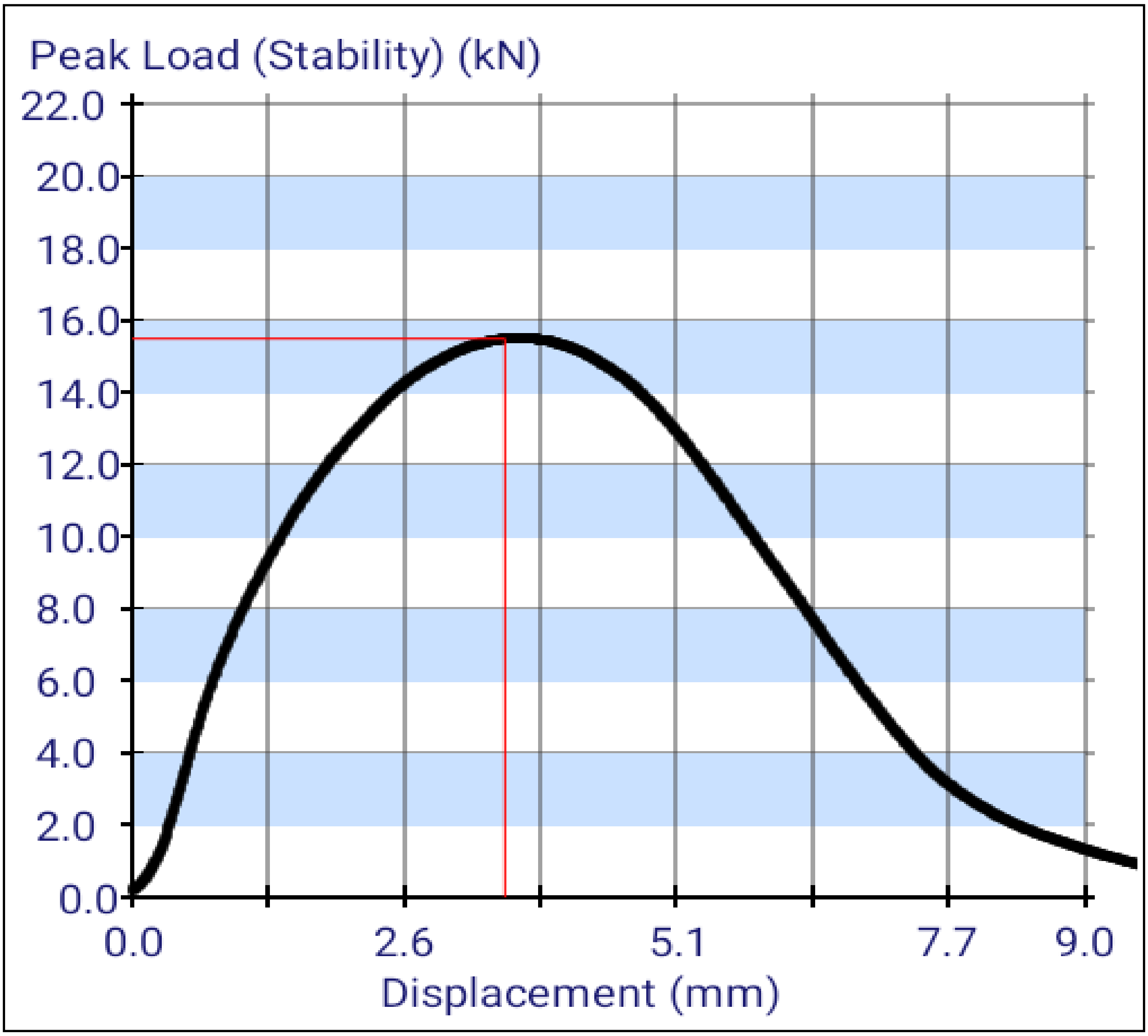
Technician: AK

Signature: ______________________________

InstroTek Inc. www.instrotek.com

Load Report

InstroTek Inc.



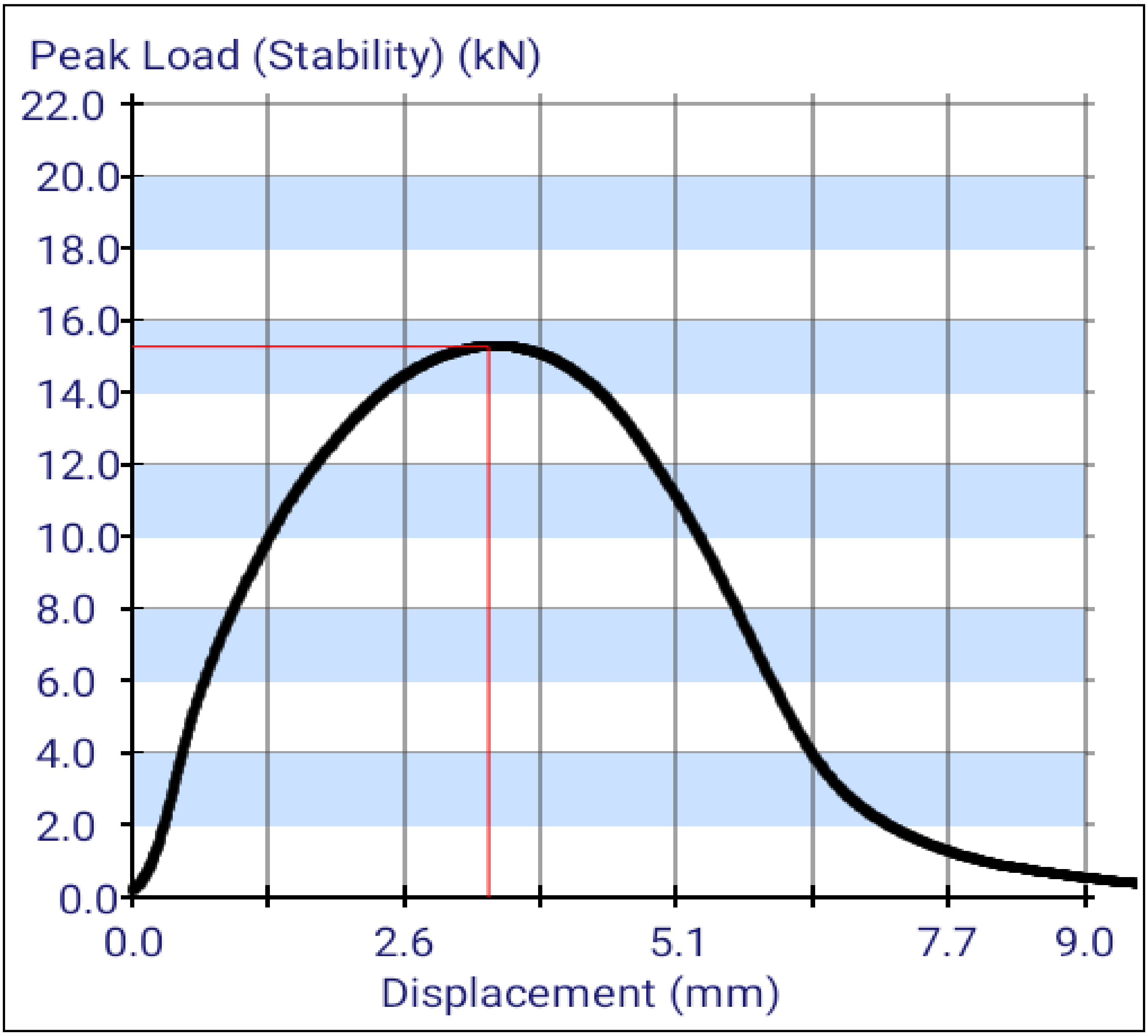
Project ID: 18-1298	**Sample ID: Mix 2 - 4**
Date / Time: 02/28/19 13:27	Peak Load (Stability): **15.49 kN**
Sample Diameter: **150 mm**	IDT Strength: **1,060 kPa (153.8 PSI)**
Sample Thickness: **62 mm**	Peak Displacement: **3.52 mm**
Starting Load: 0.20 kN	Flow (0.01 inch units): **13.9**
Stopping Load: 0.1%	Total Energy: **83.93 Joules**
Max Specific Gravity:	Energy to Peak: **35.97 Joules**
Voids:	Temperature: 25
% AC: %	IDEAL-CT Index: **83.844**
Displacement at 75%: 5.5 mm	Post-Peak Slope 75%: -3939.9 N/mm

Technician: AK

Signature: ____________________

InstroTek Inc.

Load Report



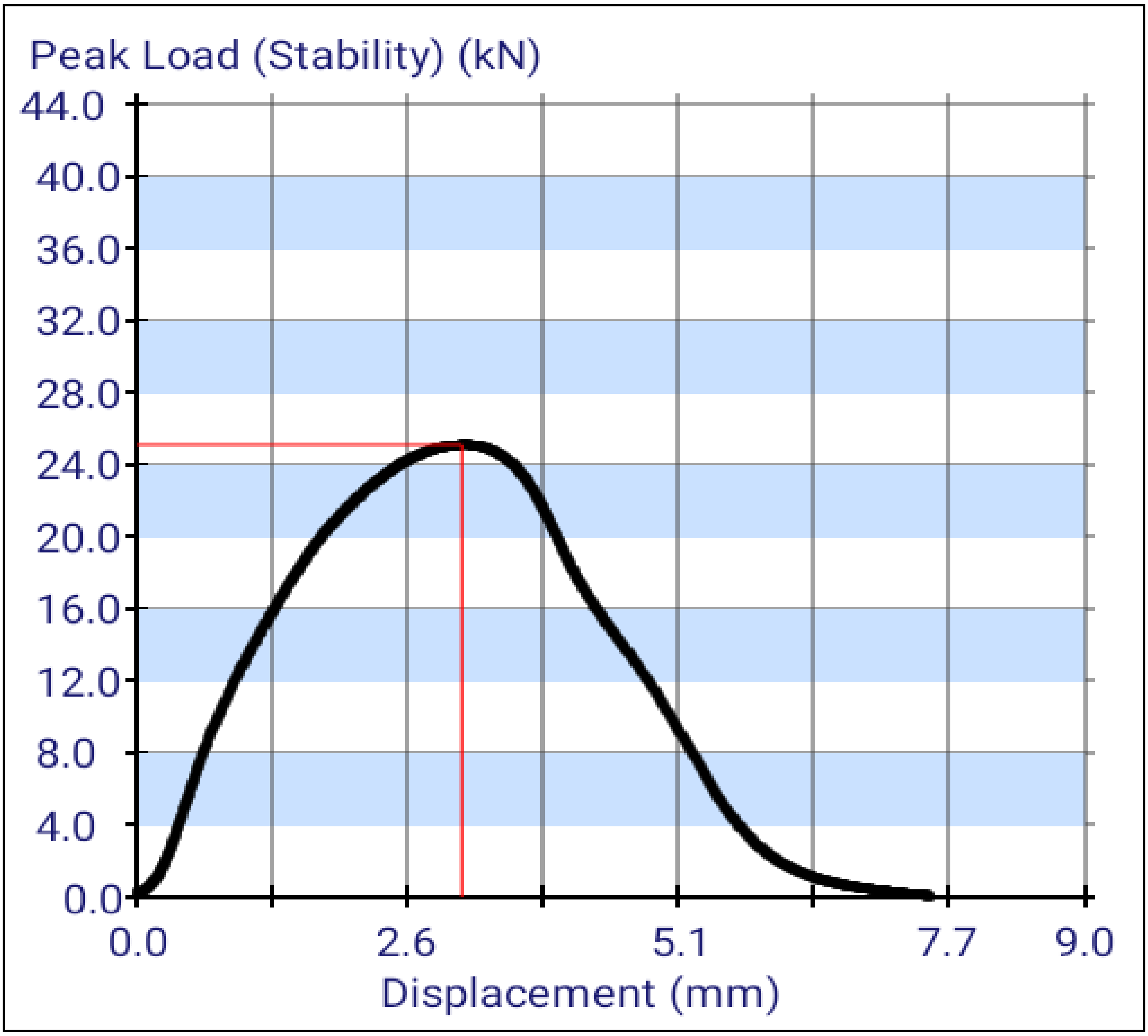
Project ID: 18-1298	**Sample ID:** Mix 2 - 8
Date / Time: 02/28/19 13:28	Peak Load (Stability): **15.27 kN**
Sample Diameter: **150 mm**	IDT Strength: **1,045 kPa (151.6 PSI)**
Sample Thickness: **62 mm**	Peak Displacement: **3.37 mm**
Starting Load: 0.20 kN	Flow (0.01 inch units): **13.3**
Stopping Load: 0.1%	Total Energy: **73.88 Joules**
Max Specific Gravity:	Energy to Peak: **34.80 Joules**
Voids:	Temperature: 25
% AC: %	IDEAL-CT Index: **57.570**
Displacement at 75%: 5.1 mm	Post-Peak Slope 75%: -4670.3 N/mm

Technician: AK

Signature: ______________________________

Load Report

InstroTek Inc.



