PERFORMANCE EVALUATION OF COLD IN-PLACE RECYCLING (CIR) MIXES FOR ONTARIO

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Abstract

Cold In-Place Recycling (CIR) is a conventional rehabilitation technique which uses 100% Recycled Asphalt Pavement (RAP). In common practices in Ontario for CIR, emulsified asphalt cement (AC) is added to the milled recycled pavement before placing it back onto the roadway. The pavement is also allowed to cure for 14 days before letting traffic back on.

It is important to determine the strength of such a pavement technique in order determine how long the pavement will perform before any deteriorations occur. Varying percentages of added asphalt emulsion also affect the strength and workability of the mixtures. Furthermore, the curing time is also important to the whole process. The 14-day curing time might not be ideal for this technology but further laboratory investigation is encouraged.

In this study, five different percentages of AC were used varying from 1.2% to 3.2% of the mass of the recycled aggregate. The workability and strength of each of these percentages were determined using dynamic modulus material testing. Along with varying percentages of AC, there was a duration test carried out using 1.2%AC in order to determine the optimal curing time for the mixture, before and after compaction, for laboratory test purposes.

Using AC extraction, it was observed that the Southern Ontario RAP contained 4.77% of existing AC. Adding an additional 3.2%AC to this RAP, gave a mixture that performed best in terms of strength gain and rutting resistance. The duration tests determined that a time of 0 to 2 days before compaction and 7 to 14 days after compaction allowed for the best strength gain for the mixes, at different frequencies.

Having a set %AC in accordance to the type and location of the obtained RAP causes a big change in the strength gain of the final mix. The curing time of the mix before and after compaction also controls the strength gain. Curing it properly allows it to resist fatigue cracking under higher frequency of loading and rutting at lower frequencies.

Key words: Cold In-Place Recycling, Rehabilitation, Emulsified Asphalt Cement, Recycled Aggregates

1.0 Introduction

Pavement rehabilitation is an important process to ensure that a given roadway reaches its design life. By carrying out rehabilitation practices, any distresses or deficiencies can be eliminated. As pavement ages, it loses its smoothness, structural stability and its overall performance. The type of rehabilitation that is carried out improves the life cycle of the pavement. Sustainable pavement rehabilitation has become an essential criterion when weighing out rehabilitation techniques for a given roadway. This ensures that there are enough resources available for future projects. Moreover, it is also crucial to optimize sustainable techniques in pavement rehabilitation to mitigate the constraints of time and budget [1]. One such rehabilitation treatment is known as Cold In-place Recycling (CIR).

1.1 Background

CIR is a continuous multi-step process in which the existing asphalt pavement is cold-milled and blended with asphalt emulsion. The cold recycled asphalt mix is then placed onto the milled roadway using conventional paving equipment and compacted with vibratory and pneumatic tire rollers [2]. The pavement is then allowed to cure and later, overlaid with a surface layer. This surface layer is usually a 25 mm thick layer of Hot Laid Asphalt (HLA) [3]. CIR is designed to extend the service life of a pavement by mitigating reflective cracking and other surface deteriorations with the exception of structural failure [4]. Figure 1-1 shows a general photo taken during on-site CIR process.

Figure 1-1: Cold In-Place Recycling on Field [5]

Recycling pavements using CIR has the potential to decrease energy consumption, reduce adverse environmental impacts and costs associated with asphalt pavement rehabilitation. However, there is uncertainty about the service life and factors that affect long term CIR pavement performance. These uncertainties limit the use of CIR to low volume pavements to minimize their exposure to aggressive traffic conditions [2]. CIR can conserve around 62% of aggregate, and reduce 52% of carbon dioxide and 54% of nitric oxide and nitrogen dioxide emissions compared with a traditional rehabilitation technique (100 mm milling and 130 mm of hot mix asphalt placement) [5].

In the CIR mix design, the ratio of emulsion and water content is critical to achieve the expected mix density, air void, and stability [4]. In most instances, the mix needs 1.5 to 2.2 percent emulsion content, and 3.5 to 4.5 percent water content [4]. In this study, the mix designs vary from 1.2 percent emulsion to 3.2 percent emulsion.

CIR materials can mitigate reflective cracking to extend pavement life [4]. However, it requires a long curing period. In current practice, a 14-day curing period is used in the field before letting any traffic back on [3]. For laboratory testing, CIR samples are not required to be cured before testing them. For this study a duration test was carried to determine the curing time required before and after compaction, for laboratory testing purposes. In the field, CIR usually needs a separate sealing-wearing surface such as a hot-mix overlay or surface treatment because of its moisture-susceptible nature and abrasion [4].

2.0 Material Details

For the purpose of this study, RAP was obtained from a stockpile from Miller paving, that consist of crushed RAP from all over Southern Ontario (Highway 400, 401 projects and other job sites that bring crushed RAP material for use in HMA paving jobs). The aggregates in this material mainly consist of crushed rock, trap rock, limestone and gravel. Table 2-1 shows the gradation of the RAP material that was obtained from the stockpile. The gradation is graphed in Figure 2-1. In comparison to a general Hot Mix Asphalt (HMA) aggregate gradation it has a lot more large-size particles. The material was passed through a 26.5 mm sieve before mixing to ensure aggregate size did not exceed 26.5 mm.

