New bitumen quality control test (QCT) for Europe

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ABSTRACT

An innovative, simple, and easy-to-use test method was developed for quality control testing of asphalt binders at the mix plant. This new method, the bitumen Quality Control Test (QCT), uses an air jet to produce indentation and a laser deflectometer to measure the resulting deflection. The QCT is conducted under constant stress and temperature similar to the traditional Penetration test (ASTM D5) except instead of the penetration needle an air jet is used with a loading time of 20s and recovery time of 50s under no load. Unlike the Penetration test, the QCT measures both the loading and recovery characteristics of a binder. The complete creep-recovery curve is measured and stored. The measurement of recovery properties allows for successful discrimination of both unmodified and polymer modified binders.

The initial data demonstrating the proof of concept and within laboratory repeatability was published recently in the proceedings of the Canadian Technical Asphalt Association (CTAA). A possible Penetration based specification approach was also briefly considered in the CTAA paper. In this new approach the Penetration value and the recovery value may both be specified for bitumen. So both unmodified and modified bitumen may be specified by merely changing the percent recovery requirement. More data has been generated using this approach for Penetration graded bitumen from Europe and Asia.

An advanced version of the QCT test is being developed. In the Advanced Quality Control Test (AQCT) the profile of indentation basin is characterized using the Shearography technique. In Shearography, advanced laser technology is used to measure the velocity profile of the out of plane displacement. Initial experiments have shown that the velocity profile generated may be used to relate to the chemistry and rheology of the bitumen being tested. Further tests are under way to characterize several bitumen samples with known chemistry and rheological properties.

This paper describes the implications of using the QCT for a new Penetration based specification that is similar to the PG specification but does not require expensive instrumentation. The progress of the AQCT method and its findings will also be discussed.

Keywords: Asphalt, Certification, Creep, Polymers, Quality assurance

INTRODUCTION

Transportation agencies have a need for a test method that can quickly determine whether an asphalt binder used during pavement construction meets required specifications on each production day. Such a test must be easy to use, portable, and offer a quick turnaround of results that can be used by the field engineer to make timely decisions about proceeding with construction or initiating more complex acceptance testing.

The Dynamic Shear Rheometer (DSR) as per AASHTO T 315 has been tried and did not meet the operational simplicity during construction as required by agency personnel (1). The melt indexer (commonly used in the plastics industry) was also evaluated and not adopted for the same reason (2). What is needed during pavement construction is either a simple acceptance test or a simple informational test that can be a trigger for the agency engineer to conduct more complex acceptance testing, or in other words a simple QC test that can be used by suppliers as well as agency personnel.

2. DEVELOPMENT OF THE QUALITY CONTROL TEST (QCT)

The Federal Highway Administration (FHWA) along with Laser Technology Inc. (LTI) of Norristown PA has developed a Quality Control Test (QCT) method for asphalt binders. This method is easy to operate and provides a quick turnaround time for QC testing; informational test results can trigger more complex acceptance testing or QC testing. This device uses an air jet to produce creep and recovery loading. The resulting deformation is measured using a method that is based on laser deflectometry. Data from a working prototype of the QCT was used to demonstrate the feasibility of such a test method. A first article version of the QCT was developed by Laser Technology Inc. (LTI). Further testing was conducted at Dongre Laboratory Services Inc. (DLSI) and FHWA using the working prototype to further evaluate the technology.

2.1 QCT method details

A schematic of the operation principle of the QCT device is shown in Figure 1 and the prototype is shown in Figure 2. A typical QCT creep and recovery data curve is shown in Figure 3, whereas, Figure 4 shows indentations produced in bitumen samples during a test.

To conduct a test using the QCT, the operator simply places a 3 ounce tin filled to the top fill line with the bitumen and presses the ‘Start’ key. The air-jet loading time (creep) and the recovery duration are pre-set in the software. The sample temperature is controlled by placing the filled sample tin in an environment chamber maintained at 25 +/- 0.1ºC for one hour +/- ten minutes before testing. At the time of testing the operator simply removes the tin from the chamber and places it in the QCT where the testing is completed in less than two minutes. The sample temperature is monitored during testing using an infrared thermometer permanently mounted inside the device. The test protocol used in QCT is similar to the Penetration test as specified by American Standard Test Method D5 (ASTM D5) (2).

Figure 1: Schematic of the air-jet indentation loading system used in the QCT

Figure 2: The first article prototype design of the bitumen QCT Device.

