12-2021

Relating the Dongre Workability Test to Cold In-Place Recycled Asphalt Pavements

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An Undergraduate Honors College Thesis

in the

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College of Engineering
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December 1, 2021

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An Honors Thesis submitted in partial fulfillment
of the requirements for Honors Studies in
Civil Engineering

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2021

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Abstract

The Dongre Workability Test (DWT) is a test for determining an asphalt pavement's relative workability from the stress-strain curve of a sample. While the DWT has seen favorable results with warm mix and hot mix asphalt, Casillas and Braham (2020) attempted to apply this test to cold in-place recycled (CIR) asphalt pavements with limited results. This paper looked at the process of reexamining the DWT method to more favorable results with CIR samples. Phase 1 consisted of defining ten possible metrics from the stress-strain curve and applying them to samples with three different curing conditions. From these preliminary results, the five metrics that showed the greatest differences between curing conditions with small relative coefficients of variation were chosen to continue with the research. In Phase 2, these five metrics were applied to three different emulsion types at four different curing conditions (10C-30, 10C-120, 60C-30, and 60C-120). The results were plotted and analyzed to recommend the best combination for further testing. From this phase, Metrics 4 and 10, both based on different areas under the stress-strain curve, were seen to have performed the best, with higher values seeming to indicate a more workable sample. The 10C-30 and 60C-30 samples provided results with the most noticeable difference in emulsions with low relative standard deviations. Moving forward, it is recommended that these metrics be tested with other emulsions and curing conditions to see if the DWT method can be modified to be applicable to CIR asphalt pavements.

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Introduction

In the United States, most roadways are usually able to be classified as rigid pavement structures, flexible pavement structures, unbound granular material, or stabilized soil subgrade (1). All types of pavement structures have a limited life span and see different amounts of wear and tear. Eventually, the pavement will no longer be operating at the designed level of service and will either need replacement or rehabilitation. To save on time, money, and materials, road rehabilitation is usually preferred compared to complete reconstruction of the road. For flexible pavements, pavement recycling, such as hot in-place recycling and cold-in recycling (CIR), is a common type of road rehabilitation (1). This paper will focus on CIR for flexible pavement structures.

CIR is a rehabilitation technique that cold mills the top two to five inches of asphalt pavement from the surface, although greater depths can be achieved using other methods, in a continuous train operation (2). Figures 1 and 2 show some different set ups for the continuous train operation. The trains can either be single unit, double unit, or multi-unit trains (2). These configurations differ by how they operate and the flexibility of these setups (ability to change gradation, etc) (2). Train configurations are chosen based on the size of the road, the amount of asphalt pavement being recycling, the gradation of mix, and many more things. The trains pulverize the existing roadway into reclaimed asphalt pavement (RAP) and screen and gradate the RAP; at this point, a stabilizing agent (chemical additive and asphalt emulsion) is added into the mixture (3). Finally, the RAP is placed and compacted. Figure 3 shows a CIR train about to compact RAP that has already been reclaimed and placed. CIR is unique in the fact that the in-place asphalt pavement is reclaimed from and then placed on an existing road, unlike other

Figure 1: Single Unit CIR Train Process (2)

Figure 2: Multi-Unit CIR Train Process (2)

Figure 3: RAP in front of CIR Train Configuration (2)

cold recycling techniques (1). Ideally, these CIR treatments should last between 20 and 25 years (2).

CIR has many benefits when compared to more traditional maintenance and rehabilitation methods. CIR can be 20-50% less expensive, be constructed 20-40% faster, and reduce greenhouse gas emissions by up to 90% (2). These cost reductions can be attributed to reduced need to transport materials and reduced energy consumption, while the greenhouse gas emission reductions can be attributed to reduced need to transport materials and the cold stabilization technique that CIR utilizes (3).

In the CIR process, the workability of the RAP is something that should accounted for. Workability, in terms of asphalt mixtures, is relative ease at which a noncompacted asphalt sample can be handled, consolidated, and placed with minimum segregation (4). Understanding the workability of the RAP is important for CIR as having the desired in place density is crucial for the durability of newly place roadway (5). To evaluate the workability, the Dongre Workability Test (DWT) was developed for the determining the relative workability of warm-mix asphalt and hot-mix asphalt using a Superpave Gyratory Compactor (SGC). A high DWT value represents more workable sample, while a low DWT value represents a less workable sample (4). The test is performed by compacting a 4810 gram asphalt sample in the SGC at a constant loading rate of 0.05mm/s until a stress of 700 kPa is reached; applied force and specimen height are recorded every 0.1 seconds (4). The result of the DWT is calculated by using the secant method between stresses of 550 kPa and 650 kPa to estimate the slope of the stress-strain curve at a stress of 600 kPa. The location of the DWT value on a typical stress-strain curve for two different displacement rates is shown in Figure 4. It is calculated by the following equation (4):

$$W = \frac{650 - 550}{\varepsilon_{650} - \varepsilon_{550}}$$

Where,

W = DWT Workability Value

ε_{550} = Volumetric Strain at 550 kPa stress (%)

ε_{650} = Volumetric Strain at 650 kPa stress (%)

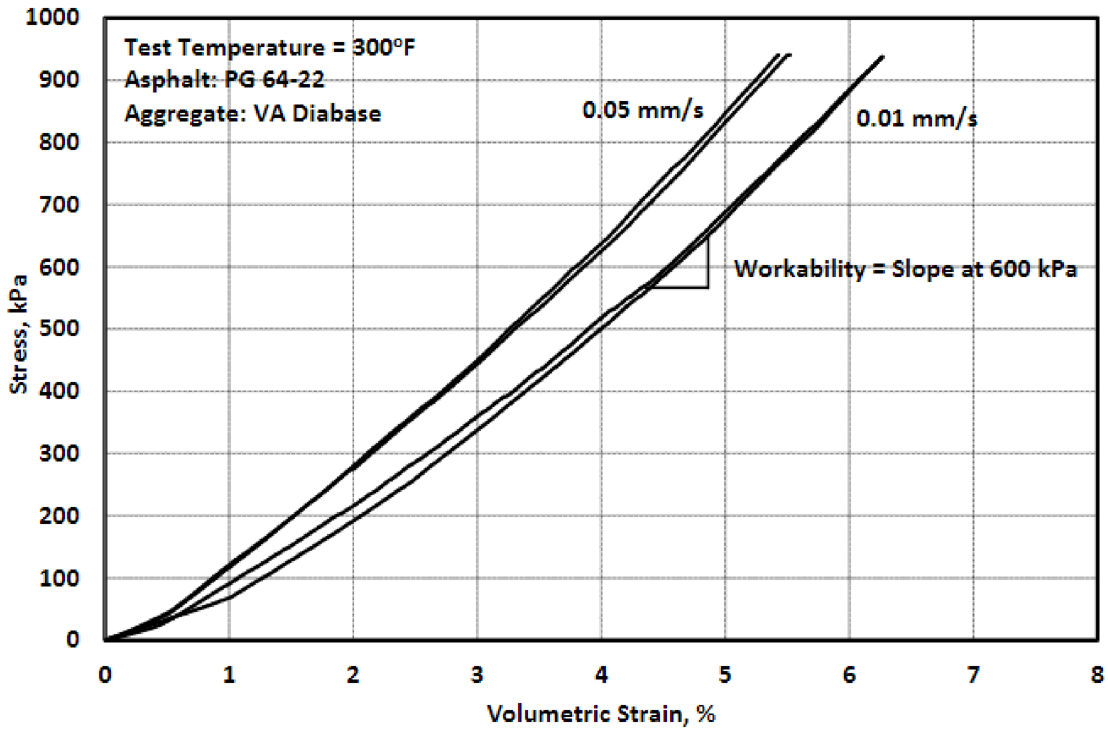

Figure 4: DWT Value on Typical Stress-Strain Curve (4)