Table 2-1: RAP Gradation, AC Extraction and Penetration test results

	Southern Ont. RAP
Sieve Size	**% Passing**
26.5 mm	100.0
19.0 mm	100.0
16.0 mm	98.9
13.2 mm	98.4
9.5 mm	88.0
4.75 mm	69.1
2.36 mm	56.3
1.18 mm	46.1
0.60 mm	35.0
0.30 mm	24.4
0.15 mm	14.4
75 µm	9.2

% AC Extraction	4.77
Penetration Value	30

Extraction and penetration tests were carried out to determine the percent of asphalt in the RAP and the stiffness of the binder. The RAP contained 4.77% of binder and the binder had a penetration value of 30. Higher values of penetration indicate softer consistency in accordance with ASTM D5/ D5M-13. Thus, a value of 30 indicates a stiff consistency.

Figure 2-1: Southern Ontario RAP Gradation

3.0 Methodology

In order to determine the strength of the different mixes with different %AC, the dynamic modulus test was used.

3.1 Dynamic Modulus Testing

Dynamic modulus (E*) number is used to relate stress to strain for linear visco-elastic materials, such as asphalt mixtures. This relationship can be mathematically described by(Equation 3-1 [6]. Figure 3-1 illustrates graphically for a one-dimensional case of a sinusoidal loading [6]. The dynamic modulus (E*) is a very good indicator of the rutting resistance and crack development of a mixture.

The testing procedure outlined in AASHTO TP 62-07 “Standard Method of Test for Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures” was used to determine E* modulus [7]. The modulus values are obtained at the specific temperatures and frequencies. Using these values a master curve is calculated using the AASHTO PP62-09 procedure, “Standard Practice for Developing Modulus Master Curve for Hot-Mix Asphalt” [8].

$$E^* = \frac{\sigma}{\varepsilon} = \frac{\sigma_o e^{i\omega t}}{\varepsilon_o e^{i(\omega t - \phi)}} = \frac{\sigma_o \sin(\omega t)}{\varepsilon_o \sin(\omega t - \phi)}$$ (Equation 3-1)

where,

E^* = complex modulus
σ_o = peak (maximum) stress amplitude, kPa
ε_o = peak (maximum) amplitude of recoverable strain
ϕ = phase angle, degrees
ω = angular load frequency
t = time of loading, seconds

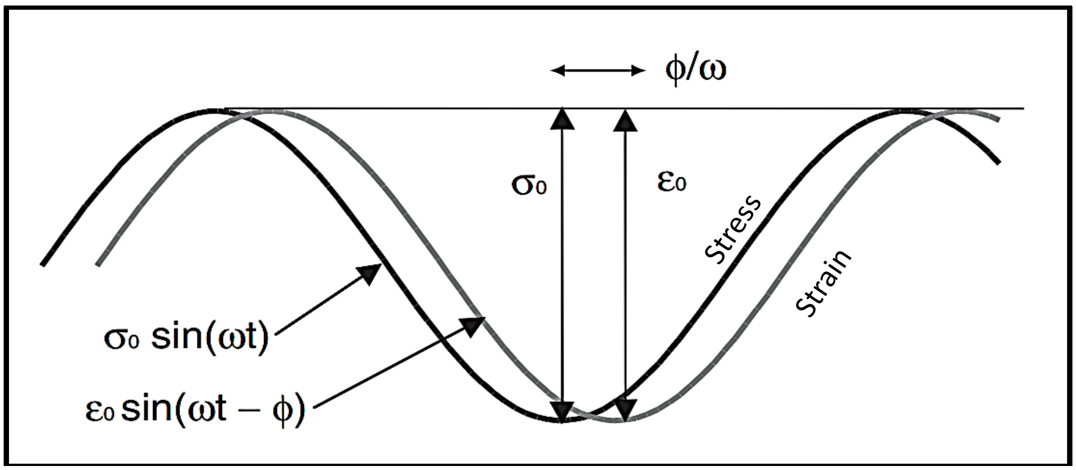

Figure 3-1: Sinusoidal loading during dynamic modulus testing [6]

The calculated master curve is, within the pavement industry, an accepted method of evaluating the effect of different temperatures and traffic frequencies on mixture stiffness [9]. This master curve is obtained by applying a shift factor to all experimental E* values to normalize them to a reference temperature of 34°C. Shifting of the values is constructed using the principal of time-temperature with respect to time until the curves merge into a simple smooth function [6].

Asphalt mixtures are sensitive to temperature and loading. Thus, it is possible to capture the impact of such factors with the E* value throughout different seasons. The E* helps model the deterioration of the pavement structure.