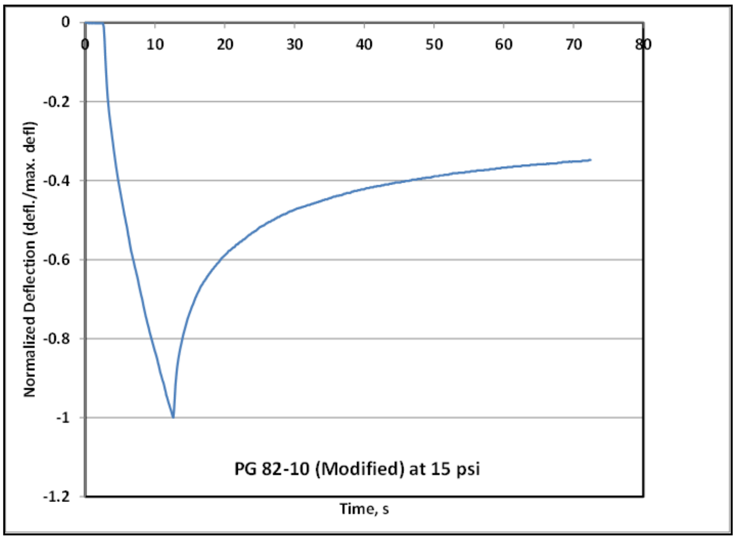


Figure 3: Typical bitumen creep and recovery data curve obtained from the QCT

Figure 4: Indentations produced during typical testing with the QCT

3. REPEATABILITY OF THE QCT DEVICE

To determine the single operator repeatability of the QCT device, several asphalt binders were tested in replicate. Between two to five replicate measurements were made as shown in Table 1. The repeatability was found to be in the range of 1 to 6 percent for maximum creep deflection and between 1 to 10 percent in the case of percent-recovery values. The averaged pooled Coefficient of Variation (COV) was found to be 3 percent for both measured values.

Table 1: Summary of data used to determine repeatability of the QCT Device

Binder ID	Binder Type	Number of Replicates	QCT Max. Deflection, mm			QCT % Recovery		
			Average	Std. Dev	COV %	Average	Std. Dev	COV %
200/300 Pen	UnModified	5	2.8598	0.0437	2	14.4	0.4	3
#1 PG 58-28		5	0.5929	0.0370	6	20.1	1.0	5
PG 64-22		5	0.1588	0.0032	2	41.5	0.9	2
PG 76-10		5	0.0092	0.0006	6	82.0	7.8	10
#2 PG 58-28		5	0.7638	0.0192	3	15.5	0.1	1
PG 64-34	PMA	4	0.3383	0.0058	2	77.4	0.7	1
PG 76-22		5	0.0689	0.0023	3	58.0	1.1	2
PG 82-22	Crumb Rubber Modified	5	0.0533	0.0030	6	57.3	2.5	4
#1 PG 76-22		2	0.1377	0.0049	4	54.7	1.2	2
#2 PG 76-22		2	0.1055	0.0028	3	57.3	1.1	2
#3 PG 76-22		2	0.0908	0.0009	1	59.9	1.8	3
Pooled Average					**3**			**3**

Note: PMA is Polymer Modified Asphalt, Std. Dev is Standard Deviation, and COV is Coefficient of Variation.

4. EVALUATION AND APPLICATION OF QCT

The QCT was evaluated using bitumen from the USA as well as to a lesser extent with bitumen available from around the world. Several common PG grades, Pen grades, and viscosity grades were tested using the QCT. Theoretical analysis was also conducted and a method was developed to determine creep compliance from the QCT indentation data. It was found that the QCT creep and recovery data correlated well with rheology data obtained using the DSR (AASHTO T-315), Penetration test (ASTM D-5), and other traditional bitumen characterization methods. Applications of the QCT to quality control of binders during paving, quick identification of asphalt tank contamination (accidental mixing of grades during production), etc. were also evaluated. The detailed results of evaluation and data analysis are documented elsewhere (3).