Part of the research conducted by Casillas and Braham (2020) was looking into the workability of asphalt pavements, specifically for CIR. In conjecture with a loose triaxial test, DWT values were obtained for twelve different curing conditions: these results of which are shown in Table 1 and Figure 5. From the results in Table 1, it is evident that there is no trend seen between the DWT values and curing conditions. Casillas and Braham (2021) ran loose triaxial tests on the three emulsions used in this research: Figure 5 shows the results of these tests. In loose triaxial testing, an increase in shear strength leads to a decrease in workability (3). At confining pressures of 100 kPa and 200 kPa, Emulsion 2 generally has larger shear strength values, correlating to a less workable mixture. This will help to define the workability of the samples used in this study.

Table 1: DWT Values (3)

	Time (minutes)					
	30		60		120	
Temperature (°C)	DWT	St. Dev.	DWT	St. Dev.	DWT	St. Dev.
10	93.6	1.5	94	1.7	93.7	1.8
23	97.8	2.8	93.9	2.9	92.3	4.7
40	100.1	1.5	97.8	3.5	98.3	2.2
60	90.6	1	102	1.9	100.5	6.9

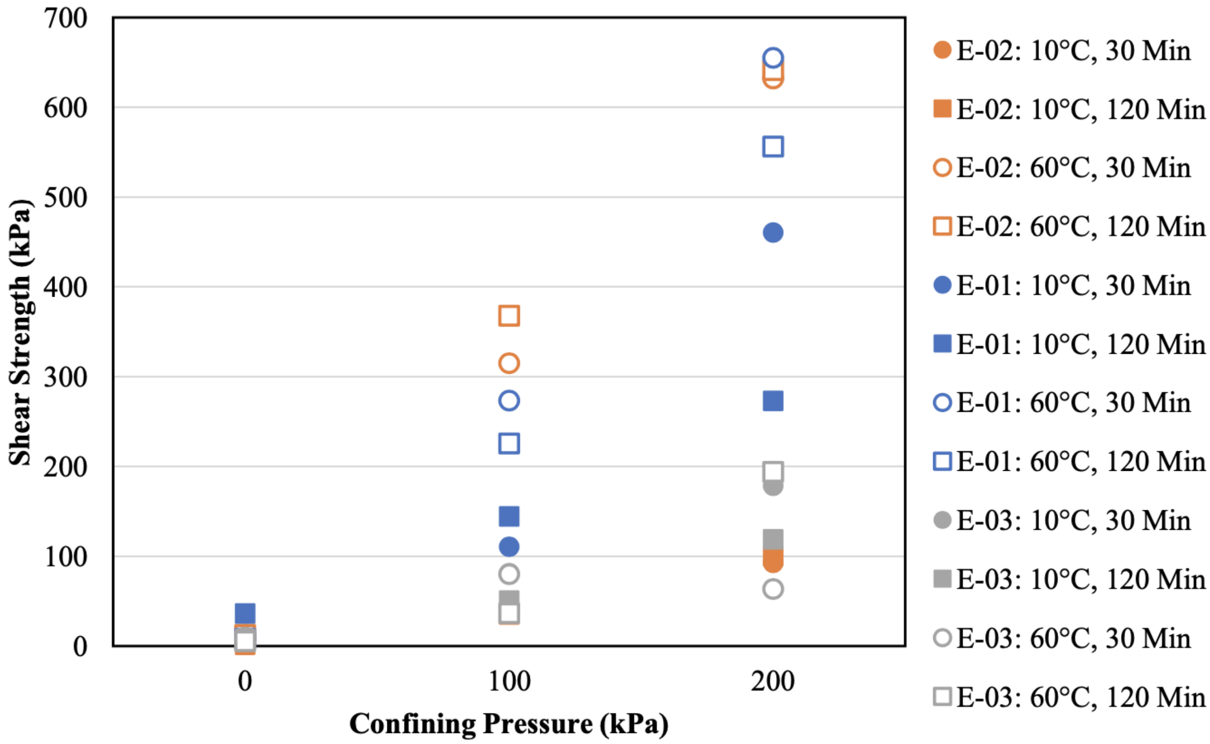

Figure 5: Results from Loose Triaxial Test (6)

The DWT test will serve as a basis for this research. The DWT test will be explored to try to determine a new metric that can serve to define workability for CIR. These new metrics will be defined by looking at the entire typical stress-strain curve while trying to draw inspiration from other methods that utilize a stress-strain curve. It is believed that other regions of the stress-strain curve could be used to better correlate to the results from the loose triaxial test.

The research will be conducted on three different asphalt emulsions using one type of RAP at different curing temperatures and curing times.

Phase 1: Initial Metric Selection and Analysis

Phase 1 data analysis was conducted to find a few new metrics that could be further explored to find a way to predict the workability of CIR samples with different emulsion types and curing temperatures. Initially, ten different metrics were decided upon to explore at first to narrow down the metrics to a few that saw the least amount of variance between samples.

Figure 6 shows the location of all the metrics on an example compaction curve of one of the samples under consideration.