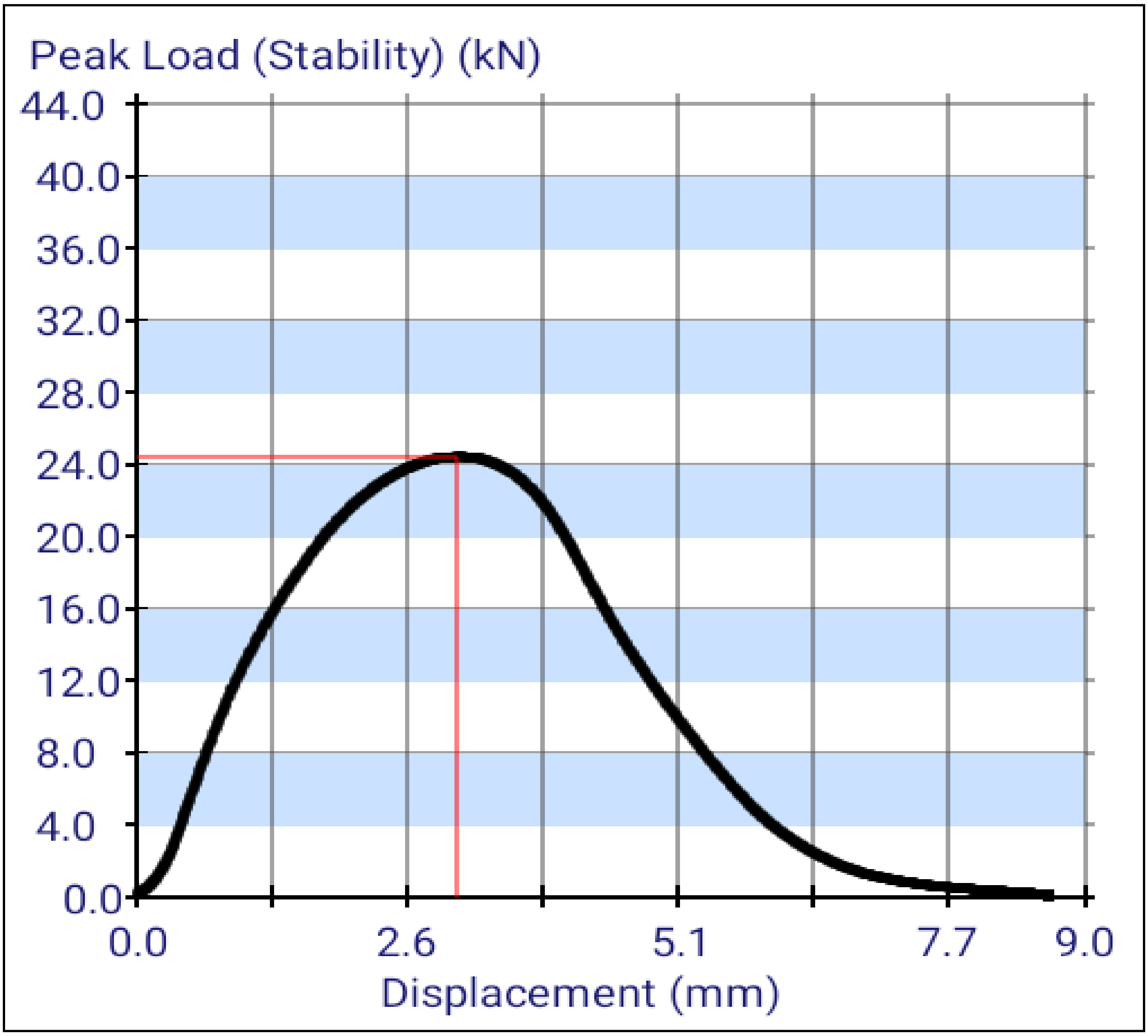
Project ID: 18-1298	**Sample ID:** Mix 3 - 1
Date / Time: 02/28/19 12:24	Peak Load (Stability): **25.10 kN**
Sample Diameter: **150 mm**	IDT Strength: **1,718 kPa (249.2 PSI)**
Sample Thickness: **62 mm**	Peak Displacement: **3.09 mm**
Starting Load: 0.20 kN	Flow (0.01 inch units): **12.2**
Stopping Load: 0.1%	Total Energy: **93.38 Joules**
Max Specific Gravity:	Energy to Peak: **49.51 Joules**
Voids:	Temperature: 25
% AC: %	IDEAL-CT Index: **24.521**
Displacement at 75%: 4.1 mm	Post-Peak Slope 75%: -11149.2 N/mm

Technician: AK

Signature: ______________________________

Load Report

InstroTek Inc.



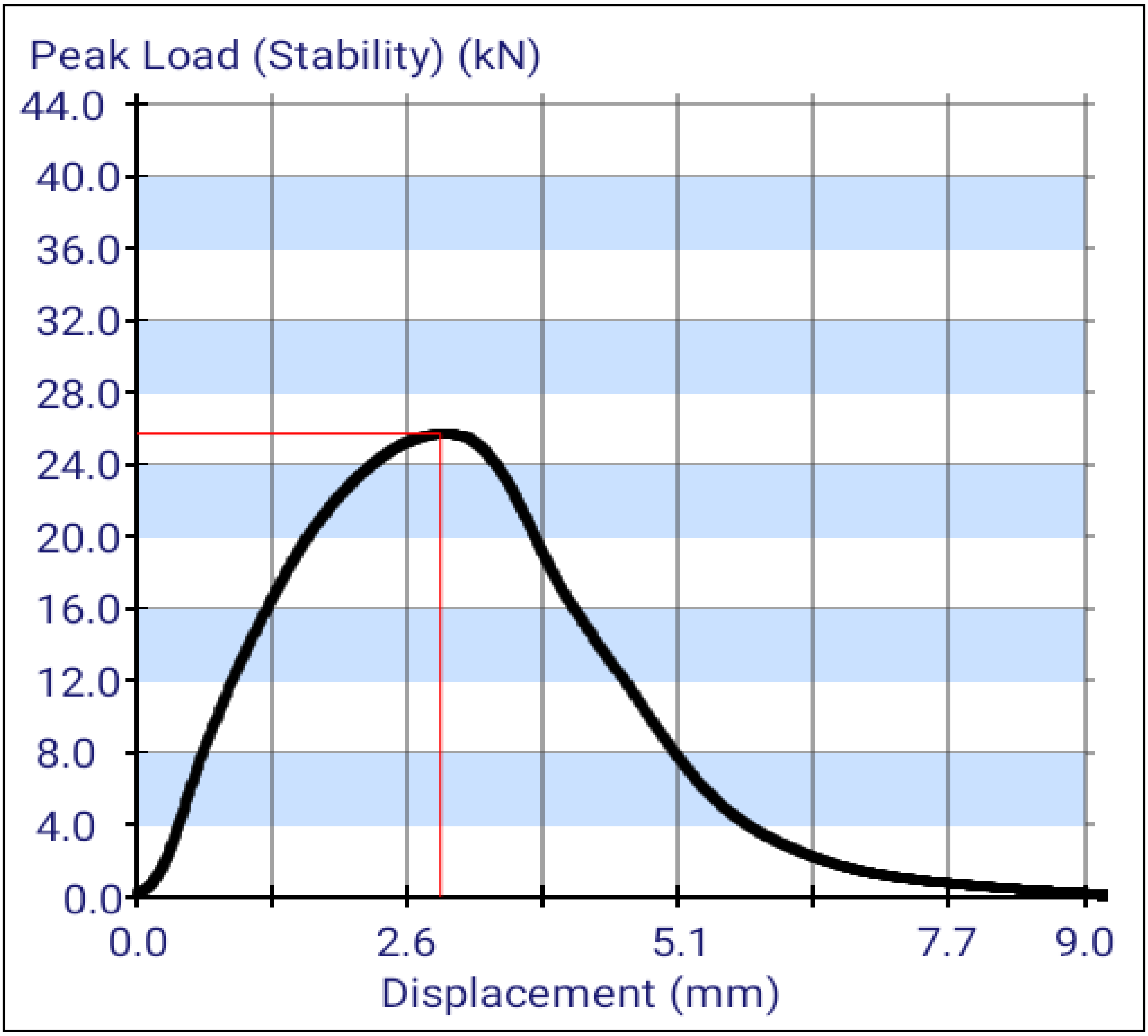
Project ID: 18-1298	Sample ID: Mix 3 - 2
Date / Time: 02/28/19 12:26	Peak Load (Stability): **24.42 kN**
Sample Diameter: **150 mm**	IDT Strength: **1,672 kPa (242.5 PSI)**
Sample Thickness: **62 mm**	Peak Displacement: **3.04 mm**
Starting Load: 0.20 kN	Flow (0.01 inch units): **12.0**
Stopping Load: 0.1%	Total Energy: **96.27 Joules**
Max Specific Gravity:	Energy to Peak: **47.56 Joules**
Voids:	Temperature: 25
% AC: %	IDEAL-CT Index: **27.748**
Displacement at 75%: 4.2 mm	Post-Peak Slope 75%: -10524.8 N/mm

Technician: AK

Signature: ______________________

Load Report

InstroTek Inc.



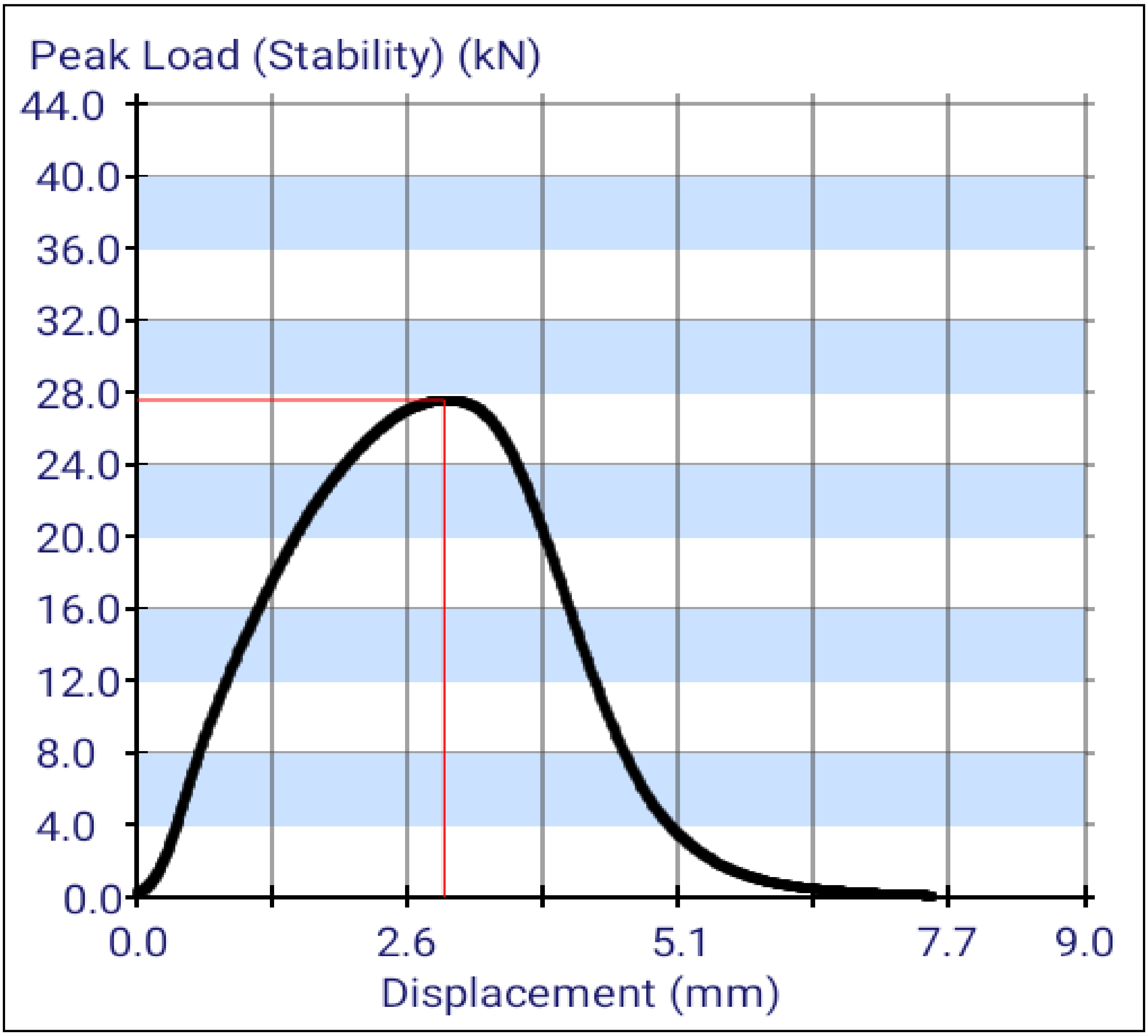
Project ID: 18-1298	**Sample ID:** Mix 3 - 3
Date / Time: 02/28/19 12:28	Peak Load (Stability): **25.71 kN**
Sample Diameter: **150 mm**	IDT Strength: **1,760 kPa (255.3 PSI)**
Sample Thickness: **62 mm**	Peak Displacement: **2.88 mm**
Starting Load: 0.20 kN	Flow (0.01 inch units): **11.4**
Stopping Load: 0.1%	Total Energy: **94.19 Joules**
Max Specific Gravity:	Energy to Peak: **46.27 Joules**
Voids:	Temperature: 25
% AC: %	IDEAL-CT Index: **22.579**
Displacement at 75%: 3.8 mm	Post-Peak Slope 75%: -11495.8 N/mm