In this paper further evaluation of the QCT is summarized. First, the relationship between the MSCR test (AASHTO T350) and the data from the QCT is briefly explored followed by a discussion of use of the QCT for testing high concentrations of crumb rubber modified bitumen (CRMB). Next, the possible use of the QCT data for a new bitumen specification that maintains the simplicity of the traditional Penetration based standard used in Europe and Asia is discussed. The new specification is applicable to polymer modified as well as crumb rubber modified bitumen. Unlike the traditional Penetration based grading system which can only account for consistency changes of a bitumen, the recovery portion of creep and recovery data obtained by QCT also allows for consideration of elasticity enhancements provided by the use of polymers and crumb rubber. The proposed new bitumen grading method provides the advancements of the PG grading system without the complexity of the testing methods employed in its application.

Finally, an innovative technique to test asphalt mixes in creep and recovery mode is also demonstrated. The asphalt mix data thus generated may be used as a quick and easy indication of quality during paving.

4.1 Relationship to MSCR test (AASHTO T 350)

Several polymer modified (PMB) and crumb rubber modified (CRMB) bitumen were tested using the DSR and the QCT. The MSCR test protocol (AASHTO T 350) was used to test the bitumen with the DSR (4). The MSCR test standard requires that the bitumen be pre-aged using the RTFO aging method (AASHTO T 240) and the test temperature is based on the climate. The QCT test data, however, were generated on the same bitumen at 25ºC in an unaged condition. Figure 5 shows the data plotted according to the polymer curve equation given in AASHTO T350 as shown in equation 1. The filled circles and solid line in Figure 5 represent the polymer curve generated from the J_{nr} value measured in the DSR at climate temperature and RTFO condition. The filled diamond symbols show the measured data from the QCT at 25ºC and unaged condition. Note that the slope of the two data sets is kept the same for comparison purposes. The constant multiplier for the QCT data is 34.149 whereas that for the DSR data is as per the AASHTO T 350 standard of 29.37. This is easily explained by the difference in compliance expected due to difference in aging (RTFO versus unaged) as well as the difference in test temperatures (25ºC versus climate temperature). The QCT compliance curve exhibits a greater recovery due to the lower test temperature but is also softer due to lack of RTFO aging. The rheological behavior represented by the slope of the two curves is the same (-0.263). This implies that it may be possible to successfully predict the MSCR behavior in RTFO aged condition at climate temperatures from the QCT creep and recovery data measured at 25ºC in unaged condition. This finding is further proof of the applicability of the QCT data to QC of bitumen during paving construction to monitor PMB and CRMB bitumen. The theoretical analysis to express creep compliance and percent recovery determined using the QCT in terms of J_{nr} and percent recovery specified in AASHTO T 350 is being explored and will be documented in the future.

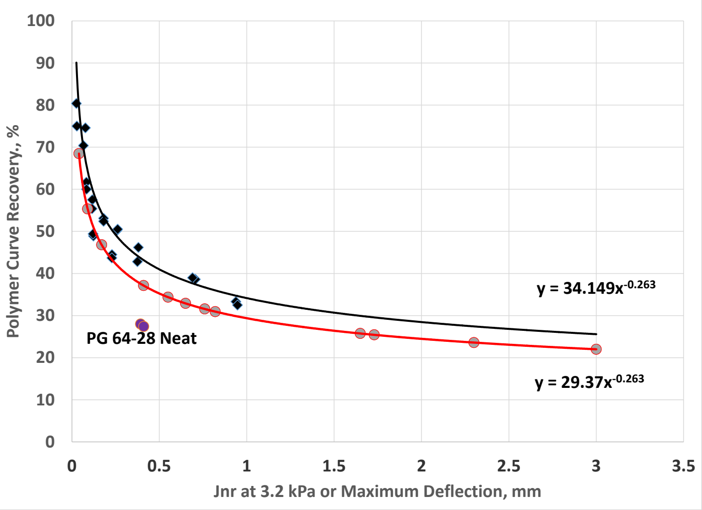


Figure 5: Relationship between QCT creep and recovery data and MSCR data from DSR

4.2 CRMB with high crumb rubber content

CRMB bitumen come in basically two forms; low and high CR content. The low content CRMB is typically made using minus 30 mesh or greater sieve size (0.6 mm particle size) containing 10 percent or lower CRM concentrations. This is popularly referred to in the US as 'smooth peanut butter consistency CRMB'. The high content CRMB consists of minus 10 mesh or lower sieve size containing more that 10 percent CRM concentration. This is called 'chunky peanut butter consistency'. While both CRMB bitumen are difficult to test using the AASHTO standard T 315, the 'smooth' low content bitumen is tested at a 2 mm gap size in the DSR. The 'chunky' CRMB cannot be readily tested using the DSR or the BBR. Figure 6 shows the results of a failed attempt to make BBR specimen for testing using the AASHTO T 313 protocols. The high content CRMB is typically used to construct open graded friction courses (OGFC) in the US.