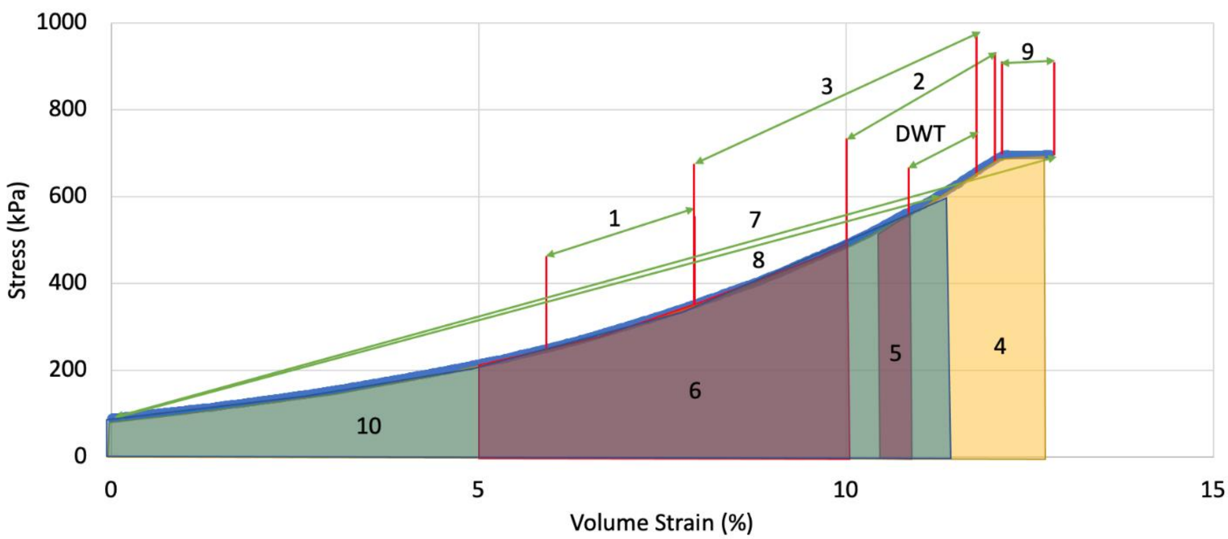

Figure 6: Metric Graph on Typical Stress-Strain Curve

Metric 1 was finding the slope of the compaction curve at the point nearest a stress of 300 kPa. Metric 1 was found by calculating the slope of the straight line between stresses nearest 250 kPa and 350 kPa and their respective strains. This method of calculating slope is similar to the DWT method and the tangent modulus method used to describe elasticity of a material (7). Although, Metric 1 is centered around 300 kPa instead of 600 kPa to look at a different area of the curve.

Metric 2 utilized the slope method like Metric 1 but looked at the curve in respect to strains. Metric 2 was found by calculating the slope of the straight line between strains nearest 10% and 12% and their respective stresses. While this falls in a similar area as DWT, it looks at a larger section of the curve overall and uses certain strains instead of stresses as endpoints.

Metric 3 utilized the slope method like the first two metrics and looked at the slope of the straight line between strains nearest 350 kPa and 650 kPa. A larger range was chosen in respect to the first two metrics to add more variety to the metrics. The metric was chosen to center on 500 kPa to be in between the centers for Metric 1 and DWT (350 kPa and 650kPa).

For Metric 4, the area under the compaction curve was considered. This metric, and others looking at area under the curve, was inspired by compactability metrics for the SGC. Metrics like the Compaction Densification Index (CDI) and Traffic Densification Index (TDI) were used as a guideline to select metrics for trying to quantify the workability of CIR; CDI and TDI look at the area under the compaction curve between a certain number of gyrations and certain percentage of maximum specific gravity (5). For this metric, the area under the entire compaction curve was looked, from 0% strain to the last recorded data point. To find the area under the curve, the trapezoid rule was used with all available data points. Since the SGC takes a measurement every 0.1 second, the trapezoid rule will give a more accurate area under the curve than integrating a generated line of best fit.

Metric 5 considers the area under the compaction curve between strains nearest 10.5% and 11%. These strains were chosen to look at a relatively small area compared to the other metrics. This range was specifically chosen to try to look at the section of the curve as it nears the part right before it starts to flatten out more. Since all the samples don't reach this point at the same strains, this range was chosen to best represent the data as a whole. This metric lies near the area the DWT lies in.

Metric 6 looks at the area under the compaction curve between strains nearest 5% and 10%. This gives a medium sized range in the middle of the curve to consider.

Metric 7 utilizes the slope method like the first three metrics. Metric 7 looks at the slope of the straight line between the strain nearest 0% and the last data point recorded. With this method, the entire curve is summed up to one slope.

Metric 8 draws inspiration from the secant modulus, a way to determine a material's elasticity. The secant modulus is determined by finding the slope of the straight line between the strain nearest 0% and any selected point (for example, strain nearest 2%) on the compaction curve (8). Since the DWT finds the slope at 600 kPa, metric 8 goes from the strain nearest 0% to the stress nearest 600 kPa.

Metric 9 looks at the part of the compaction curve near the end when the slope changes dramatically. In this region, the sample is undergoing an increase in strain with not much increase in stress relative to the rest of the curve. For this metric, the slope of this part of the graph is considered. Since all the samples reached this point at different times during the compaction process, the beginning of the horizontally sloped part of the graph was estimated visually; the last recorded point was used as the end point. Metric 9 was chosen to look at a part of the curve that had not been considered yet to increase the diversity of the metrics.

Metric 10 considered the area under the compaction curve from 0% strain to the stress nearest 600 kPa. 600 kPa was chosen specifically since the DWT method was centered on this stress. This metric also gives a large area, similar to metric 4, that could see variability between the samples.

These 10 metrics were initially tested on samples made using Emulsion 1 with different curing temperatures and times. The samples looked at were either cured at 10°C, 23°C, or 60°C and compacted at 30 minutes, 0 minutes, and 120 minutes (respectively) after mixing. Each curing temperature/time combination had 3 samples, so each metric was tested on a total of 9 different samples. Using a wide variety of samples to test the data will allow a better understanding of how the metrics will behave based on different curing temperatures and times and allow us to select the best metrics to consider moving forward.

Table 2 is a summary of the data gathered in Phase 1 while Figures 7 and 8 show this data visually. Each metric was tested on the 3 samples for each of the different mixes (10C-30, 23C-0, and 60C-120). The averages of the 3 samples were reported as well as the standard deviation. To normalize this standard deviation between all the different metrics, the coefficient of variation was also reported. To decide which metrics were most promising for continued analysis, the coefficients of variation were compared. Metrics 1,4,7,8, and 10, which are designated below, had the lowest relative coefficients of variation; these metrics were chosen to continue with for the research.

Table 2: Phase 1 Summary (designated metrics chosen to move forward with)

Metric	Mix	Average	Standard Deviation	Coefficient of Variation
1	10C-30	50.98	0.71	1.39
	23C-0	51.64	4.40	8.52
	60C-120	51.56	3.24	6.28
2	10C-30	88.74	5.19	5.85
	23C-0	72.41	10.38	14.34
	60C-120	84.24	10.69	12.69
3	10C-30	75.64	0.05	0.07
	23C-0	76.61	6.40	8.35
	60C-120	78.98	8.72	11.04
4	10C-30	4091.29	19.92	0.49
	23C-0	4046.11	292.13	7.22
	60C-120	4055.13	223.05	5.50
5	10C-30	291.77	6.61	2.27
	23C-0	305.4	43.71	14.31
	60C-120	286.18	31.95	11.16
6	10C-30	1781.26	43.67	2.45
	23C-0	1836.56	217.41	11.84
	60C-120	1690.21	131.32	7.77
7	10C-30	48.66	0.57	1.17
	23C-0	49.83	4.02	8.07
	60C-120	48.06	2.76	5.74
8	10C-30	46.53	0.66	1.42
	23C-0	47.96	4.00	8.34
	60C-120	45.93	2.77	5.74
9	10C-30	4.89	1.91	39.06
	23C-0	9.85	3.08	31.27
	60C-120	5.21	3.52	67.56
10	10C-30	3066.91	23.83	0.78
	23C-0	3039.00	286.45	9.43
	60C-120	3018.36	184.37	6.11