Technician: AK

Signature: ______________________

InstroTek Inc.

Load Report

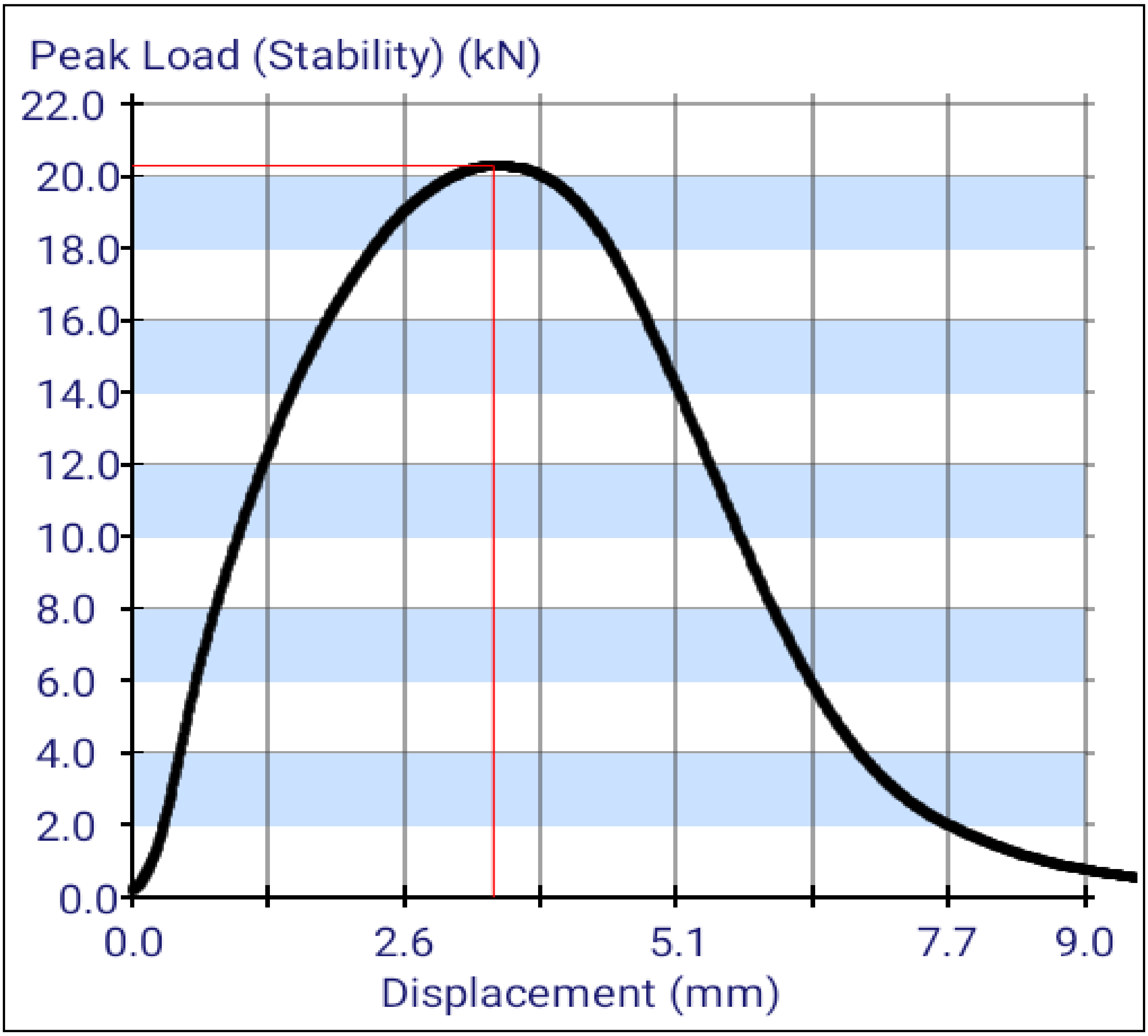


Project ID: 18-1298	Sample ID: Mix 3 - 4
Date / Time: 02/28/19 12:34	Peak Load (Stability): **27.57 kN**
Sample Diameter: **150 mm**	IDT Strength: **1,887 kPa (273.7 PSI)**
Sample Thickness: **62 mm**	Peak Displacement: **2.92 mm**
Starting Load: 0.20 kN	Flow (0.01 inch units): **11.5**
Stopping Load: 0.1%	Total Energy: **89.85 Joules**
Max Specific Gravity:	Energy to Peak: **50.25 Joules**
Voids:	Temperature: 25
% AC: %	IDEAL-CT Index: **15.307**
Displacement at 75%: 3.8 mm	Post-Peak Slope 75%: -16151.1 N/mm

Technician: AK

Signature: ______________________

Load Report



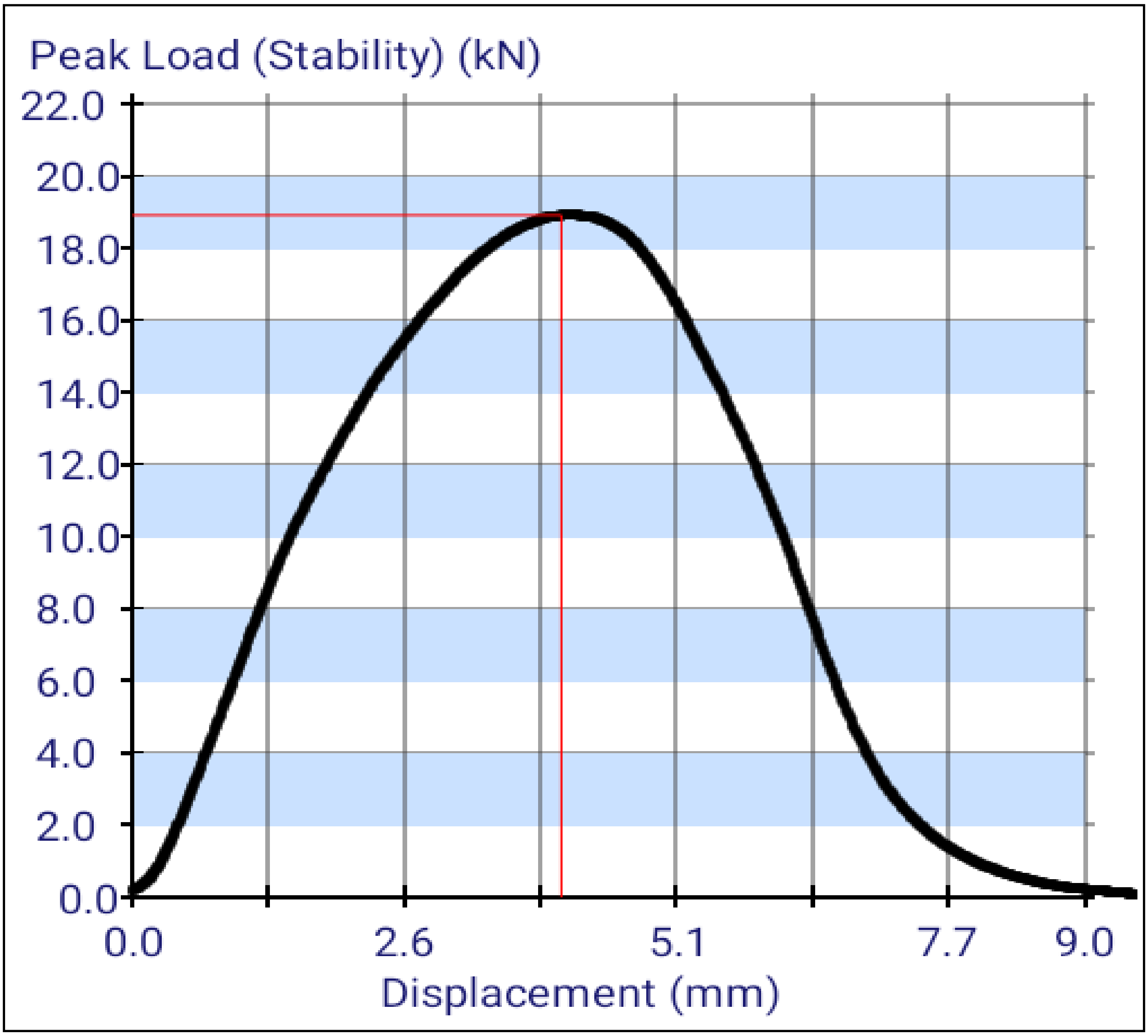
Project ID: 18-1298	**Sample ID:** Mix 4 - 1
Date / Time: 02/28/19 12:39	Peak Load (Stability): **20.28 kN**
Sample Diameter: **150 mm**	IDT Strength: **1,388 kPa (201.3 PSI)**
Sample Thickness: **62 mm**	Peak Displacement: **3.41 mm**
Starting Load: 0.20 kN	Flow (0.01 inch units): **13.4**
Stopping Load: 0.1%	Total Energy: **96.79 Joules**
Max Specific Gravity:	Energy to Peak: **45.46 Joules**
Voids:	Temperature: 25
% AC: %	IDEAL-CT Index: **53.555**
Displacement at 75%: 5 mm	Post-Peak Slope 75%: -6461.5 N/mm

Technician: AK

Signature: ______________________

Load Report

InstroTek® Inc.