Figure 6: Failed attempt to mold BBR (AASHTO T 313) specimen from high content CRMB

The QCT can easily test both types of CRMB. The 3-oz size tin used in the QCT test allows one to determine average bulk properties of the CRMB with negligible interference from the particle size or content. Figure 7 shows the sample tins filled with high content CRMB ‘chunky type’ that were used in testing for the data reported in this paper.

Figure 7: High content CRMB sample tins used for testing with QCT

Figure 8 shows the typical creep and recovery curves for replicate high content CRMB samples. Figure 9 shows the same data plotted (inverted to depict classical creep and recovery style curves) on QCT data for various performance grade (AASHTO M320) bitumen (5). Table 2 shows summary of the QCT data whereas Table 3 shows the variability of the high content CRMB tests done with the QCT. Both Figure 8 and Table 3 indicate that the QCT test data is relatively repeatable (COV data in the last row of the table) in a single laboratory and single operator setting. The reproducibility has not yet been determined. Figure 9 shows that the high content CRMB (25% CRM of -10 mesh sieve size) behaves similar to a PG 64-34 PMB bitumen when the creep data is considered whereas the recovery data shows elastic behavior is similar to a PG 76-22 PMB. This implies that the QCT test may be a simple way to grade CRMB bitumen using one grading system that is blind to the type of modified bitumen being tested.

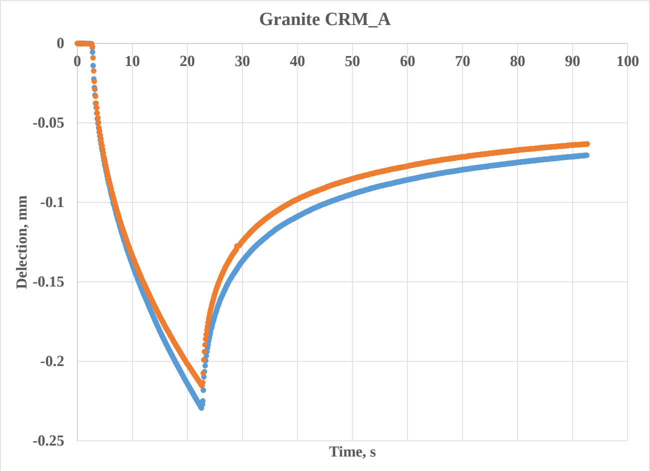


Figure 8: QCT creep and recovery replicate sample curves for high content CRMB

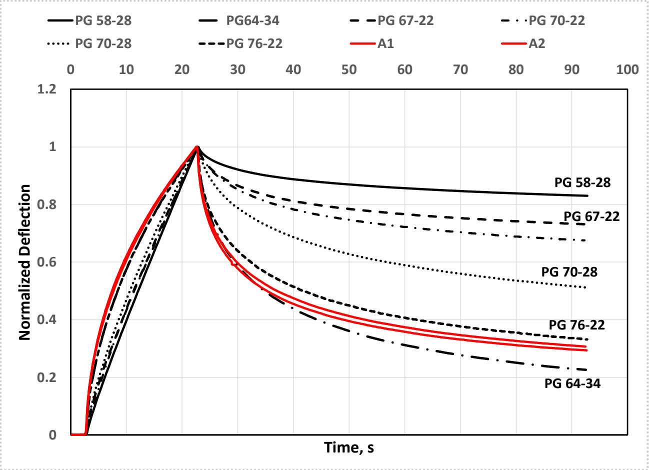


Figure 9: PG grade representation of high content CRMB using the QCT data

Table 2: Summary of QCT data for high content CRM bitumen

				Averages		
Sample ID	**Max. Deflection mm**	**Recovery %**	**Recovery mm**	**Max. Deflection mm**	**Recovery %**	**Recovery mm**
GRNT_A1	-0.229	69	-0.070	-0.222	70	-0.067
GRNT_A2	-0.216	71	-0.063			
GRNT_B1	-0.178	67	-0.058	-0.172	68	-0.056
GRNT_B2	-0.166	68	-0.053			
GRNT_C1	-0.201	71	-0.058	-0.192	72	-0.054
GRNT_C2	-0.182	72	-0.051			
GRNT_D1	-0.140	74	-0.036	-0.143	74	-0.037
GRNT_D2	-0.145	73	-0.039			