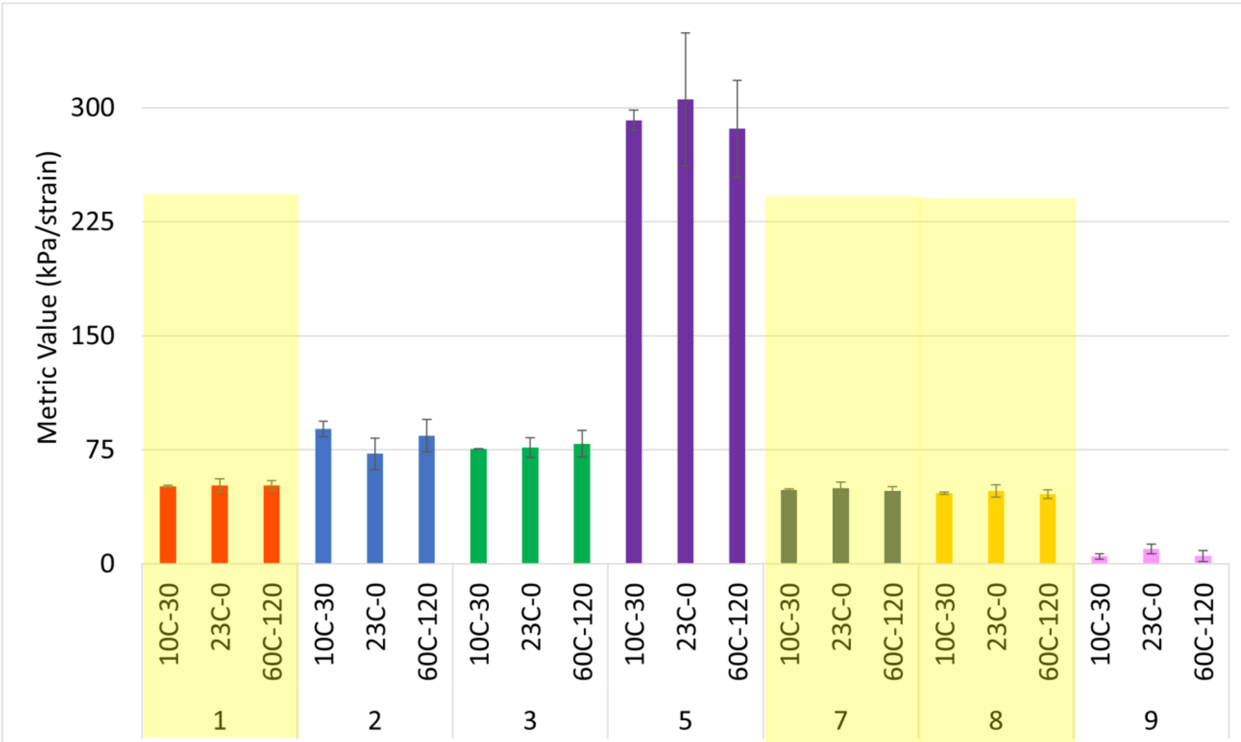

Figure 7: New Metrics Summary Graph 1 (designated metrics chosen to move forward with)

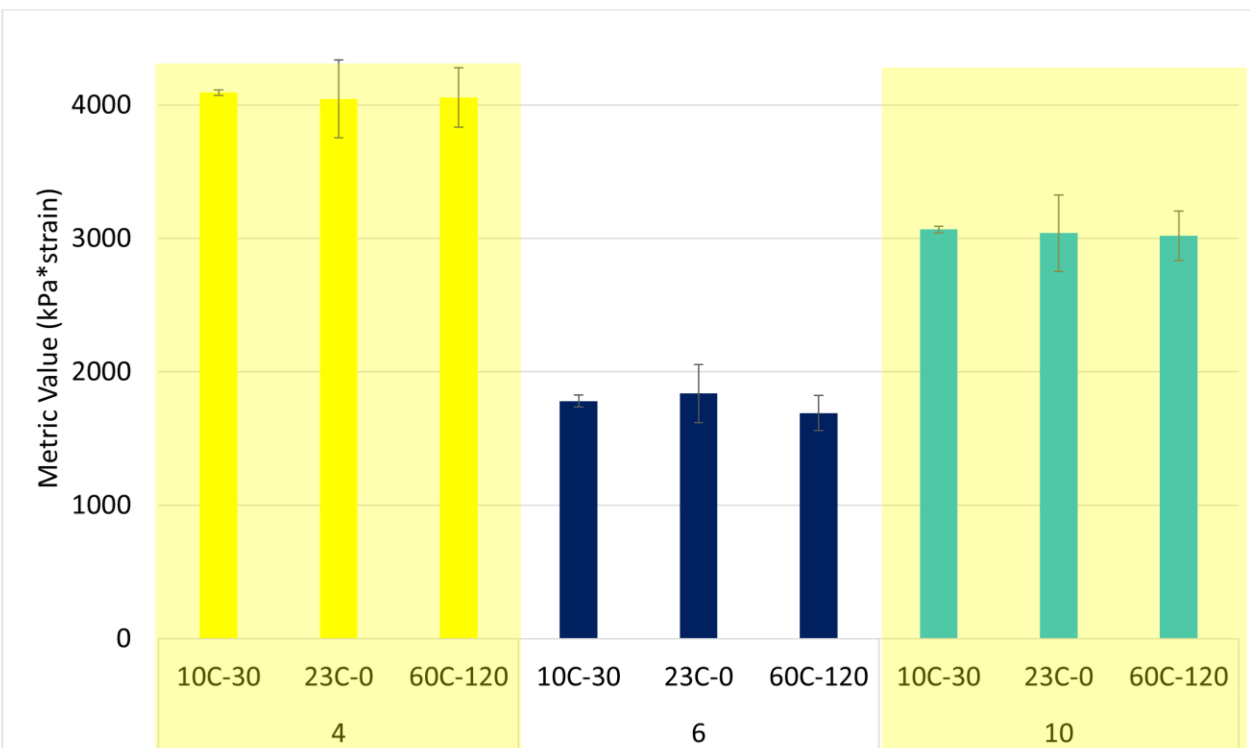

Figure 8: New Metrics Summary Graph 2 (designated metrics chosen to move forward with)

Phase 2: New Metric Exploration

Phase 2 data analysis was conducted to apply the newly selected metrics (1,4,7,8,10) to three different asphalt emulsions. The samples for Phase 2 were cured at 10°C or 60°C and compacted at either 30 minutes or 120 minutes after mixing. The 23°C curing temperature and 0 minute curing time was excluded from Phase 2. While Phase 1 explored 10 potential metrics on one emulsion, Phase 2 took the new metrics and applied them to Emulsion 2 and Emulsion 3, and the remaining curing times and temperatures that were not explore in Phase 1with Emulsion 1. With this, data from the three different emulsions can analyzed and related to the workability of the different emulsions.