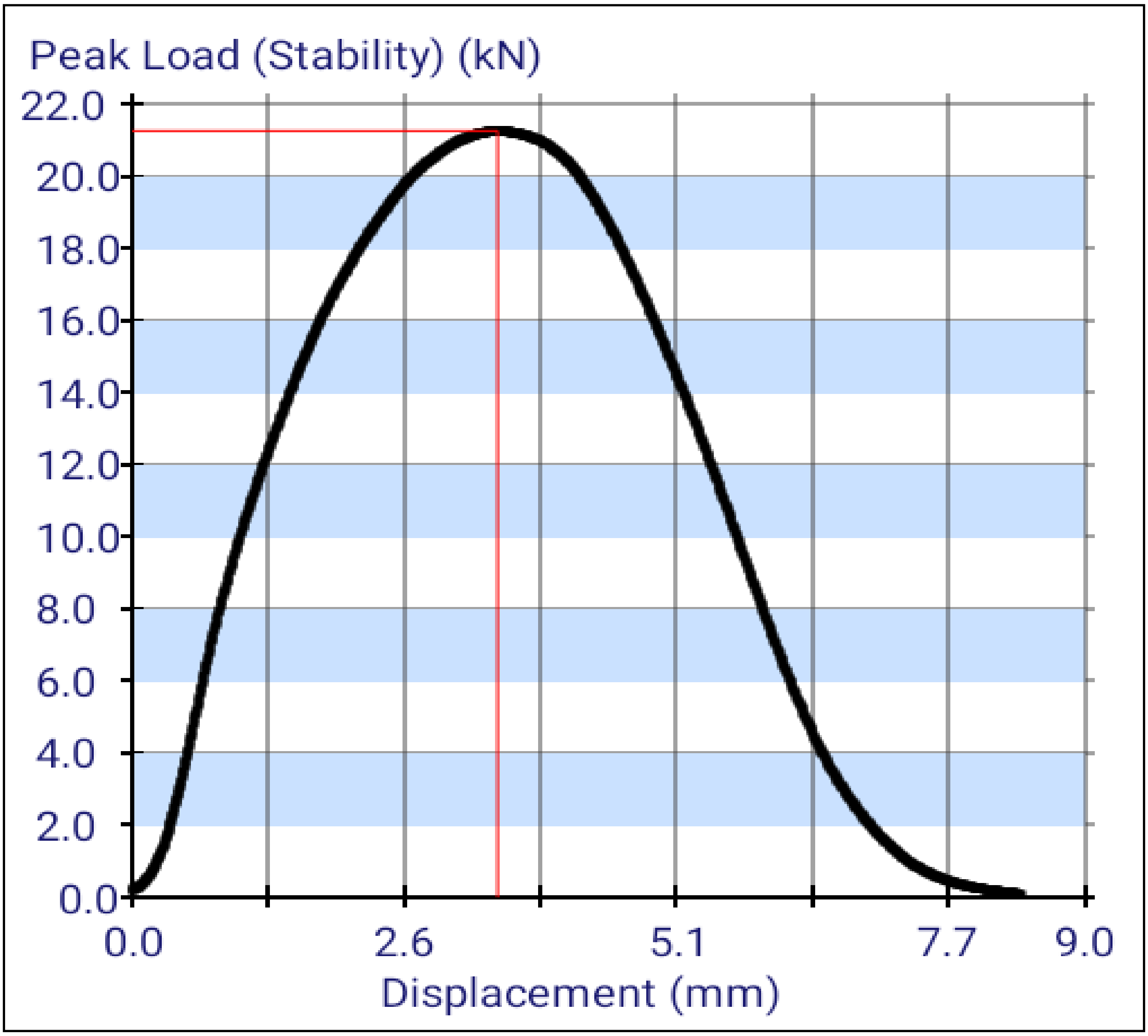
Project ID: 18-1298	**Sample ID:** Mix 4 - 2
Date / Time: 02/28/19 12:40	Peak Load (Stability): **18.91 kN**
Sample Diameter: **150 mm**	IDT Strength: **1,294 kPa (187.7 PSI)**
Sample Thickness: **62 mm**	Peak Displacement: **4.06 mm**
Starting Load: 0.20 kN	Flow (0.01 inch units): **16.0**
Stopping Load: 0.1%	Total Energy: **88.58 Joules**
Max Specific Gravity:	Energy to Peak: **46.96 Joules**
Voids:	Temperature: 25
% AC: %	IDEAL-CT Index: **58.354**
Displacement at 75%: 5.6 mm	Post-Peak Slope 75%: -6040.8 N/mm

Technician: AK

Signature: ______________________

Load Report

InstroTek Inc.



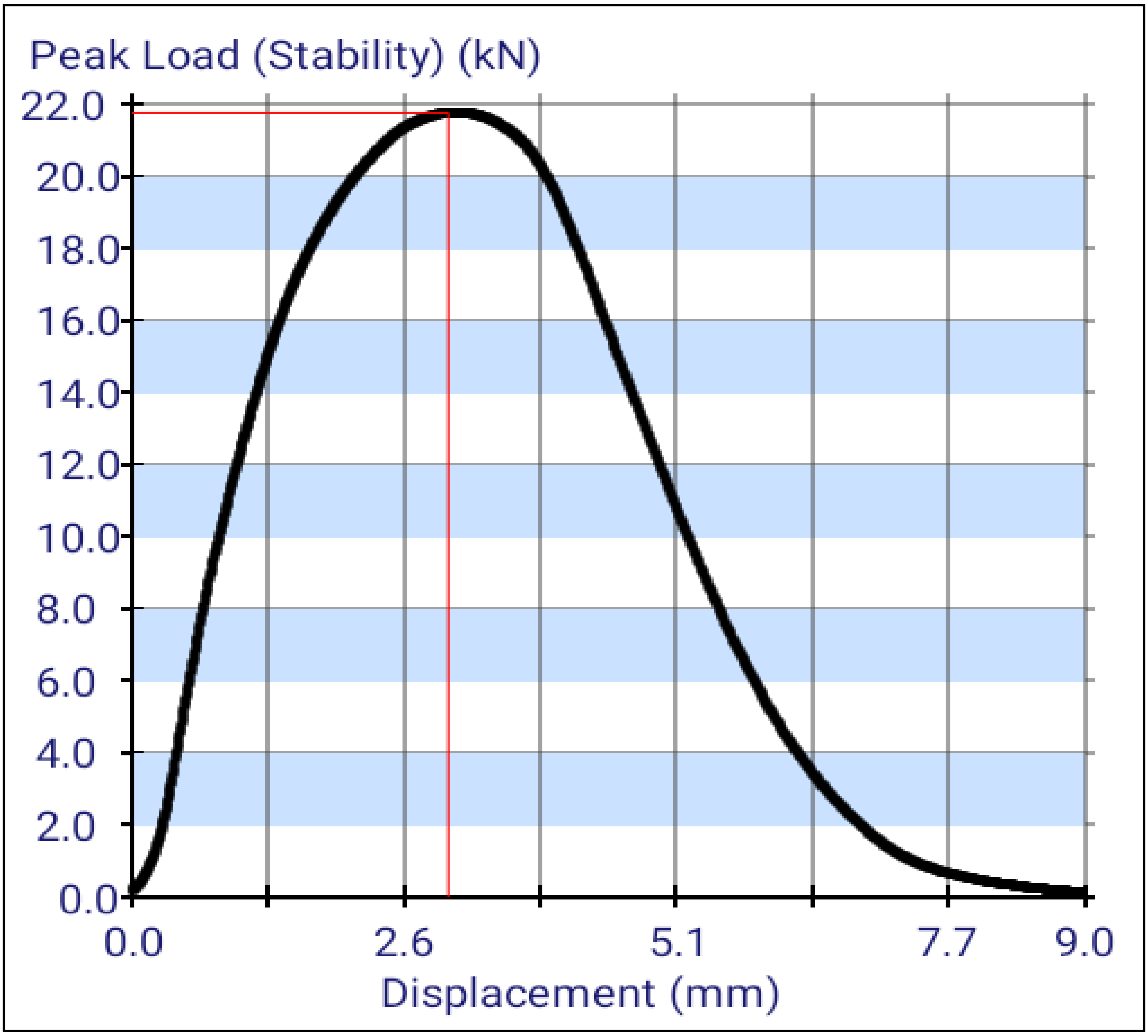
Project ID: 18-1298	**Sample ID:** Mix 4 - 3
Date / Time: 02/28/19 12:45	Peak Load (Stability): **21.25 kN**
Sample Diameter: **150 mm**	IDT Strength: **1,455 kPa (211.0 PSI)**
Sample Thickness: **62 mm**	Peak Displacement: **3.45 mm**
Starting Load: 0.20 kN	Flow (0.01 inch units): **13.6**
Stopping Load: 0.1%	Total Energy: **93.99 Joules**
Max Specific Gravity:	Energy to Peak: **46.96 Joules**
Voids:	Temperature: 25
% AC: %	IDEAL-CT Index: **48.886**
Displacement at 75%: 4.9 mm	Post-Peak Slope 75%: -6816.1 N/mm

Technician: AK

Signature: ______________________

Load Report

InstroTek® Inc.



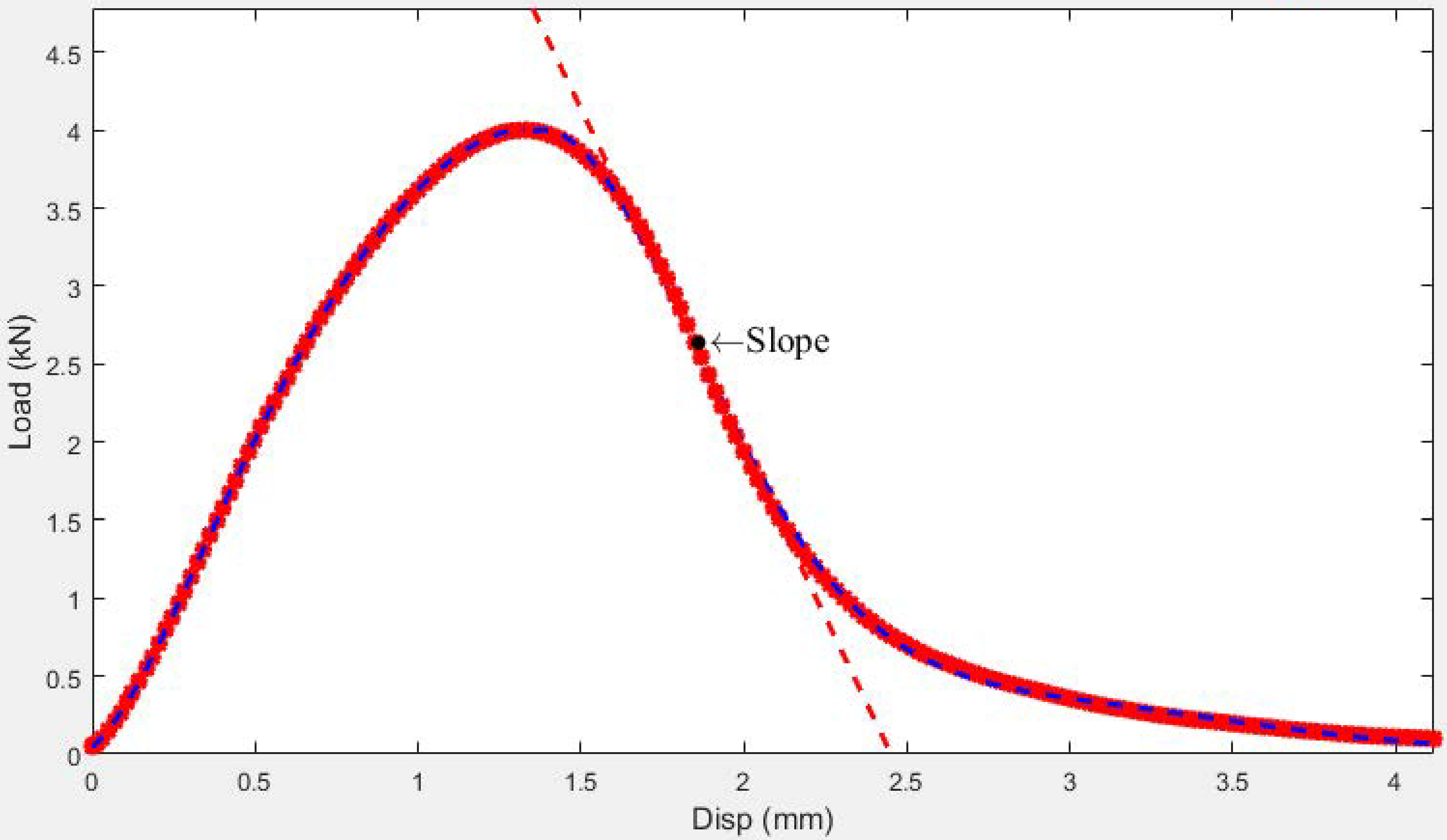
Project ID: 18-1298	Sample ID: Mix 4 - 4
Date / Time: 02/28/19 12:46	Peak Load (Stability): **21.75 kN**
Sample Diameter: **150 mm**	IDT Strength: **1,489 kPa (215.9 PSI)**
Sample Thickness: **62 mm**	Peak Displacement: **2.99 mm**
Starting Load: 0.20 kN	Flow (0.01 inch units): **11.8**
Stopping Load: 0.1%	Total Energy: **92.82 Joules**
Max Specific Gravity:	Energy to Peak: **42.70 Joules**
Voids:	Temperature: 25
% AC: %	IDEAL-CT Index: **37.398**
Displacement at 75%: 4.4 mm	Post-Peak Slope 75%: -7882.2 N/mm