3.2 Test Setup

In this setup three replicate specimens of each of the different mixtures were tested to get average, validated data. Figure 3-2 shows the dimensions of these specimens. Each %AC mixture had three replicate specimens of cylindrical shape (100 mm diameter by 150 mm height). These specimens were cored out of a Superpave gyratory compacted specimen as shown in Figure 3-2.

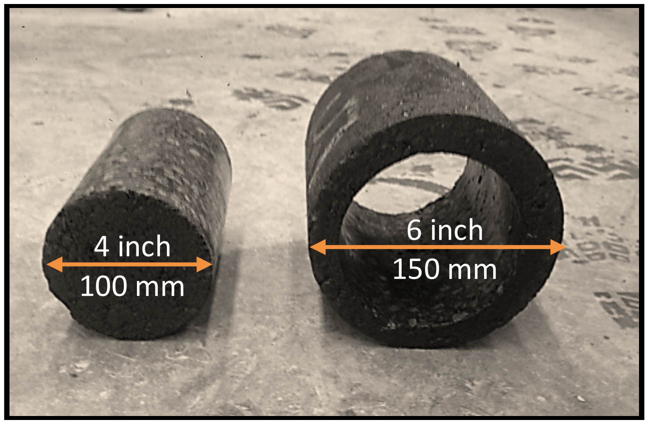

Figure 3-2: A dynamic modulus test specimen cored from a Superpave specimen

The specimens were tested in a temperature-controlled chamber at six different loading frequencies (0.1, 0.5,1,5,10, and 25 Hz) for five different temperatures (-10, 4, 21, 37 and 54°C). For each frequency, specified load cycles (200 cycles for 25 Hz, 200 cycles for 10Hz, 100 cycles for 5 Hz, 20 cycles for 1 Hz, 15 cycles for 0.5 Hz, and 15 cycles for 0.1 Hz) were applied. Refer to Figure 3-3 to see a flow chart of the different cycles, frequencies, temperatures and corresponding loads.

The stress applied and the cross section of the samples tested is kept constant with a constant load for each corresponding temperature. An increase in the dynamic modulus value thus reflects a decrease in the strain corresponding to the same load, which can also be interpreted as an increase in the stiffness of that mix [10]. In contrast, a decrease in the dynamic modulus indicates an increase in strain and can be interpreted as a decrease in the stiffness of that mix [10].

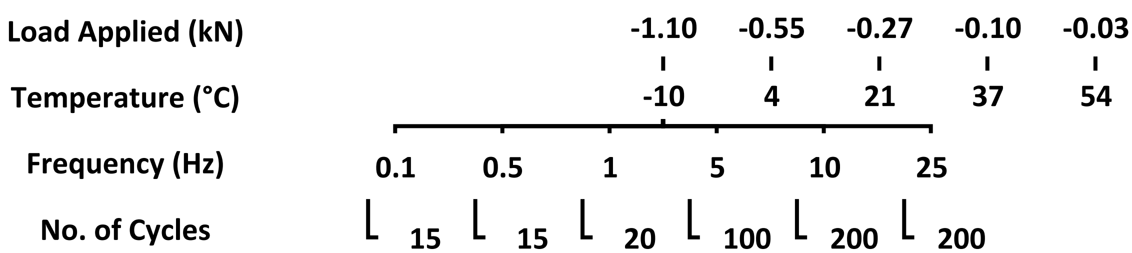

Figure 3-3: Flow chart of the dynamic modulus testing process

The testing procedure involved applying a sinusoidal axial compressive stress to the specimen. The stress was applied over the specified range of frequencies and temperatures and their corresponding number of cycles. The resulting recoverable axial strain response was measured using transducers connected to the specimen, and used to calculate the dynamic modulus and the phase angle for each mixture [11].

Figure 3-4 shows the general setup of the test with the attached extensometers which measured the deflection in the specimen while the load was applied.

Figure 3-4: Dynamic Modulus Test Setup

3.2.1 Workability and Strength Testing

In this study, five different percentages of AC were used in five different mixes. These percentages varied from 1.2% to 3.2% of the mass of the recycled aggregate at an increment of 0.5% AC. A constant increment was used for consistency in comparison of the results. Three specimen replicates were used for the dynamic modulus testing for proper validation of the results.

Table 3-1 shows the different mixes for strength testing and their corresponding air voids.