Table 3: Summary of repeatability statistics for high content CRMB bitumen QCT data

Statistics					
Max. Defl.		% Recov		Recovered Defl.	
Std. Dev.	Average	Std. Dev.	Average	Std. Dev.	Average
0.00983	-0.2225	0.91923882	69.95	0.00502	-0.0669
0.00905	-0.172	0.42426407	67.7	0.00361	-0.0556
0.01365	-0.1918	0.42426407	71.7	0.00467	-0.0543
0.00361	-0.1427	0.70710678	73.8	0.00191	-0.0374
Averages					
0.00903	-0.1822	0.61871843	70.7875	0.0038	-0.0535
5		0.9		7	

4.3 Proposed new specification using the QCT data

To determine if the QCT could be an alternative to the traditional Penetration test, a study was conducted to determine the relationship between QCT maximum deflection value and the penetration values (ASTM D5). A range of modified and unmodified asphalt binders were tested. The modifiers included polymers, crumb rubber, and fluxes.

Figure 10 shows the correlation between the QCT maximum deflection data and the penetration values. Both tests were conducted at 25°C. The standard protocol was used for the penetration test. The QCT was conducted using 5 psi pressure which produces a creep load of 10.2 g. The loading time of 20s was used with a recovery time of 70s at zero pressure or load. The QCT maximum deflection shown in Figure 10 is the deflection measured at 20s. The correlation coefficient of 0.9 shown in Figure 10 is better than expected.

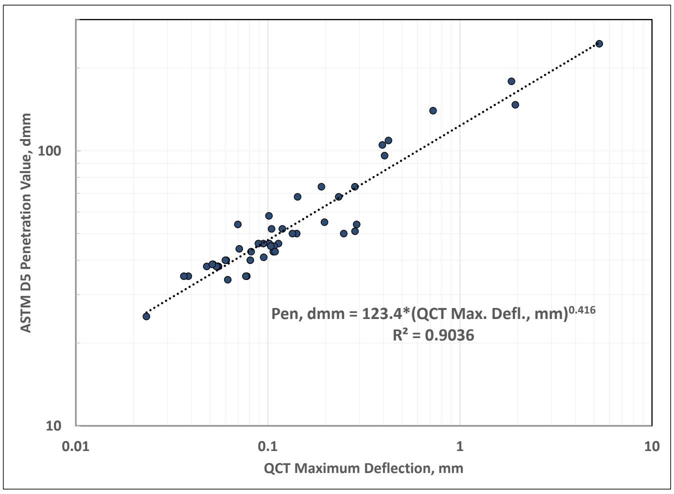


Figure 10: Correlation between Penetration Values and QCT maximum deflection values

The Penetration test is an empirical test and does not produce consistent results for modified asphalt binders. This limitation of the penetration test is due to the fact that the penetration needle often encounters polymer rich, crumb rubber particles, and asphalt rich phases in polymer modified and crumb rubber modified asphalt binders. The QCT produces indentation using air pressure which does not penetrate the asphalt binder surface thus produces significantly more repeatable measurements regardless of whether the tested binder is modified or not. This suggests that the QCT maximum creep deflection value may be used in lieu of the penetration value and the percent recovery value may be used to further distinguish between unmodified and modified binders, Figure 11.

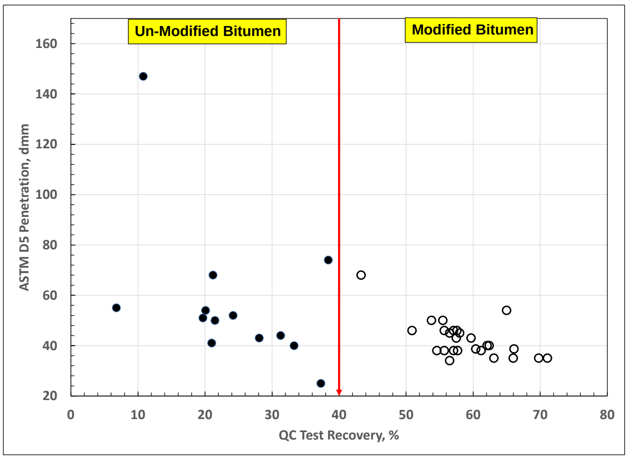


Figure 11: Proposed new QCT based grading system relationship between Penetration from ASTM D5 and % Recovery from QCT