Technician: AK

Signature: ______________________

Upload Data

Project ID: 18-1278 Specimen ID: Mix 1 - 1
Thickness: 51 mm Ligament: 58 mm

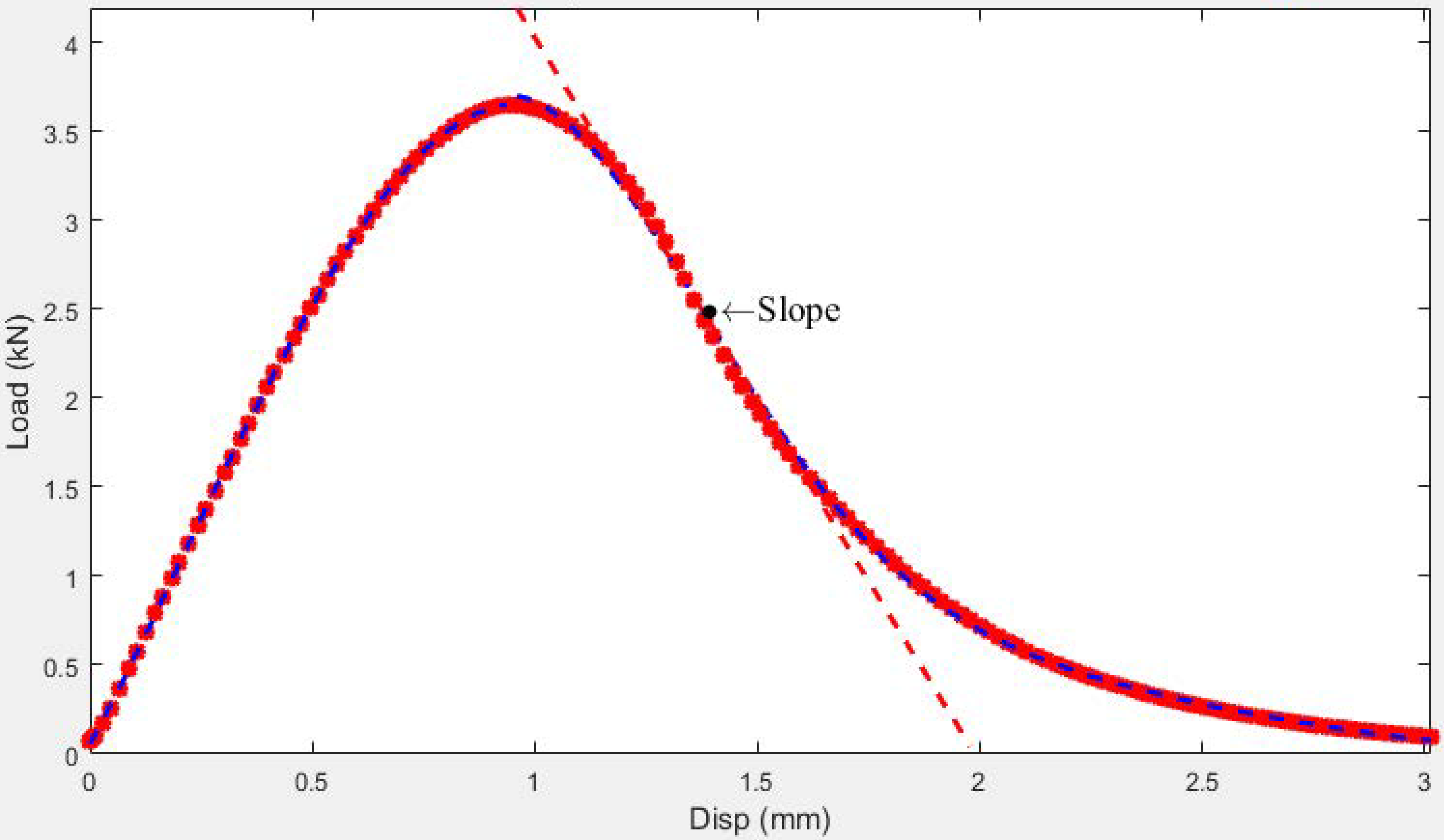


Summary Output

Fracture Energy (J/m2)	2188.16
Strength (Psi)	77.92
Slope	-4.35
Flexibility Index	5.03

Upload Data

Project ID: 18-1278 Specimen ID: Mix 1 - 2
Thickness: 51 mm Ligament: 58 mm

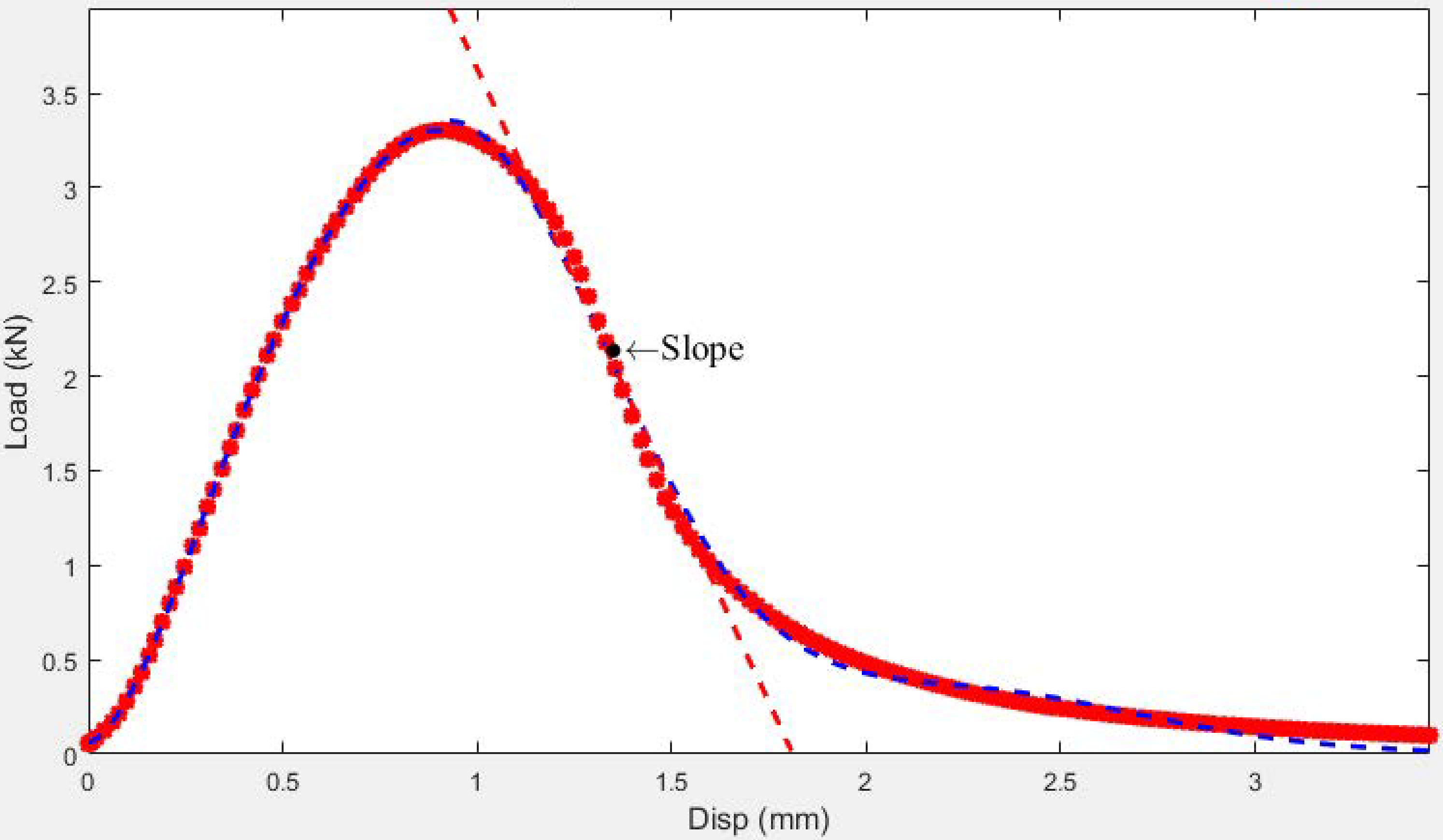


Summary Output

Fracture Energy (J/m2)	1596.88
Strength (Psi)	71.09
Slope	-4.08
Flexibility Index	3.91

Upload Data

Project ID: 18-1278 Specimen ID: Mix 1 - 3
Thickness: 50 mm Ligament: 57 mm

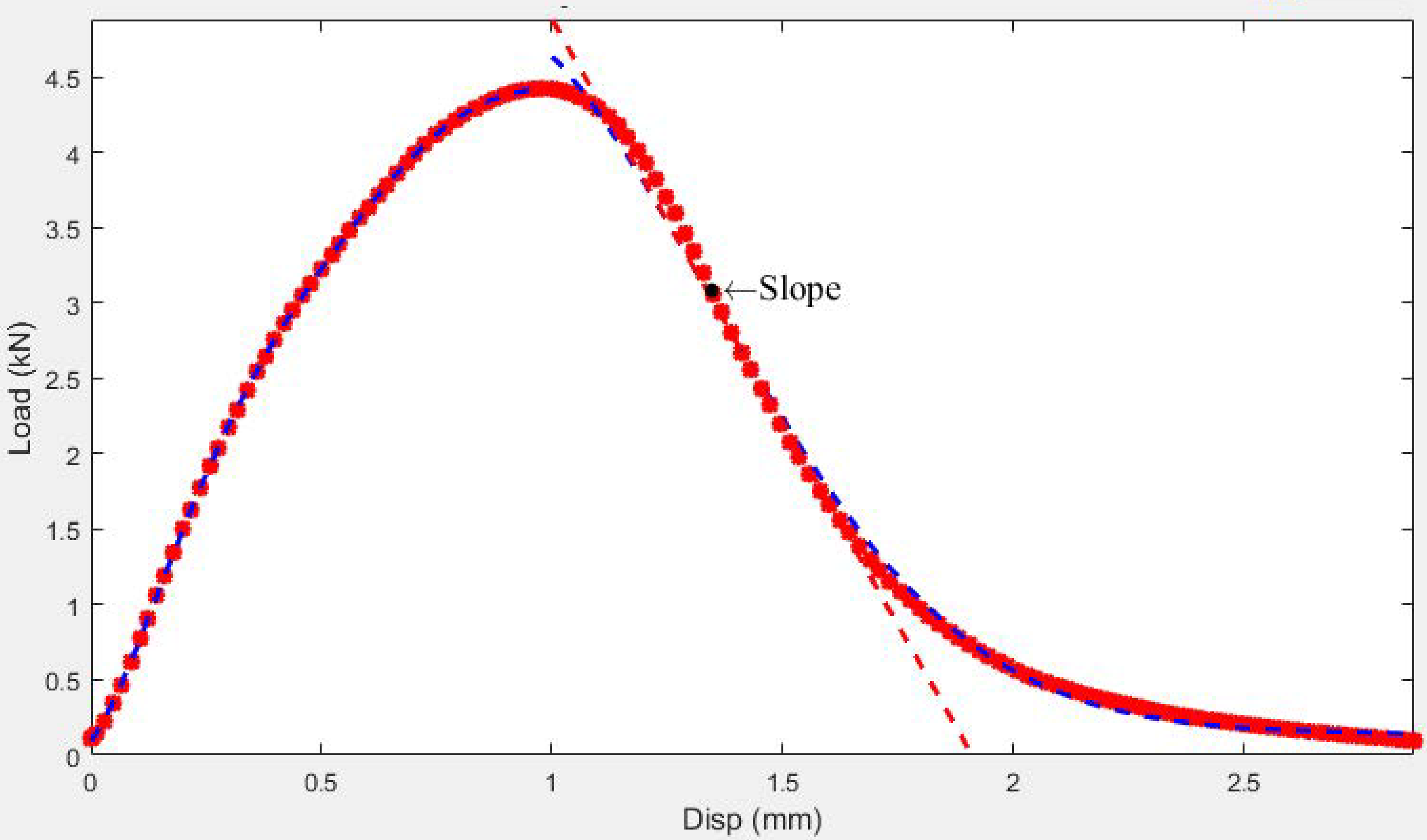


Summary Output

Fracture Energy (J/m2)	1389.15
Strength (Psi)	66.58
Slope	-4.48
Flexibility Index	3.1