Table 3-1: Sample Mixes and corresponding % air voids

Strength Testing		
Sample ID	**%AC**	**Avg. %Air Voids**
CIR-S1	1.2%	6.29
CIR-S2	1.7%	6.89
CIR-S3	2.2%	5.62
CIR-S4	2.7%	5.44
CIR-S5	3.2%	5.42

3.2.2 Duration Testing

The duration test was designed to allow determination of the optimum curing time. The typical construction standard for CIR allows the pavement to cure for 14 days before placing a hot mix surface and allowing traffic back on [3]. The surface of the existing pavement is milled and re-paved at once. During the lab tests, the standard requires the samples to be cured for one hour at 60 degrees Celsius before compaction. However, this curing time may not be sufficient for optimal performance of the samples for strength tests. Due to inconsistencies noticed in the test results in the initial stage because of inconsistent specimen curing, the duration test was designed to determine the ideal curing time. For this test, specimens were mixed and compacted on different days in order to vary the curing time. Table 3-2 shows the mixes and their corresponding air voids for the duration testing. The mix was consistent with 1.2%AC for all the mixed samples. This %AC was chosen as lowest %AC of the strength test in order to save material. Moreover, the focus of this test was on the duration of curing and, therefore, the %AC needed to be constant. All specimens were mixed on day 0. The first set of samples (DT-S0) was compacted on the same day. The rest of the mix sample was stored in an airtight container to prevent the loss of moisture. The rest of the specimens were compacted on days 2, 7 and 14, respectively; thus allowing for different curing time for the mix, before compaction. The specimens compacted on day 0 were cured for at least 14 days, after compaction, whereas the specimens compacted on day 14 were cured for 7 days. In this manner, the curing time before and after compaction was varied for testing.

Table 3-2: 1.2% AC Sample mixes and corresponding % air voids

Duration Testing			
Sample ID	**Curing time (Before compaction)**	**Curing time (After Compaction**	**Avg. %Air Voids**
DT-S0	0	14	6.30
DT-S2	2	14	6.85
DT-S7	7	7	5.93
DT-S14	14	7	5.77

4.0 Analysis and Observations

The data were collected once the tests were completed. The data output for the dynamic modulus tests showed different dynamic modulus values at all different temperatures and frequencies. These values were used to calculate the equivalent dynamic modulus values for 34°C to obtain the master curve. Each master curve for all specimens was compiled and plotted.

4.1 Strength Test Results

Figure 4-1 shows the master curves obtained from the results of the dynamic modulus strength testing. The test results are provided in detail in Appendix A. Using the methodology, all the data was organized and plotted for 34°C. Figure 4-1 shows the final results and it can be noted that, for low frequencies, the samples with 3.2%AC (CIR-S5) performed the best. This could be because of the increased % AC in the mix. For low frequencies, the higher the modulus the better resistance it has against rutting. With greater % AC, it is better able to resist rutting due to the increased density. The samples with 2.7%AC (CIR-S4) performed reasonably well. However, the samples with 2.2%AC (CIR-S3) performed the worst for low frequencies. For higher frequency, the lower the dynamic modulus value, the better the performance against fatigue cracking. After conducting a statistical study, it was determined that the dynamic modulus values of the samples at high frequencies (ranging from 1E03 Hz to 1E07 Hz) were similar. The t-test results are provided in detail in Appendix C. The t-test also concluded that the dynamic modulus values at low frequencies (ranging from 1E-07 Hz to 1E-03 Hz) were different. The t-test was conducted for 95% confidence interval.