For example, let us examine bitumen in Figure 11 with the Pen grade 50/60 and a penetration value of say 52 dmm. To specify a polymer modified bitumen with a penetration similar to a 50/60 bitumen grade but with 3 percent Styrene-Butadiene-Styrene (SBS) one would simply require a Pen grade of 50-60/70% as the new proposed grade. So the new unmodified grade bitumen would be designated as 50-60/20 percent. To validate this concept further, bitumen supplied to the Utah Department of Transportation in USA (UDOT) for the 2015 paving season was tested using the QCT. Figure 12 shows the results plotted as per the proposed new grading method. All the PG 58-28 binders supplied can be found on the un-modified part of the grading chart in Figure 12, whereas the modified binders are all located on the modified side. Note that various modified PG grades are further distinguishable using the new grading concept. For example, a PG 70-28 can be specified as Pen 80-90/60%.

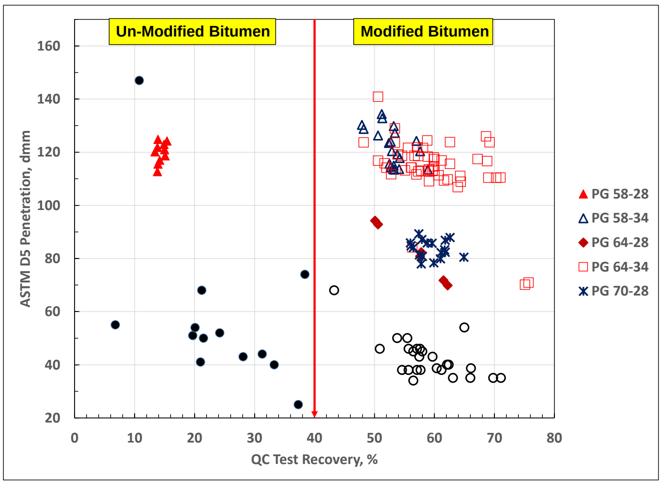


Figure 12: Validation of the new Pen grading concept based on the QCT

In Figure 12 the Penetration (ASTM D5) data for the UDOT bitumen was calculated using the equation shown in Figure 10 as no corresponding Pen data was available. In the future it is anticipated that the new grading system will be based solely on the QCT maximum deflection range and percent recovery. For example, let us again examine a bitumen in Figure 11 with the Pen grade 50/60 and a penetration value of say 52 dmm. This corresponds to a maximum deflection value from the QCT of about 0.25 mm or 25 dmm. So one would simply specify a 25/70 QCT grade to purchase an SBS modified binder similar to a PG 76-22 grade. It is also anticipated that when the QCT deflection is used in lieu of the Pen value a range may not be necessary because the repeatability of the QCT maximum deflection values is 3% or lower.

5. APPLICATION OF SHEAROGRAPHY TO BITUMEN CHARACTERIZATION

The laser deflection measurement method used in the QCT simply measures deflection at the center point of the indentation created by the air jet in the bitumen sample. While this is adequate for QC of bitumen and for grading purposes, it does not give complete characterization of the bitumen response to creep load and recovery. For that, a detailed profile of the indented surface is required. One option to do that is the Shearography measurement method.

Shearography is a non-destructive strain measurement system with a resolution of 1 nm. It is a type of Laser interferometry which, unlike Holography is not sensitive to vibration and can directly measure out of plane strain (6). The Shearography system being used for bitumen indentation characterization is shown schematically in Figure 13.