Upload Data

Project ID: 18-1278 Specimen ID: Mix 1 - 4
Thickness: 50 mm Ligament: 57 mm

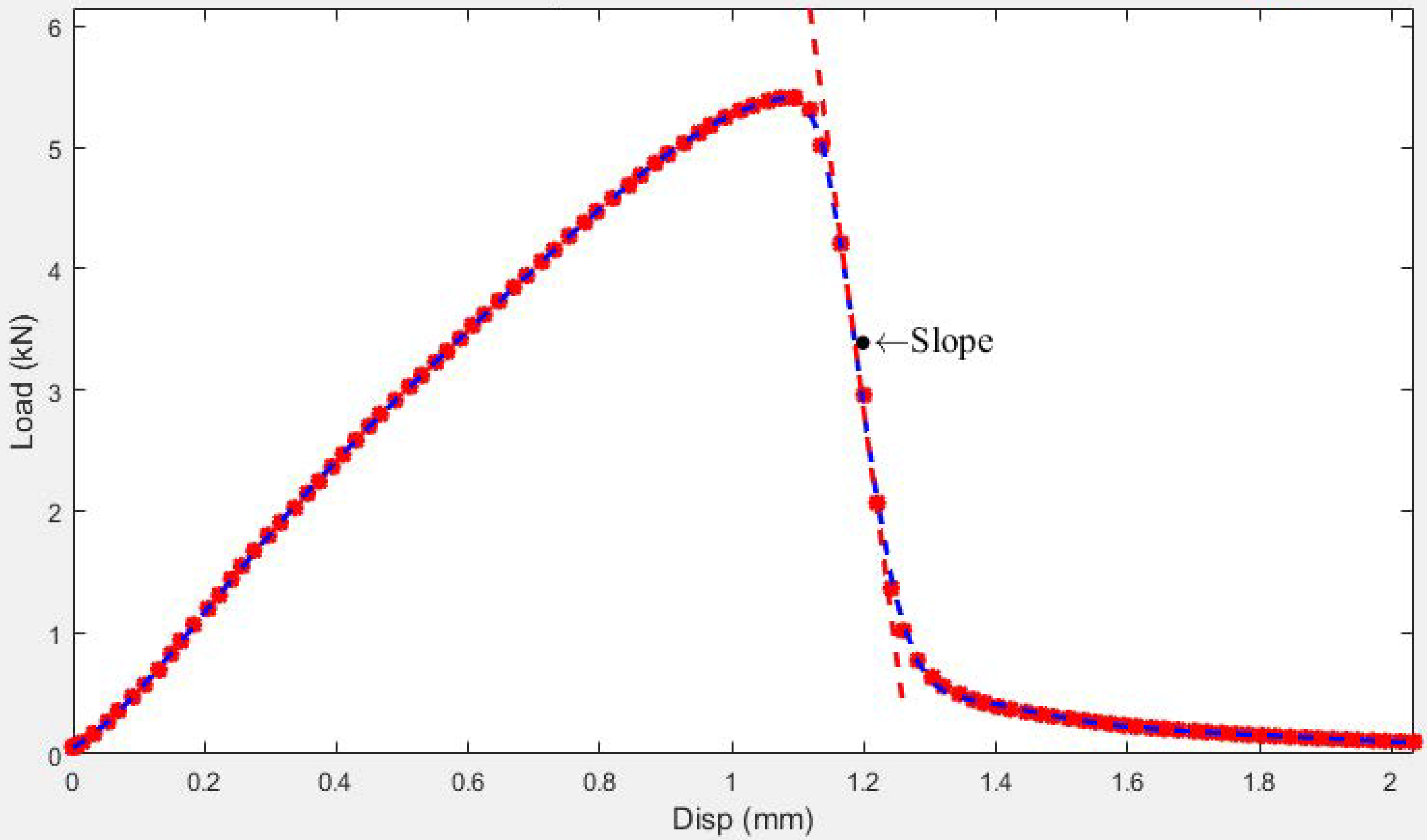


Summary Output

Fracture Energy (J/m2)	1964.32
Strength (Psi)	89.16
Slope	-5.36
Flexibility Index	3.66

Upload Data

Project ID: 18-1278 Specimen ID: Mix 2 - 1
Thickness: 50 mm Ligament: 57 mm



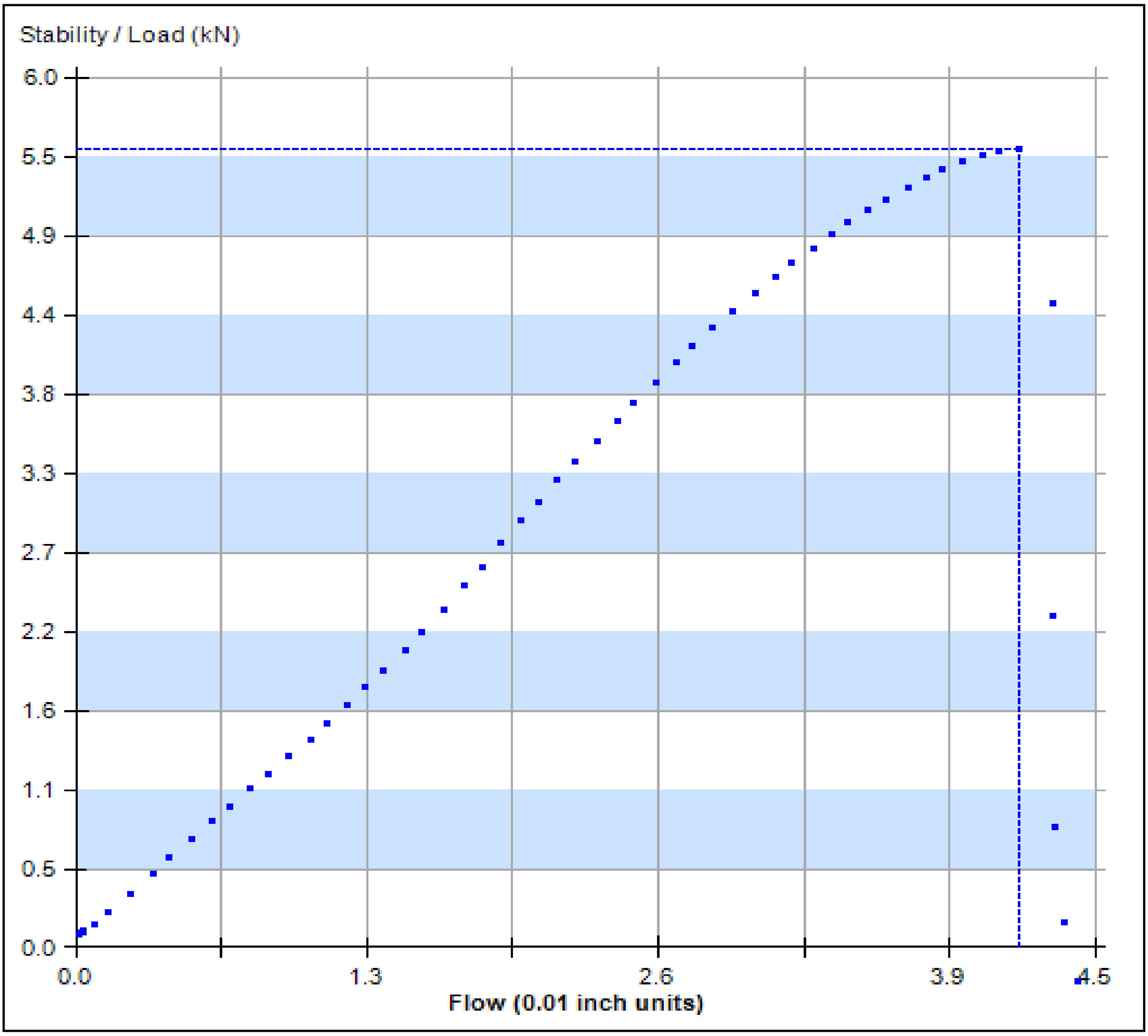
Summary Output

Fracture Energy (J/m2)	1463.29
Strength (Psi)	109

Warning: Mix is BRITTLE! The Flexibility Index (FI) is less than 1.0. The FI is truncated to 1.0

InstroTek Inc.

Load Report



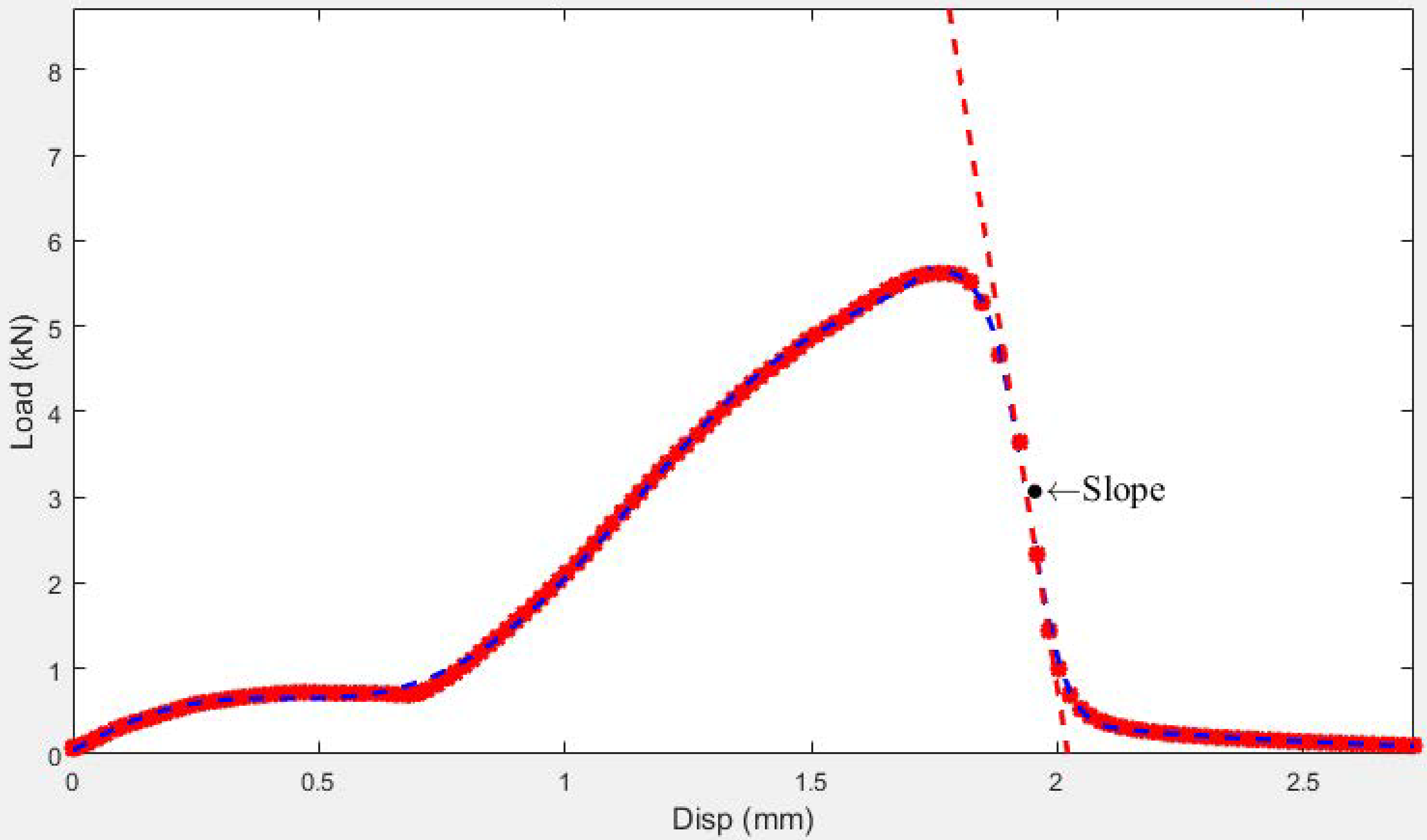
Project ID:	Specimen ID: 2-2
Date / Time: 04/04/19 10:08	Stability (Peak Load): **5.51 kN**
Specimen Diameter: **150.00 mm**	IDT Strength: **377.5 kPa (54.7 PSI)**
Specimen Thickness: **62.00 mm**	Peak Displacement: **1.06 mm**
Starting Load: 0.09 kN	Flow (0.01 inch units): **4.2**
Stopping Load: -0.2 kN	Total Energy: **3.41 Joules**
Max Specific Gravity:	Energy to Peak: **3.21 Joules**
% Voids:	Temperature: 22 °C
% AC: %	IDEAL-CT Index: **0.001**