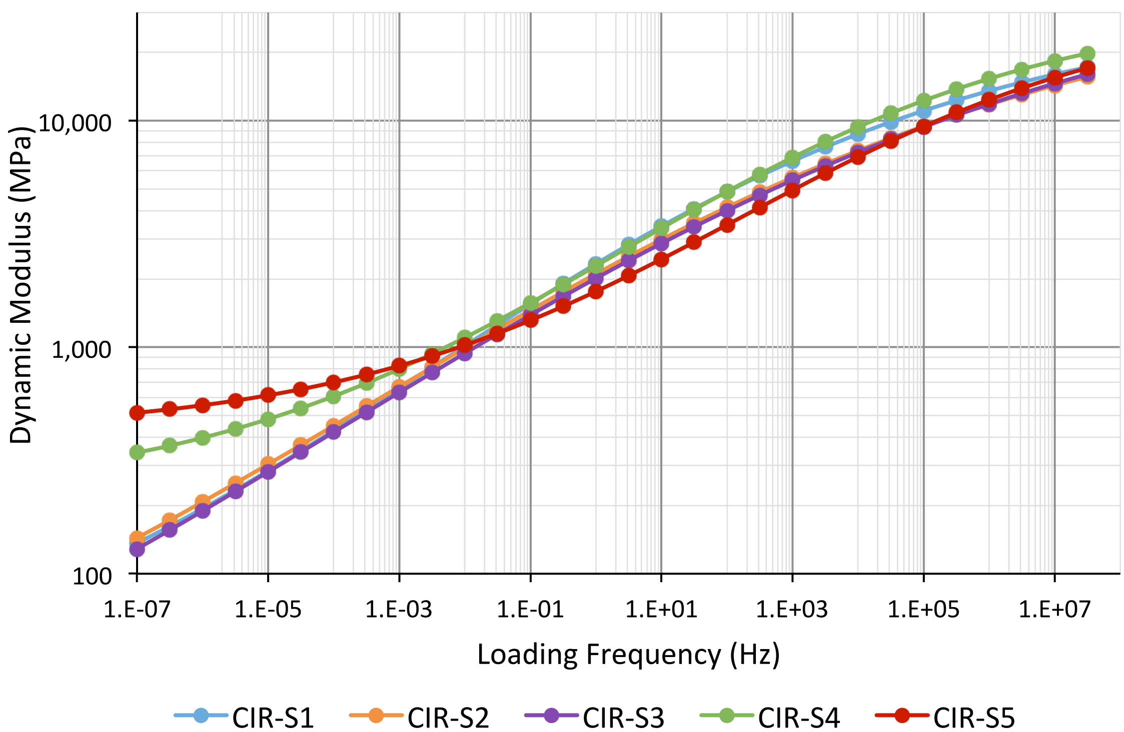

Figure 4-1: Dynamic modulus master curve - CIR samples

4.2 Duration Test Results

Similar to the strength test, the duration test results were also graphed as master curves for 34°C. The test results are provided in Appendix B. These curves indicate that the sample DT-S0 had the highest dynamic modulus for low frequency and had the highest dynamic modulus at higher frequency. As curing time before compaction increased, the modulus of the samples decreased for low frequency. Samples DT-S7 and DT-S14 performed the best (very similar results) at higher frequencies with lower modulus values, in comparison to samples DT-S0 and

DT-S2. The statistical test shown in Appendix C shows the statistical study that was carried out. The study concluded that sample DT-S0 was statistically different from samples DT-S7 and DT-S14 for very high and very low frequencies.

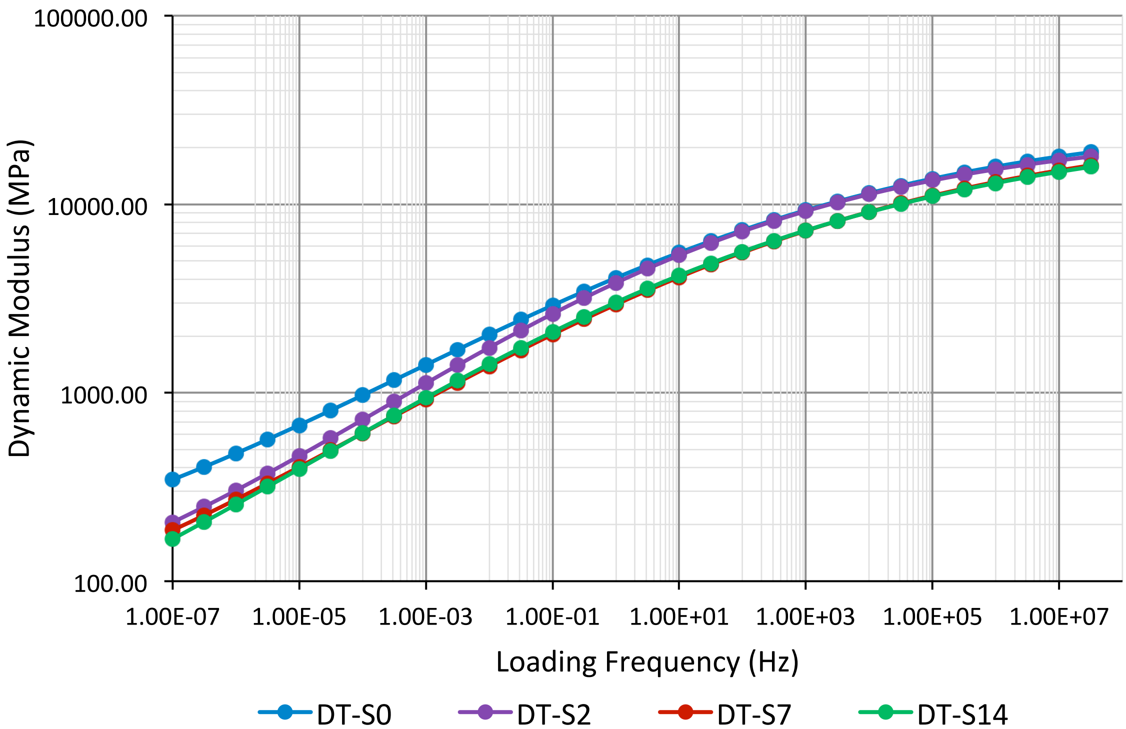

Figure 4-2: Dynamic modulus master curve - duration testing

5.0 Conclusions and Recommendations

CIR is a conventional rehabilitation technique that uses 100% recycled aggregate from an existing pavement and repaves the same pavement with the milled material. Learning the strength of such a pavement is very crucial to determine the pavement design life.

By carrying out dynamic modulus testing on sample mixes, it can be determined that the CIR mixes can be optimized to improve resistance to rutting and fatigue cracking. After testing five mixtures with different %AC proportions, it can be concluded that an additional 3.2%AC added to the existing RAP can improve workability and strength, improving its rutting and fatigue life. These results are specific to the RAP obtained from Southern Ontario but a similar approach can be applied for different types of RAP from other parts of Ontario with different aggregate gradation and asphalt extraction percentage.