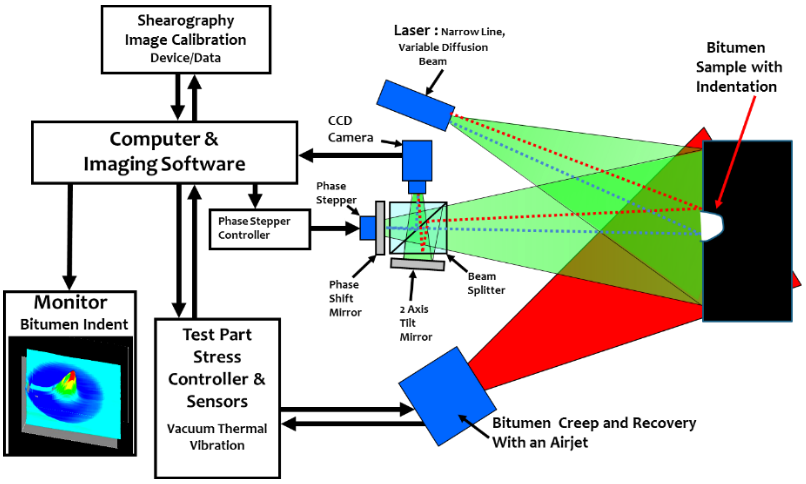
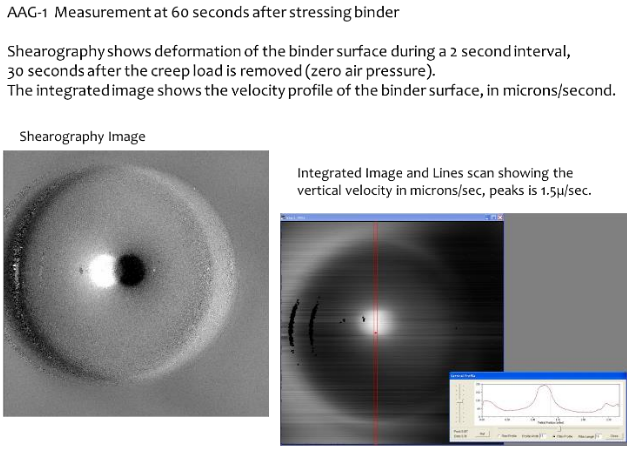


Figure 13: Shearography NDT system schematic diagram

5.1 Why characterize bitumen indentation using Shearography?

The shape of the indentation produced due to creep load and its recovery behavior must be related to the microstructure of the material. For example, one idea being explored is to relate the molecular distribution of the bitumen and thus its chemical composition to the shape and velocity of the creep and recovery phase of the indented surface. At the time of this writing the work has just begun. Several bitumen were tested using the system shown in Figure 13. The shearograms are shown in Figure 14. The 3-D out of plane velocity profile (strain) calculated from a typical shearogram (by unwrapping the phase map) is shown in Figure 15. The horizontal and vertical profiles are depicted in Figure 16. The final velocity results are plotted in Figure 17 for two bitumen studied. Further development and analysis is underway the results of which will be reported in the future.


AAG-1 Measurement at 60 seconds after stressing binder

Shearography shows deformation of the binder surface during a 2 second interval,
30 seconds after the creep load is removed (zero air pressure).
The integrated image shows the velocity profile of the binder surface, in microns/second.

Integrated Image and Lines scan showing the vertical velocity in microns/sec, peaks is 1.5μ/sec.

Figure 14: Typical shearogram of a bitumen sample

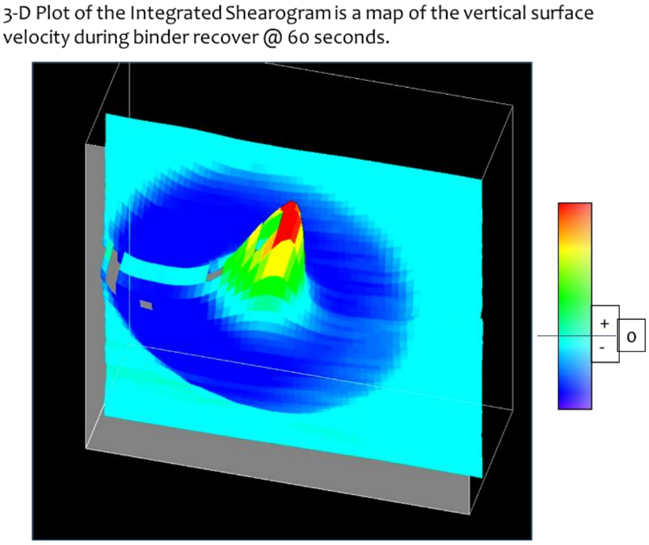

3-D Plot of the Integrated Shearogram is a map of the vertical surface velocity during binder recover @ 60 seconds.