Technician:

Signature: ______________________________

Upload Data

Project ID: 18-1278 Specimen ID: Mix 2 - 3
Thickness: 50 mm Ligament: 58 mm



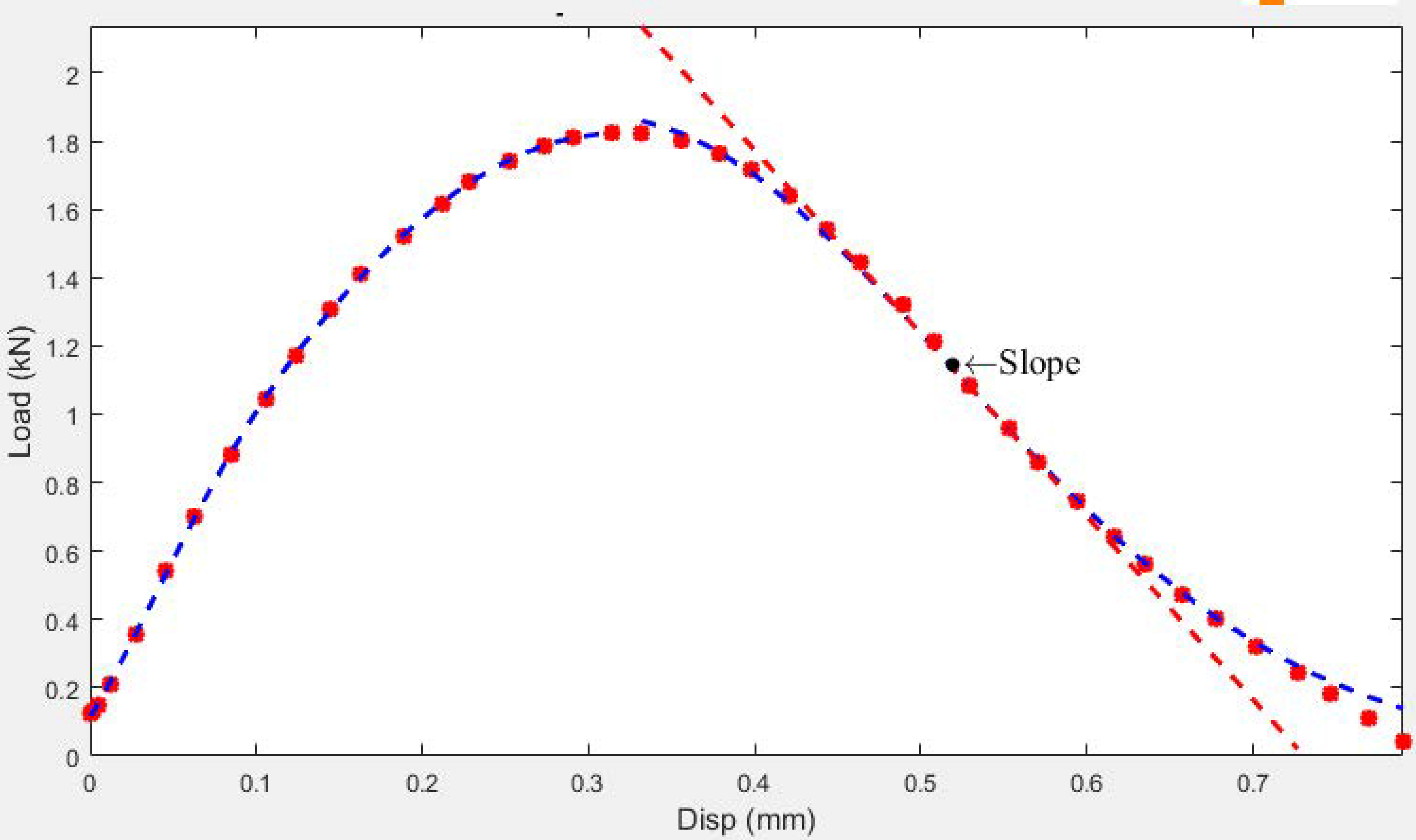
Summary Output

Fracture Energy (J/m2)	1786.79
Strength (Psi)	111.67

Warning: Mix is BRITTLE! The Flexibility Index (FI) is less than 1.0. The FI is truncated to 1.0

Upload Data

Project ID: 18-1278 Specimen ID: Mix 2 - 4
Thickness: 50 mm Ligament: 61 mm



Summary Output

Fracture Energy (J/m2)	285.98
Strength (Psi)	34.82

Warning: Mix is BRITTLE! The Flexibility Index (FI) is less than 1.0. The FI is truncated to 1.0

InstroTek Inc.

Load Report

Project ID:	Specimen ID: 3-1
Date / Time: 04/04/19 10:30	Stability (Peak Load): **3.21 kN**
Specimen Diameter: **150.00 mm**	IDT Strength: **219.6 kPa (31.8 PSI)**
Specimen Thickness: **62.00 mm**	Peak Displacement: **0.31 mm**
Starting Load: 0.14 kN	Flow (0.01 inch units): **1.2**
Stopping Load: -1.2 kN	Total Energy: **0.73 Joules**
Max Specific Gravity:	Energy to Peak: **0.55 Joules**
% Voids:	Temperature: 22 °C
% AC: %	IDEAL-CT Index: **0.001**

Project ID:	Specimen ID: 3-2
Date / Time: 04/04/19 10:31	Stability (Peak Load): **6 kN**
Specimen Diameter: **150.00 mm**	IDT Strength: **411.8 kPa (59.7 PSI)**
Specimen Thickness: **62.00 mm**	Peak Displacement: **0.93 mm**
Starting Load: 0.1 kN	Flow (0.01 inch units): **3.6**
Stopping Load: 0.1 kN	Total Energy: **3.12 Joules**
Max Specific Gravity:	Energy to Peak: **2.58 Joules**
% Voids:	Temperature: 22 °C
% AC: %	IDEAL-CT Index: **0.019**

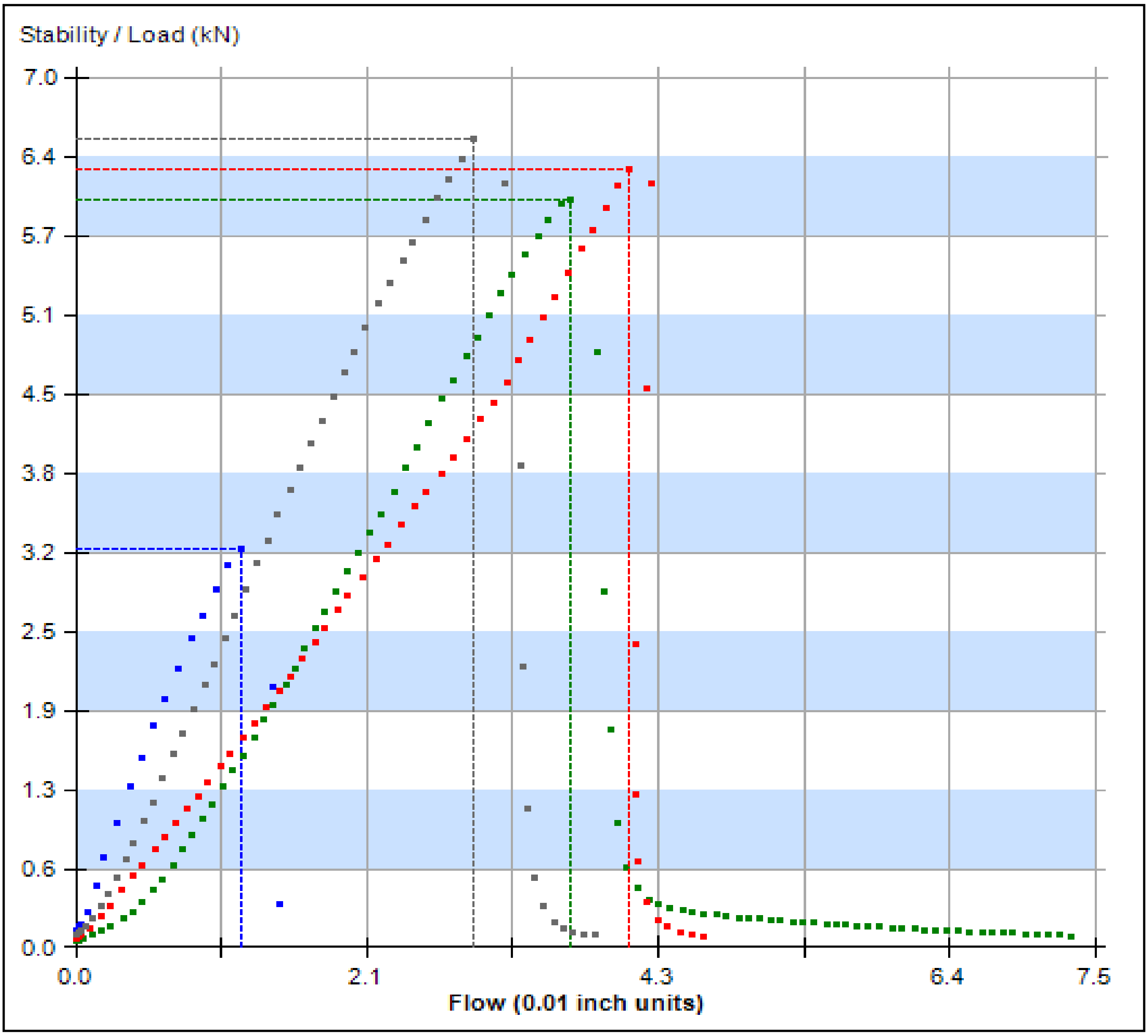
Project ID:	Specimen ID: 3-3
Date / Time: 04/04/19 10:28	Stability (Peak Load): **6.3 kN**
Specimen Diameter: **150.00 mm**	IDT Strength: **429.3 kPa (62.3 PSI)**
Specimen Thickness: **62.00 mm**	Peak Displacement: **1.03 mm**
Starting Load: 0.1 kN	Flow (0.01 inch units): **4**
Stopping Load: 0.1 kN	Total Energy: **3.47 Joules**
Max Specific Gravity:	Energy to Peak: **3.03 Joules**
% Voids:	Temperature: 22 °C
% AC: %	IDEAL-CT Index: **0.028**

Project ID:	Specimen ID: 3-4
Date / Time: 04/04/19 10:29	Stability (Peak Load): **6.5 kN**
Specimen Diameter: **150.00 mm**	IDT Strength: **445.5 kPa (64.6 PSI)**
Specimen Thickness: **62.00 mm**	Peak Displacement: **0.74 mm**
Starting Load: 0.1 kN	Flow (0.01 inch units): **2.9**
Stopping Load: 0.1 kN	Total Energy: **3.06 Joules**
Max Specific Gravity:	Energy to Peak: **2.49 Joules**
% Voids:	Temperature: 22 °C
% AC: %	IDEAL-CT Index: **NA**

Technician: Signature: ____________________________

InstroTek Inc.