It can be concluded from the duration testing that curing the mixes for 0 to 2 days before compaction is acceptable and curing it for at least 7 days after compaction for laboratory testing provides better results against rutting and fatigue failure. It is recommended to allow for these curing times for laboratory testing to better represent field performance.

6.0 Acknowledgements

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APPENDIX A: Strength Test Results (Dynamic Modulus data)

Equivalent 34°C dynamic modulus values calculated for each sample for the respective temperatures and frequencies:

Temperature	Frequency	Dynamic Modulus |E*| (MPa)				
		CIR-S1	CIR-S2	CIR-S3	CIR-S4	CIR-S5
-10	1.00E-07	136.43	143.82	128.62	341.90	513.30
-10	3.16E-07	161.96	172.42	155.79	367.26	531.86
-10	1.00E-06	193.95	207.62	189.33	398.02	554.10
-10	3.16E-06	234.18	250.97	230.70	435.50	580.83
-10	1.00E-05	284.84	304.33	281.70	481.37	613.04
-10	3.16E-05	348.71	369.92	344.48	537.77	651.99
4	1.00E-04	429.17	450.40	421.57	607.41	699.25
4	3.16E-04	530.38	548.89	515.95	693.73	756.81
4	1.00E-03	657.26	668.98	631.08	801.05	827.16
4	3.16E-03	815.61	814.77	770.92	934.80	913.46
4	1.00E-02	1012.03	990.87	939.94	1101.65	1019.68
4	3.16E-02	1253.83	1202.34	1143.07	1309.72	1150.77
21	1.00E-01	1548.85	1454.60	1385.71	1568.61	1312.88
21	3.16E-01	1905.17	1753.39	1673.63	1889.42	1513.58
21	1.00E+00	2330.67	2104.54	2012.82	2284.45	1761.93
21	3.16E+00	2832.56	2513.81	2409.41	2766.75	2068.67
21	1.00E+01	3416.87	2986.70	2869.46	3349.30	2446.00
21	3.16E+01	4087.86	3528.16	3398.76	4043.94	2907.35
37	1.00E+02	4847.58	4142.37	4002.61	4860.08	3466.67
37	3.16E+02	5695.50	4832.51	4685.62	5803.33	4137.44
37	1.00E+03	6628.34	5600.53	5451.44	6874.31	4931.34
37	3.16E+03	7640.03	6446.97	6302.63	8067.82	5856.70
37	1.00E+04	8721.95	7370.90	7240.45	9372.58	6916.90
37	3.16E+04	9863.27	8369.82	8264.76	10771.63	8109.13
54	1.00E+05	11051.53	9439.69	9373.94	12243.31	9423.65
54	3.16E+05	12273.15	10575.07	10564.91	13762.80	10843.84
54	1.00E+06	13514.12	11769.21	11833.15	15303.85	12347.09
54	3.16E+06	14760.60	13014.31	13172.80	16840.53	13906.40
54	1.00E+07	15999.38	14301.69	14576.86	18348.76	15492.44
54	3.16E+07	17218.38	15622.15	16037.29	19807.53	17075.76

Note: These values are obtained by averaging the actual dynamic modulus values from the three replicates of the samples.

APPENDIX B: Duration Test Results (Dynamic Modulus data)

Equivalent 34°C dynamic modulus values calculated for each sample for the respective temperatures and frequencies:

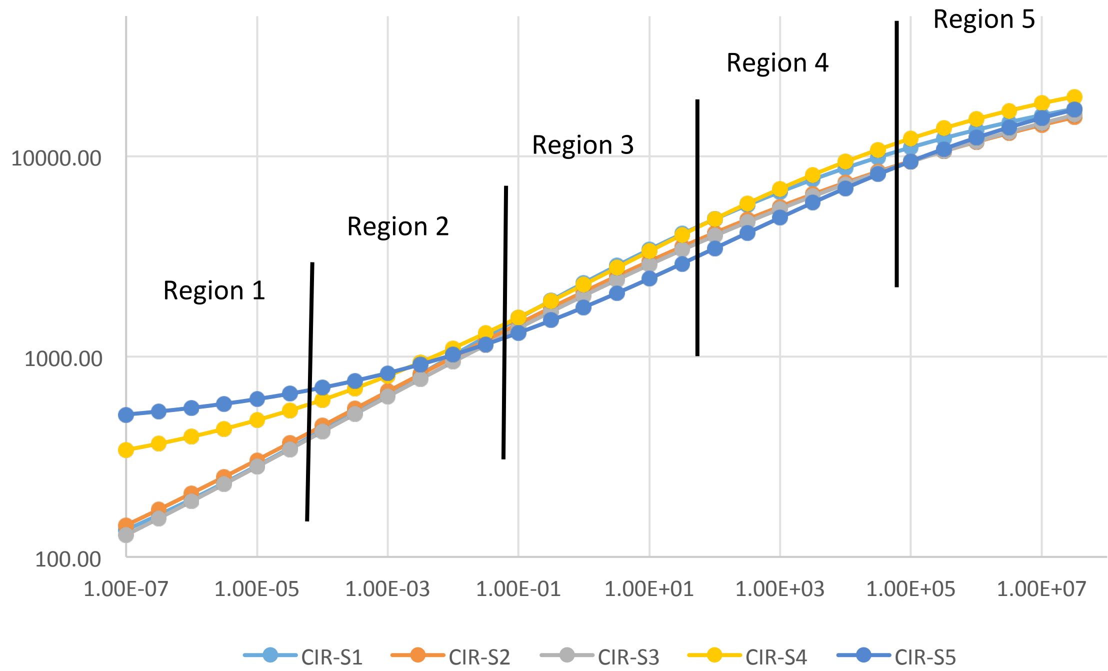
Temperature	Frequency	Dynamic Modulus |E*| (MPa)			
		DT-S0	DT-S2	DT-S7	DT-S14
-10	1.00E-07	345.42	205.24	185.96	167.38
-10	3.16E-07	404.22	248.32	223.91	206.32
-10	1.00E-06	476.38	303.18	271.27	255.37
-10	3.16E-06	564.98	373.10	330.38	317.06
-10	1.00E-05	673.68	462.15	404.07	394.38
-10	3.16E-05	806.83	575.27	495.73	490.89
4	1.00E-04	969.43	718.35	609.34	610.71
4	3.16E-04	1167.12	898.17	749.46	758.45
4	1.00E-03	1406.12	1122.33	921.24	939.20
4	3.16E-03	1693.05	1398.91	1130.28	1158.40
4	1.00E-02	2034.67	1736.17	1382.49	1421.62
4	3.16E-02	2437.59	2141.92	1683.89	1734.32
21	1.00E-01	2907.80	2622.91	2040.30	2101.63
21	3.16E-01	3450.29	3184.11	2456.97	2527.94
21	1.00E+00	4068.53	3828.12	2938.26	3016.65
21	3.16E+00	4764.10	4554.58	3487.27	3569.88
21	1.00E+01	5536.38	5359.96	4105.48	4188.17
21	3.16E+01	6382.31	6237.51	4792.55	4870.41
37	1.00E+02	7296.44	7177.55	5546.19	5613.72
37	3.16E+02	8271.05	8168.00	6362.12	6413.57
37	1.00E+03	9296.51	9195.06	7234.20	7263.84
37	3.16E+03	10361.66	10244.10	8154.71	8157.16
37	1.00E+04	11454.41	11300.36	9114.62	9085.15
37	3.16E+04	12562.24	12349.78	10104.03	10038.79
54	1.00E+05	13672.80	13379.51	11112.58	11008.76
54	3.16E+05	14774.32	14378.41	12129.87	11985.79
54	1.00E+06	15856.07	15337.26	13145.82	12960.96
54	3.16E+06	16908.58	16248.87	14151.00	13925.95
54	1.00E+07	17923.88	17108.02	15136.92	14873.23
54	3.16E+07	18895.54	17911.36	16096.12	15796.21

Note: These values are obtained by averaging the actual dynamic modulus values from the three replicates of the samples.

APPENDIX C: Statistical study

Strength test statistical study:

The Figure below is the same plot that is shown in Figure 4-1 from the report:



ANOVA summary:

Section ID	F-calc	F-crit	Reject H_o?	
Region 1	26.31	2.76	Yes	--> At least one value is different in this region
Region 2	0.50	2.76	No	f-calc < f-crit
Region 3	0.71	2.76	No	f-calc < f-crit
Region 4	1.39	2.76	No	f-calc < f-crit
Region 5	1.98	2.76	No	f-calc < f-crit