Figure 15: A typical 3-D plot of the indented surface of the bitumen sample

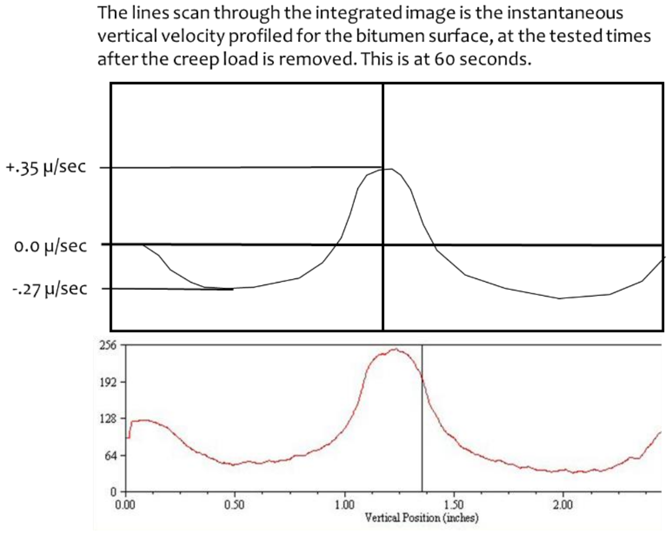

The lines scan through the integrated image is the instantaneous vertical velocity profiled for the bitumen surface, at the tested times after the creep load is removed. This is at 60 seconds.

Figure 16: Typical vertical and horizontal velocity profiles of the indented bitumen surface

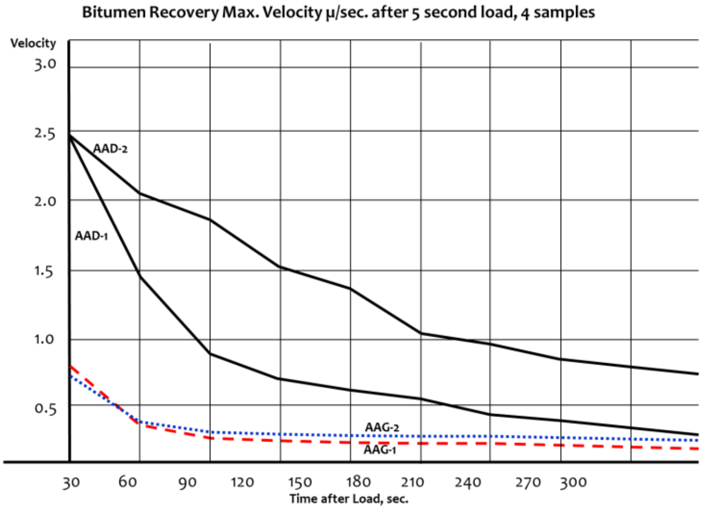


Figure 17: Typical velocity data for bitumen recovery for two samples

6. SUMMARY AND FINDINGS

FHWA and Laser Technology Inc. (LTI) of Norristown PA have developed a QC test method for asphalt binders. This method, simply called QC Test (QCT), is easy to operate and provides a quick turnaround time for QC results. This device uses an air jet to produce creep and recovery loading. The resulting deformation is measured using a method that is based on laser technology. Initially, data from a working prototype of the QCT were used to demonstrate the feasibility of such a test method. A first article version of the QCT was developed by Laser Technology Inc. (LTI). Further testing was conducted at Dongre Laboratory Services Inc. (DLSI) and FHWA using the working prototype to further evaluate the technology.

The results of the evaluation program suggest that the QCT produces rheological characteristics of asphalt binders that are similar to the traditional more time consuming test methods such as the DSR and the Elastic Recovery. It was found to be easy to use and produced repeatable data quickly. Within lab repeatability appears to be very good (< 5% COV for single operator). A more detailed ruggedness study is recommended followed by an ILS study to establish repeatability and reproducibility data for the QCT. A new proposal for a bitumen grading system that uses QCT data was also introduced. This new system is similar to the PG grading system but without its complexity and use of multiple test methods. In its current form the QCT is ready for field testing and possible commercialization.

A Shearography NDT system to characterize the indented surface of the bitumen sample was briefly introduced. It is anticipated that the results from the Shearography analysis will help us better understand the microstructure of bitumen and its impact on indentation due to creep and recovery loading.

Specific findings of the evaluation of the new QCT are as follows:

- Able to distinguish PG and pen graded binders
- Able to discriminate between various types and contents of modifiers
- Compares well with other rheological and empirical bitumen test methods
- Maybe used as a possible alternative to the Penetration Test (ASTM D5) with capability to test modified bitumen

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