Figures 9 and 10 below show the initial results from the Phase 2 data analysis. Metrics 1, 7, and 8 are shown on Figure 9 while Figure 10 shows Metrics 4 and 10 due to the scale of the metrics. According to loose triaxial test data collected from Casillas and Braham (2021), Emulsion 2 was found to be the least workable. From this, the figures make it evident that Metrics 1,7, and 8 should have lower values for more workable mixtures, and Metrics 4 and 10 should display higher values for more workable mixtures. Most metric and curing time/temperature combinations follow this trend, except for the 60C-120 samples. These samples consistently did not behave like the other curing conditions considered, which is evident in the figures. It is believed that the longer curing time in addition with the higher curing temperature led to some of the asphalt binder activating before compaction, making it not behave like the other samples. For this reason, this curing condition was not considered moving forward.

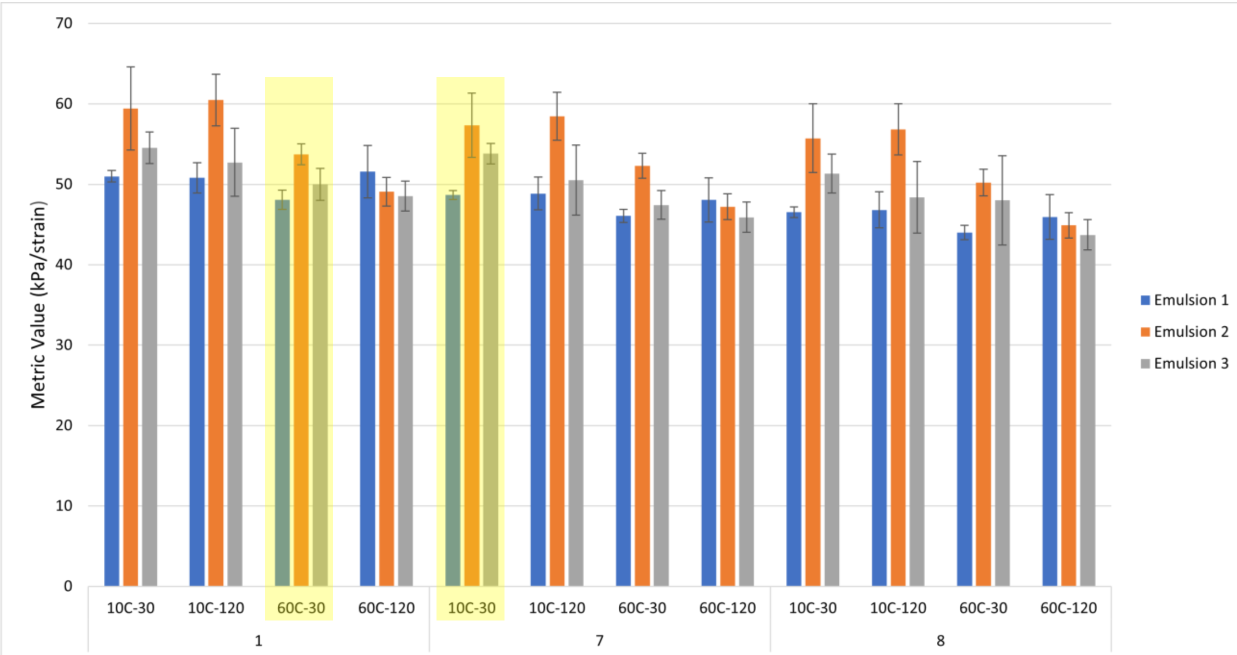

Figure 9: Phase 2 Summary Graph 1 (designated curing conditions analyzed further)

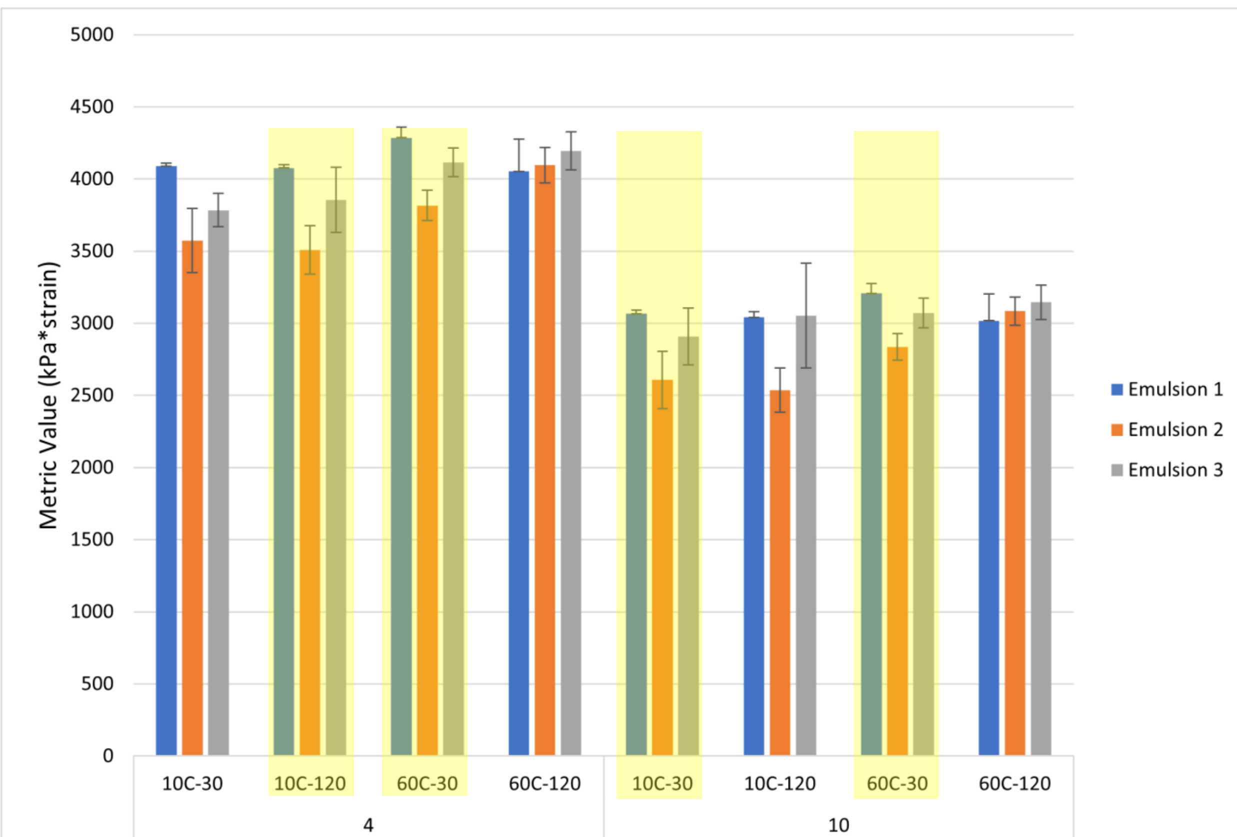

Figure 10: Phase 2 Summary Graph 2 (designated curing conditions analyzed further)

From this data, several things are observed among the different metrics and curing conditions. First, Metrics 1, 7, and 8, which were based on slopes, had a negative parabolic trend amongst the curing conditions, while Metrics 4 and 10, which were based on area under the curve, had a positive parabolic trend: Figures 11 and 12 below show this trend. Also, in these figures, it is apparent that the 60C-120 curing condition did not behave like the other conditions: another reason why this curing condition was disregarded. Relative to the other metrics, Metric 8 saw higher standard deviations across all the curing conditions. Because of this, Metric 8 was also not considered for further analysis.