Load Report



In order of peak load (High to Low):

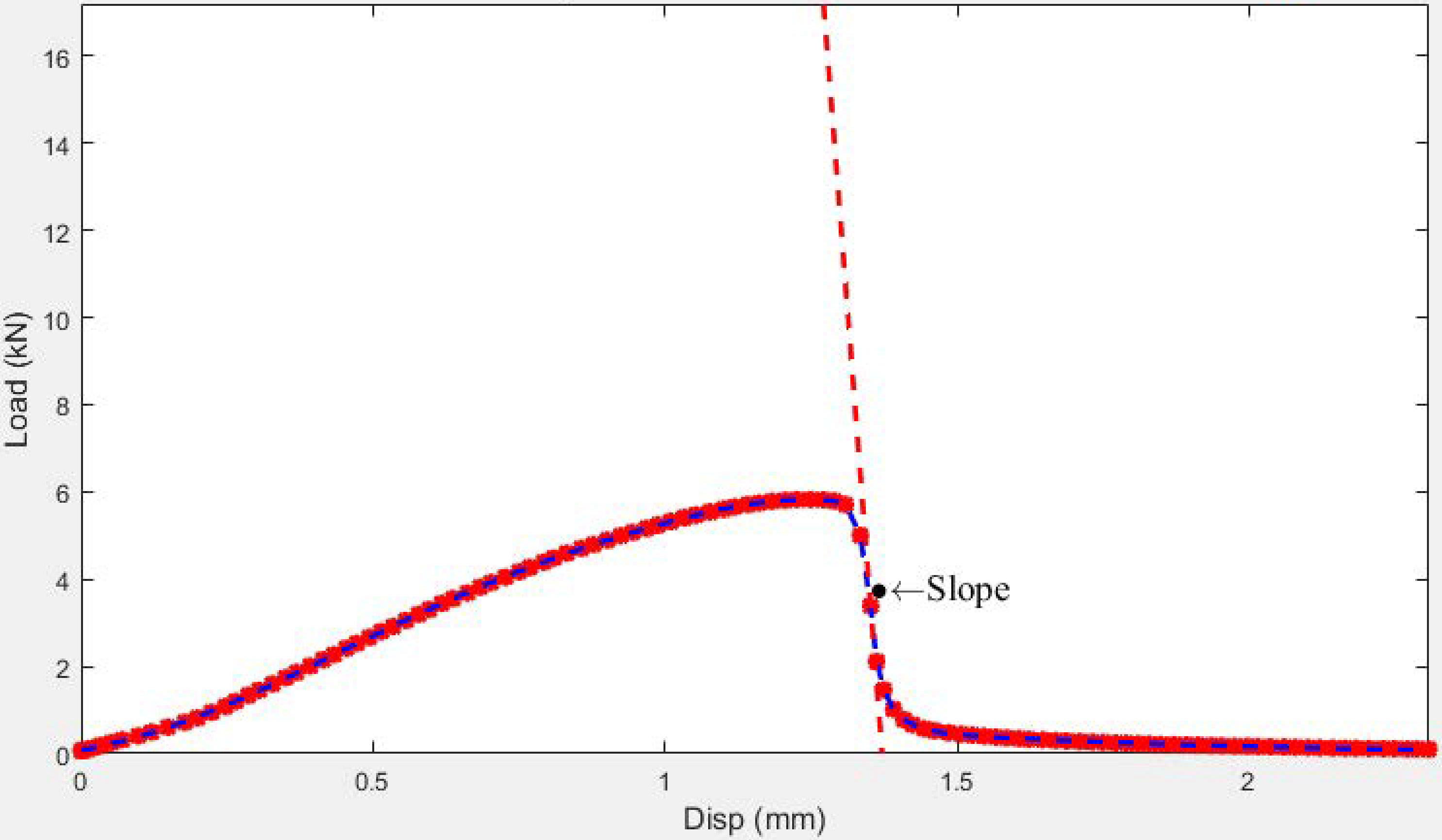
[redacted]

Technician:

Signature: ______________________________

Upload Data

Project ID: 18-1278 Specimen ID: Mix 4 - 1
Thickness: 52 mm Ligament: 59 mm



Summary Output

Fracture Energy (J/m2)	1624.59
Strength (Psi)	109.7

Warning: Mix is BRITTLE! The Flexibility Index (FI) is less than 1.0. The FI is truncated to 1.0

InstroTek® Inc.

Load Report

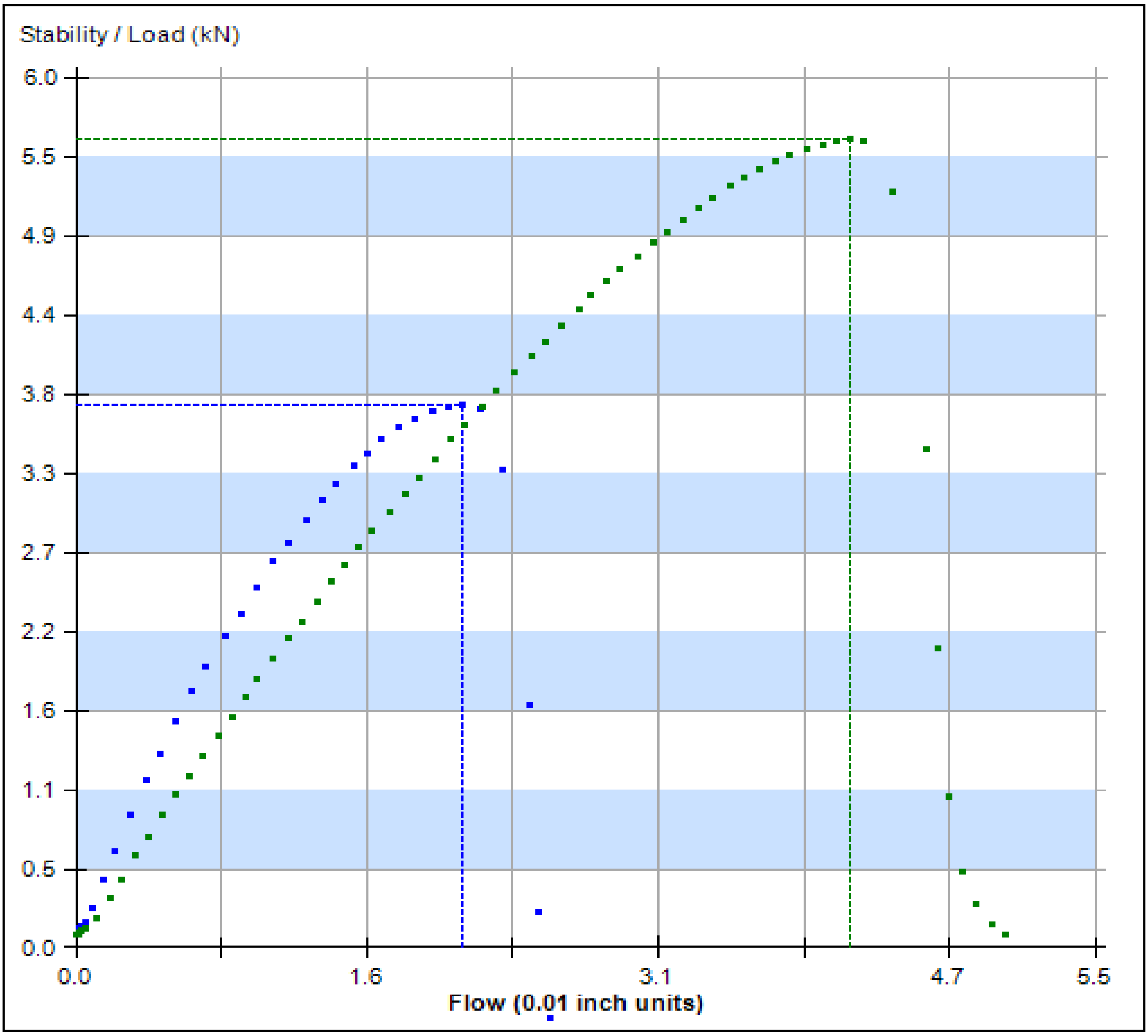
Project ID:		Specimen ID: 4-2	
Date / Time:	04/04/19 10:26	Stability (Peak Load):	**3.74 kN**
Specimen Diameter:	**150.00 mm**	IDT Strength:	**256 kPa (37.1 PSI)**
Specimen Thickness:	**62.00 mm**	Peak Displacement:	**0.53 mm**
Starting Load:	0.13 kN	Flow (0.01 inch units):	**2.1**
Stopping Load:	-0.5 kN	Total Energy:	**1.57 Joules**
Max Specific Gravity:		Energy to Peak:	**1.26 Joules**
% Voids:		Temperature:	22 °C
% AC:	%	IDEAL-CT Index:	**NA**

Project ID:		Specimen ID: 4-3	
Date / Time:	04/04/19 10:23	Stability (Peak Load):	**5.6 kN**
Specimen Diameter:	**150.00 mm**	IDT Strength:	**381.5 kPa (55.3 PSI)**
Specimen Thickness:	**62.00 mm**	Peak Displacement:	**1.06 mm**
Starting Load:	0.1 kN	Flow (0.01 inch units):	**4.2**
Stopping Load:	0.1 kN	Total Energy:	**4.16 Joules**
Max Specific Gravity:		Energy to Peak:	**3.55 Joules**
% Voids:		Temperature:	22 °C
% AC:	%	IDEAL-CT Index:	**NA**

Technician:

Signature: ______________________________

Load Report



In order of peak load (High to Low):

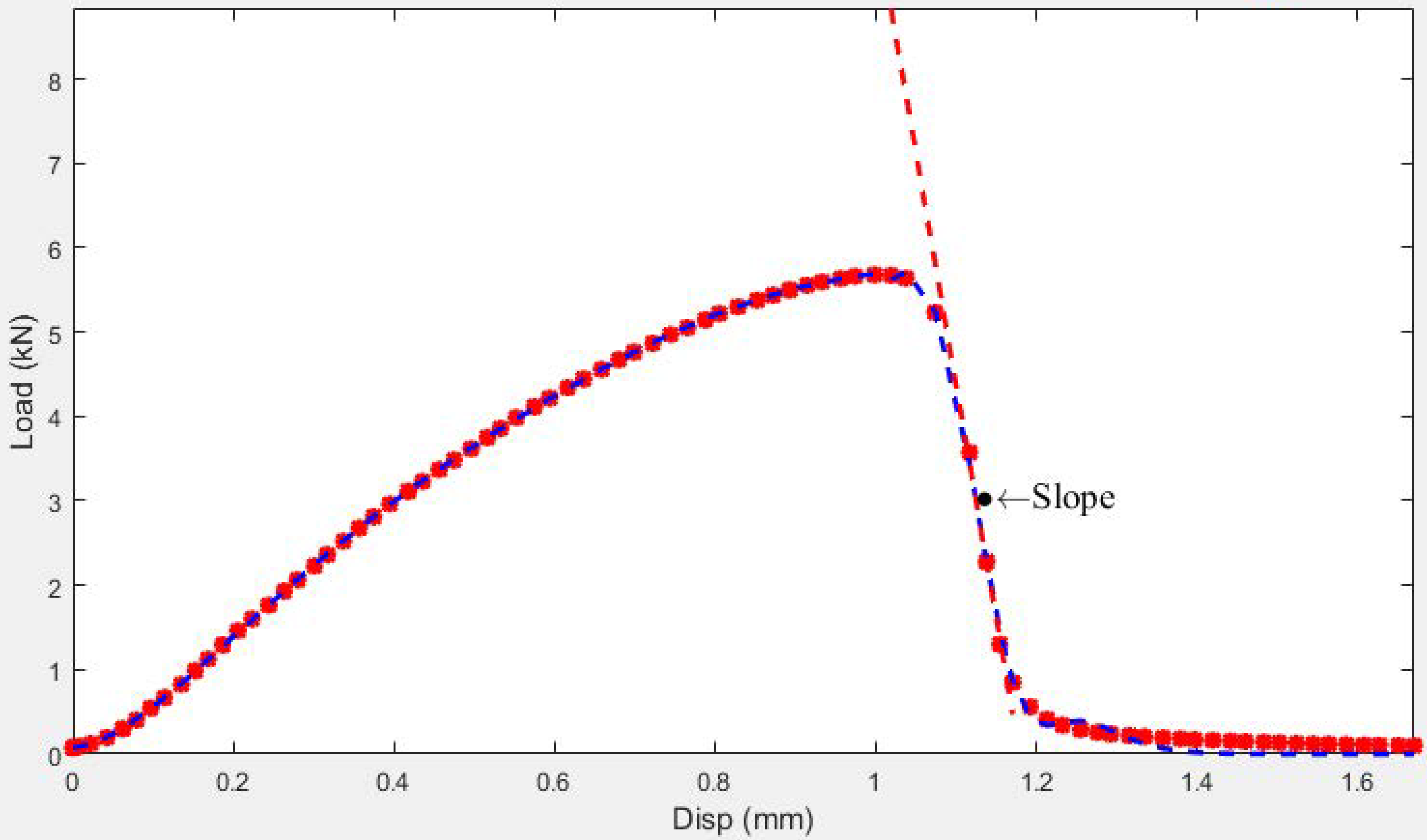
[redacted]

Technician:

Signature: ______________________________

Upload Data

Project ID: 18-1278 Specimen ID: Mix 4 - 4
Thickness: 48 mm Ligament: 60 mm



Summary Output

Fracture Energy (J/m2)	1429
Strength (Psi)	114.33

Warning: Mix is BRITTLE! The Flexibility Index (FI) is less than 1.0. The FI is truncated to 1.0