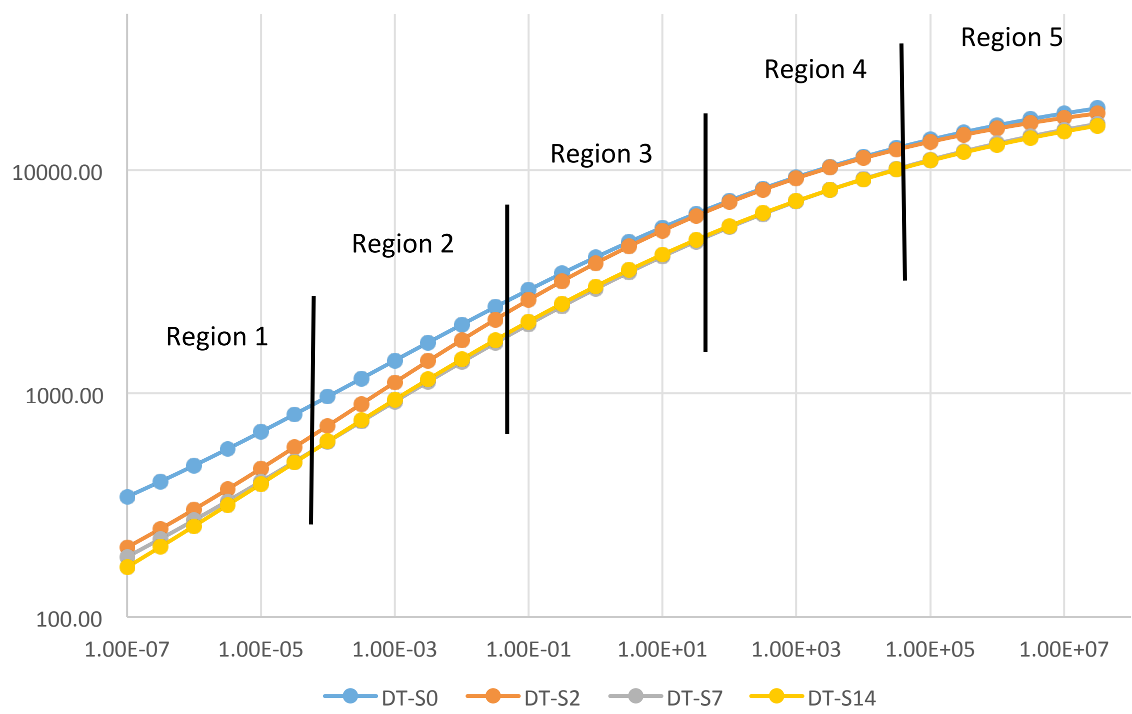
t-test (two-tailed) summary:

Section ID	Comparison samples		t - stat	t-crit	Reject H_o?	
Region 1	CIR-S1	CIR-S2	-0.31	2.23	No	|t-stat| < t-crit
	CIR-S1	CIR-S3	0.11	2.23	No	|t-stat| < t-crit
	CIR-S1	CIR-S4	-4.53	2.23	Yes	|t-stat| > t-crit
	CIR-S1	CIR-S5	-8.95	2.23	Yes	|t-stat| > t-crit
	CIR-S2	CIR-S3	0.41	2.23	No	|t-stat| < t-crit
	CIR-S2	CIR-S4	-4.05	2.23	Yes	|t-stat| > t-crit
	CIR-S2	CIR-S5	-8.19	2.23	Yes	|t-stat| > t-crit
	CIR-S3	CIR-S4	-4.60	2.23	Yes	|t-stat| > t-crit
	CIR-S3	CIR-S5	-8.97	2.23	Yes	|t-stat| > t-crit
	CIR-S4	CIR-S5	-4.01	2.23	Yes	|t-stat| > t-crit

The t-test concludes that samples CIR-S4 and CIR-S5 are statistically different from one another and from the rest of the samples, in Region 1 of the frequencies. Samples CIR-S1. CIR-S2 and CIR-S3 could be considered as statistically similar.

Duration test statistical study:

The Figure below is the same plot that is shown in Figure 4-2 from the report:



ANOVA summary:

Section ID	F-calc	F-crit	Reject H_o?	
Region 1	3.82	3.10	Yes	--> At least one value is different in this region
Region 2	1.62	3.10	No	f-calc < f-crit
Region 3	1.64	3.10	No	f-calc < f-crit
Region 4	2.52	3.10	No	f-calc < f-crit
Region 5	3.87	3.10	Yes	--> At least one value is different in this region

t-test (two-tailed) summary:

Section ID	Comparison samples		t - stat	t-crit	Reject H_o?	
Region 1	DT-S0	DT-S2	2.03	2.23	No	$\|t\text{-stat}\| < t\text{-crit}$
	DT-S0	DT-S7	2.66	2.23	Yes	$\|t\text{-stat}\| > t\text{-crit}$
	DT-S0	DT-S14	2.78	2.23	Yes	$\|t\text{-stat}\| > t\text{-crit}$
	DT-S2	DT-S7	0.58	2.23	No	$\|t\text{-stat}\| < t\text{-crit}$
	DT-S2	DT-S14	0.74	2.23	No	$\|t\text{-stat}\| < t\text{-crit}$
	DT-S7	DT-S14	0.19	2.23	No	$\|t\text{-stat}\| < t\text{-crit}$
Region 5	DT-S0	DT-S2	2.03	2.23	No	$\|t\text{-stat}\| < t\text{-crit}$
	DT-S0	DT-S7	2.66	2.23	Yes	$\|t\text{-stat}\| > t\text{-crit}$
	DT-S0	DT-S14	2.78	2.23	Yes	$\|t\text{-stat}\| > t\text{-crit}$
	DT-S2	DT-S7	0.58	2.23	No	$\|t\text{-stat}\| < t\text{-crit}$
	DT-S2	DT-S14	0.74	2.23	No	$\|t\text{-stat}\| < t\text{-crit}$
	DT-S7	DT-S14	0.19	2.23	No	$\|t\text{-stat}\| < t\text{-crit}$

From the t-test it can be concluded that samples DT-S7 and DT-S14 are similar to all samples except DT-S0 in both the frequency regions.

Note: t-tests were conducted with 95% confidence interval and assuming equal variances in the data sets.