With this in mind, the six curing conditions with the biggest difference between emulsions and smallest standard deviations were chosen to look at; these are designated on the figures above. Different metrics and different curing conditions were chosen to get the most variety. Curing conditions that had smaller standard deviations with the least amount of overlap were selected. For further analysis, 60C-30 for Metric 1, 4, and 10, 10C-30 for Metric 7 and 10, and 10C-120 for Metric 4 were chosen (shown above).

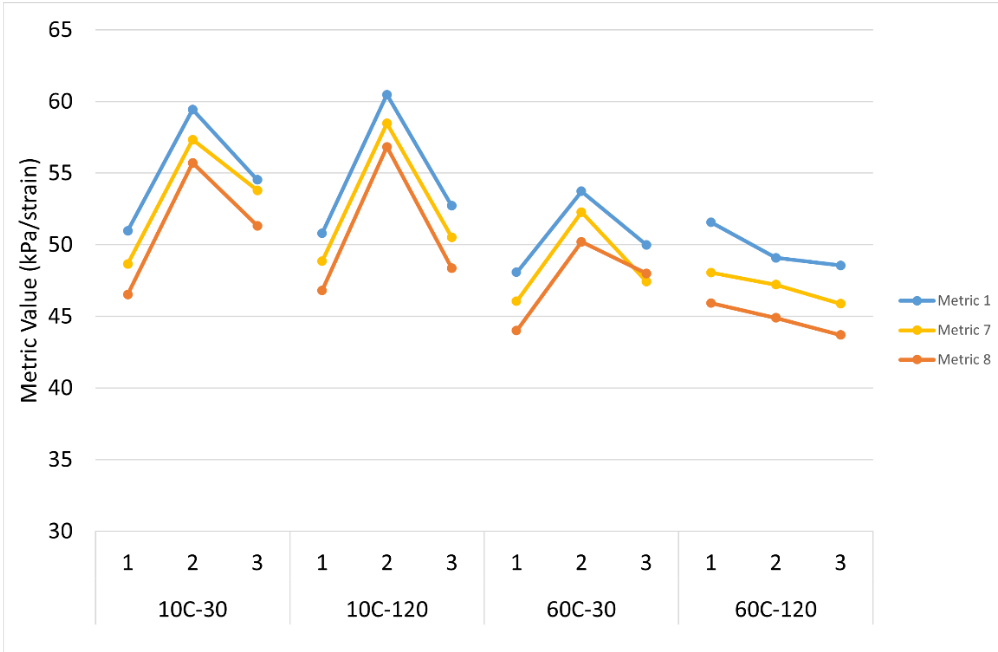

Figure 11: Phase 2 Summary Graph 3

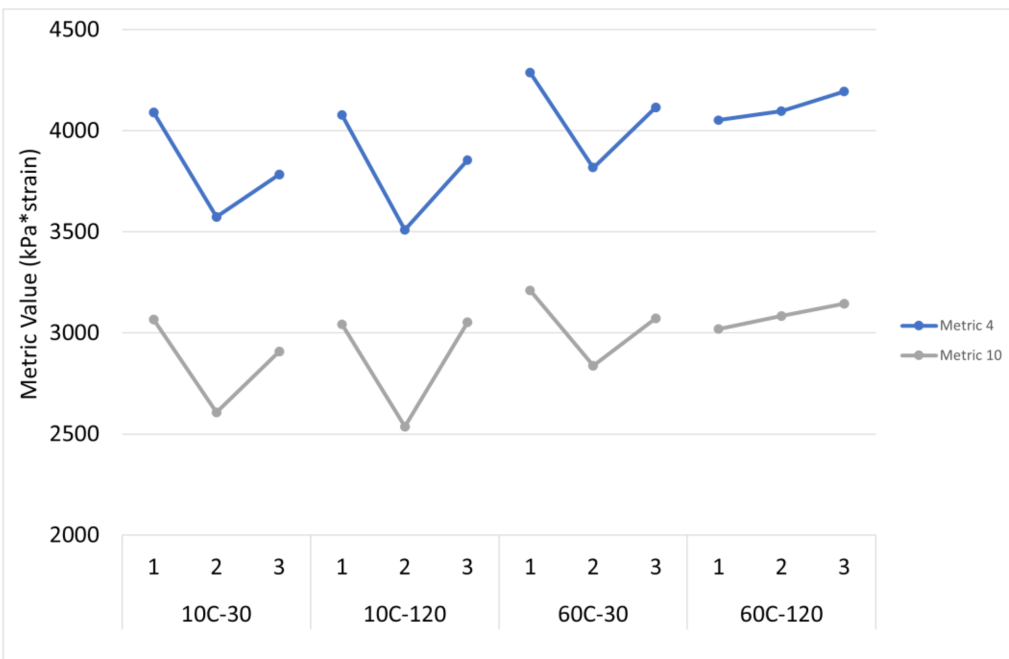

Figure 12: Phase 2 Summary Graph 4

With the six different curing conditions and metric combinations selected, they were graphed together to compare, shown below in Figures 13 and 14. With these values on the same charts, in addition to Figures 9 and 10, it is easy to see which curing conditions and metrics performed better among the different emulsions.

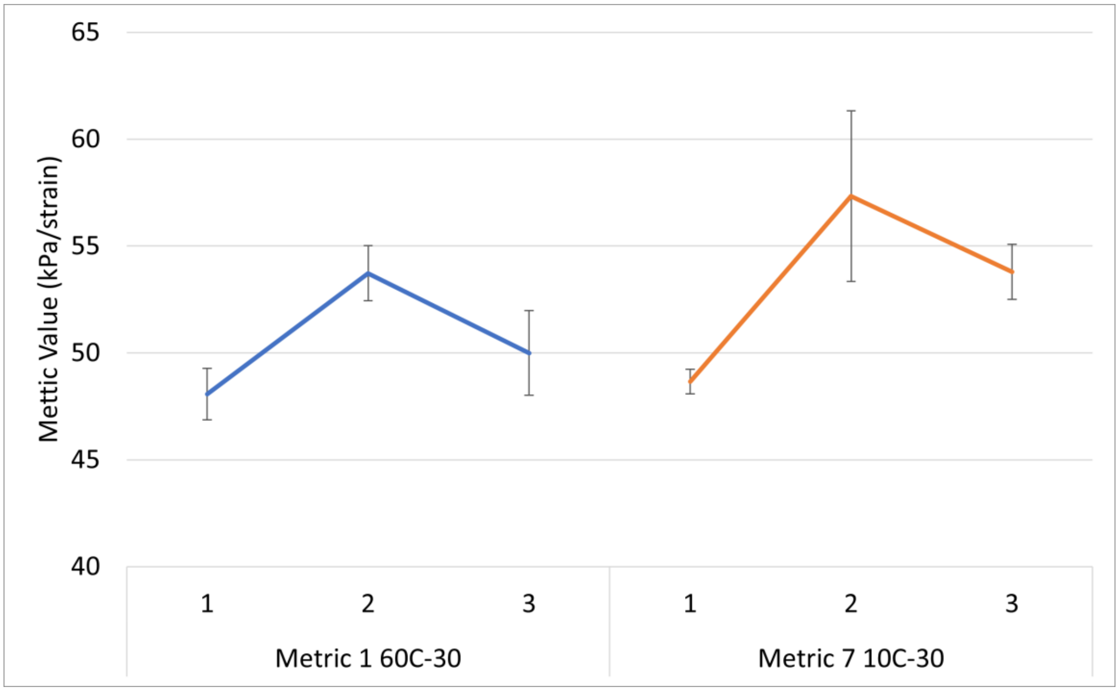

Figure 13: Phase 2 Final Selection 1

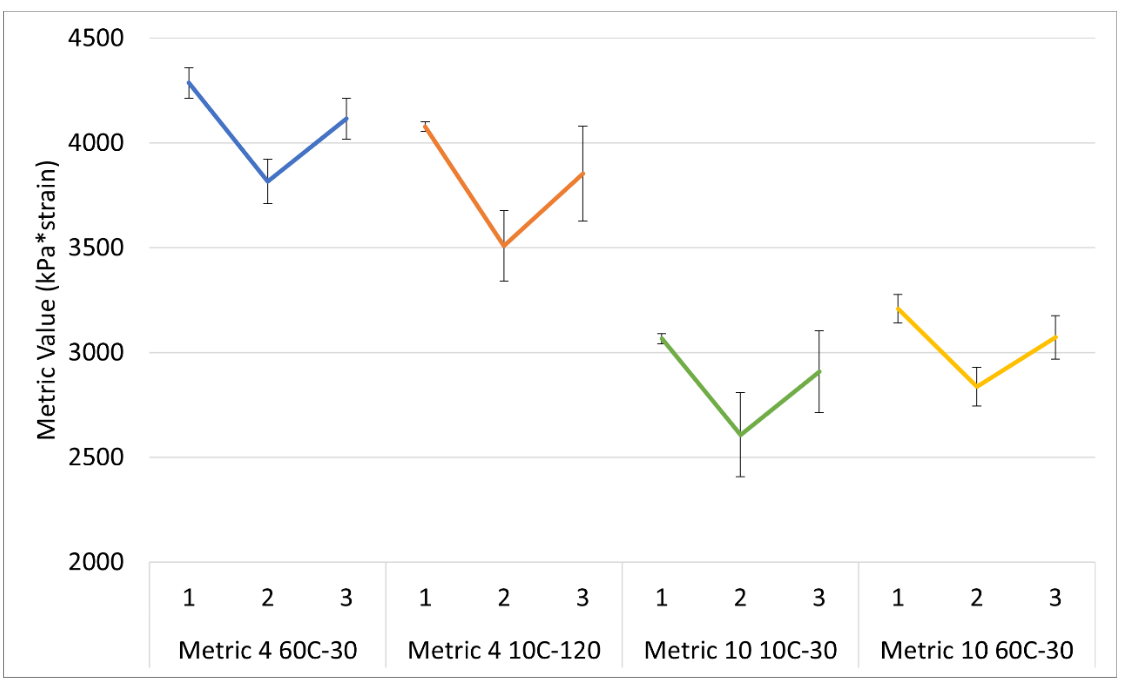

Figure 14: Phase 2 Final Selection 2

When looking at these figures, the first two combinations that stand out from the rest are Metric 4 and 10 for the 60C-30 curing condition. They both have notable differences between the three emulsions, and their standard deviations have almost no overlap, suggesting a high confidence in these values. When looking at Figures 9 and 10 for the rest of the 60C-30 results, on average, they see lower standard deviations with less overlap as well when compared to 10C-30 and 10C-120. While comparing the metrics, it became evident that Metrics 4 and 10, which were based on area under the curve, saw smaller standard deviations with less overlap than Metrics 1,7, and 8. Another interesting thing that stood out was that throughout the different metrics and curing conditions, Emulsion 1 had much lower standard deviations on average, therefore providing more consistent data overall.

Figures 15 and 16 show the three curing conditions considered for further analysis for Metrics 4 and 10. From these graphs, it is evident that 60C-30 preformed the best; 10C-30 preformed more favorably than 10C-120. The 60C-30 curing condition had well defined differences with greater confidences in these values. After Phase 2 analysis, it is recommended that either Metric 4, the area under the entire stress-strain curve, or Metric 10, area under the stress-strain curve up to a stress of 600 kPa, is used for further testing.

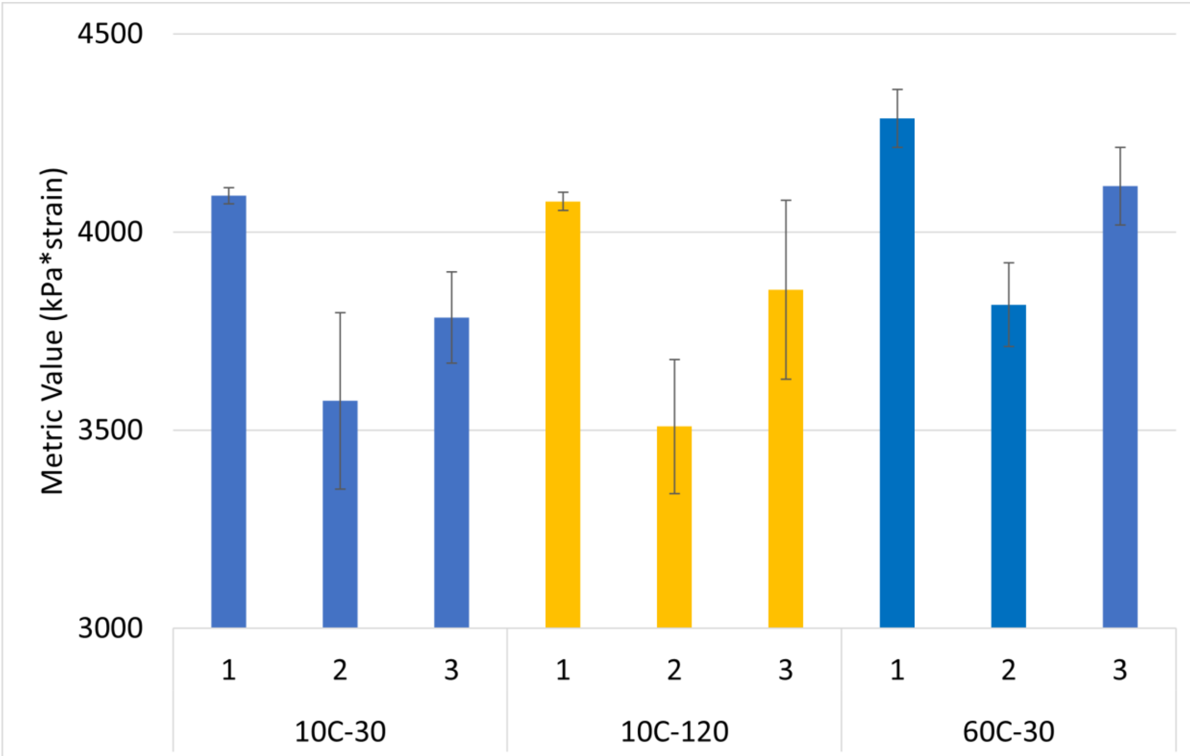

Figure 15: Final Comparison, Metric 4

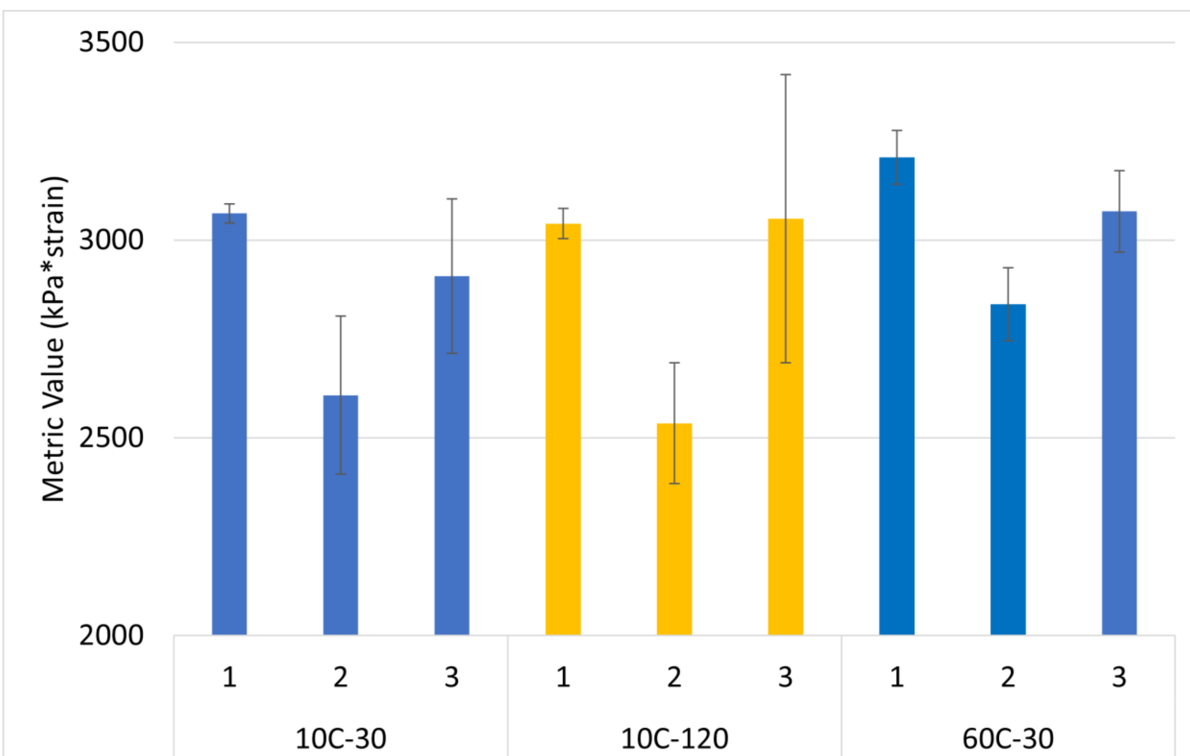

Figure 16: Final Comparison, Metric 10

Moving Forward

For further validation of these results, it is recommended that either Metric 4 or Metric 10 continued to be analyzed. Overall, these metrics, which were based on area under the curve, performed better than metrics based on slopes. Both metrics behaved similarly, but the differences between emulsions were greatest in Metric 4 when compared to Metric 10. For example, Emulsion 1 and 3 had similar values for Metric 10 in the 10C-120 curing condition. When compared to Metric 4, there is a more noticeable difference in Emulsion 1 and 3. This is evident in Figures 15 and 16. For this reason, Metric 4 would be recommended before Metric 10. In this testing situation, a 60°C curing temperature and 30 minute curing time performed most favorably, with 10°C and 30 minutes performing the next best. Further research could include this curing conditions in addition to others for more variety in the results. Additionally, more types of RAP and emulsions should be used to see how these metrics behave with other types of samples.

The DWT method has been successful in determining the relative workability of warm-mix and hot-mix asphalt pavements and does show promise for CIR asphalt pavements, but some modifications are necessary; simply using the warm/hot-mix DWT value for CIR does give favorable results. Thus, the metrics defined in this study could be useful in modifying the DWT method to also apply to CIR, but further research is required. Moving forward, these metrics should be tested on more asphalt pavement samples with different types of RAP, asphalt emulsions, and curing conditions to determine the metric's validity with quantifying the relative workability of CIR.

Conclusion

The DWT is a test for determining the relative workability of warm-mix asphalt and hot-mix asphalt using an SGC, with a higher DWT value correlating to a more workable mixture. Casillas and Braham (2020) applied the DWT to CIR samples to see if the DWT could be applicable. From their research, no correlation was seen between DWT value and curing conditions. The objective of research conducted for this paper was to reexamine the DWT and try to find a similar metric that could be used to quantify the workability of CIR asphalt pavements. The DWT value is found by taking the slope of the line between stresses of 550 and 650 kPa from the sample's stress-strain curve. The metrics chosen for this research looked at different regions of the curve, including the area under the curve. These metrics drew inspiration from the DWT, as well as established metrics like the secant and tangent modulus.

The ten initial metrics were applied to samples of three different curing times and temperatures. The metrics were plotted, and their standard deviations and coefficients of variation were analyzed to choose the five most promising metrics to continue with. With the five final metrics chosen, three different emulsions were analyzed. These samples had two curing times (30 minutes or 120 minutes) and temperatures (10°C or 60°C) for a total of four different curing conditions. Once these metrics were applied, the results were analyzed graphically to see which combination of curing conditions and metric saw the most promise for determining a sample's workability.

After this phase of the data analysis, it was evident that Metric 4 and Metric 10 showed the most notable difference between emulsions with low relative standard deviations. These metrics, which were based on different areas under the curve, saw the best results with the

10C-30 and 60C-30 curing conditions, with a higher value seeming to indicate a more workable mixture.

While the DWT method has shown favorable results for warm mix and hot mix asphalt, preliminary testing with CIR to determine relative workability was inconclusive. With this in mind, it is recommended that Metric 4 and Metric 10 be further explored with different asphalt emulsions and curing conditions to determine its legitimacy.

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