Enhanced Aggregate-Asphalt Adhesion and Stability of Local Hot Mix Asphalt

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Abstract

A polymer modification is used to improve the fundamental properties of asphalt binders as those properties relate to the performance of asphalt mixtures. Adhesion and cohesion are two important related properties of asphalt binders that can affect asphalt mixture performance. The first target of this study is to quantify the effects of polymers on the adhesion and cohesion of the binders. Two types of stones are used in this study, limestone and sandstone. The pneumatic adhesion tensile tester (PATTI) is used to measure the pull-off tensile strength in Wisconsin University, it is found that the tensile strength between limestone and styrene butadiene styrene (SBS) polymer increase 26% to 55% as using 2% and 4% of SBS respectively, while increase 54% to 76% when use 2% and 3.5% of Functionalized Polyethylene (PE) polymer respectively. For sandstone, 2% and 4% of SBS causes increasing the strength 5% and 18% respectively, while these values becomes 29% and 51% for asphalt binder modified with 2% and 3.5% of PE respectively.

The second objective of this paper is to find the effect of the fine aggregate and polymer on the stability of the local asphalt mixture. To achieve this target two blends have been selected, the first blend is passing under restricted zone (S-shaped blend) and second blend passing through restricted zone (fine blend). The pressure distribution analyzer (PDA) which is developed to Gyratory Load-cell Plate assembly (GLPA) by asphalt research group in Wisconsin University to measure and evaluate the resistance of mixture to distortion, the (PDA) is placed in the gyratory compactor mold and provide load measure which is recorded simultaneously with deflection, the vertical load and the eccentricity of the load are measured using three load cells placed at the edge of the plate, the measurements are used to calculate the resistive effort (w) as a function of number of gyrations. Functionalized polyethylene (PE) polymer and styrene-butadiene-styrene (SBS) are used to show effect of polymers on Construction Force Index (CFI) which is related to the amount of the work done for rising density of the mix to 92%. The results indicated that CFI is reduced by about 68% as using 3.5% of PE, while it is reduced about 42% when using 4% of SBS which give good indication for contractors to use polymers for reducing cost. Resistive effort results show that fine blend has higher stability than coarse (S-shape) blend, all the tests of local asphalt binders are done in the University of Wisconsin-Madison- USA.

Keywords: modified Asphalt binder, Cohesion, PATTI, , Stability, PDA analyzer.

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زيادة تلاصق الركام بالاسفلت والثبوتية للخرسانة الاسفلتية المحلية

الخلاصة

التعدّيل بالبوليمر يتستخدم لتحسين الخواص الاساسية للاسفلت الرابط، وهذه الخواص لها علاقة بدرجة اداء الخرسانة الاسفلتية. التلاصق والتماسك من الخواص المهمة التي لها علاقة بخواص الاسفلت الرابط والتي تؤثر على درجة اداء الخرسانة الاسفلتية. الهدف الاول من هذه الدراسة هو تحديد تاثير البويمرات على التلاصق والتماسك للاسفلت الرابط. نوعين من الحجر استخدمت في هذه الدراسة ، الحجر الجيري والحجر الرملي. جهاز فحص شد التلاصق بالهواء المضغوط (PATTI) في جامعة وسكونسن استخدُم لقياس مقاومة شد التلاصق. وجد بانه مقاومة شد التلاصق بين الحجر الجيري والاسفلت المعدل ببوليمير الستايرين بيوتادين ستايرين (SBS) تزداد 26% الى 55% باستخدام 2% و 4% من ال (SBS) على التوالي. بينما تزداد المقاومة 54% الى 76% عند استخدام 2% و 3.5% من الاسفلت المعدل ببوليمير البولي اثيلين الفعّال على التوالي. للحجر الرملي والاسفلت المعدل بنسبة 2%و 4% من بوليمر ال (SBS) تزداد مقاومة شد التلاصق 5% و 18% على التوالي، بينما هذه القيم تزداد الى 29% و 51% لاسفلت المعدل ببوليمر البولي اثيلين الفعّال بنسبة 2% و3.5% على التوالي. الهدف الثاني من هذا البحث هو ايجاد تأثير الحصى الناعم والبوليمر على ثبوتية الخلطة الإسفلتية المحلية. لتحقيق هذا الهدف تم اختيار مزيجين ، الأول يمر تحت المنطقة المقيدة (مزيج على شكل حرف S) والاخر مزيج ناعم يمر بالمنطقة المقيدة. محلل توزيع الضغط (PDA) المطور عن تركيبة صفيحة خلية الاحمال الدورانية (GLPA) من قبل مجموعة باحثين الأسفلت في جامعة وسكونسن لقياس وحساب مقاومة الخلطة للتشوه. توضع صفيحة (PDA) في قالب الضغط الدوراني لقياس الحمل المسلط انياً لكل تشوه. مقدار ومركزية الحمل العمودية تقاس بواسطة ثلاثة خلايا موجودة في حافة الصفيحة ، هذه القياسات تستخدم لحساب الجهد المقاوم بدلالة عدد الدوران ، بوليمر البولي الأثيلين الفعّال (PE) مع ستايرين بيوتادين ستايرين (SBS)استخدمت لبيان تأثير البوليمرات على دليل قوة الأنشاء (CFI) والمرتبط بمقدار الشغل المبذول لرفع كثافة الخلطة الى 92%. النتائج أشارت ان (CFI) يقل بمقدار 68% باستخدام 3.5% من بينما يقل بمقدار 42% عند استخدام 4% من (SBS) وهذا يعطي مؤشر جيد للمقاولين لإستخدام البوليمرات لتقليل الكلفة. نتائج مقاومة الجهد بينتْ ان الخلطة الناعمة تعطي ثبوتية اعلى من الخلطة الخشنة (شكل حرف S) كل نماذج الاسفلت المحلي تم فحصها في جامعة وسكونسن –ماديسون في الولايات المتحدة الامريكية.

Introduction

The polymers are successfully used for modifying binder properties by changing their microstructure and enhancing the rheological properties and the damage resistance characteristics of asphalt binders and mixtures [1]. The use of polymer modified asphalt cements in pavement construction is an important step in increasing the life and durability of asphalt roads. Adhesion and cohesion are two important related properties of asphalt binders that can affect asphalt mixture performance, adhesion can be measured with the pull-off tensile strength test by using the pneumatic adhesion tensile tester (PATTI). Two types of stones are used in this study, limestone and sandstone, and two types of polymers are used in this paper Elastomers "Styrene Butadiene Styrene (SBS) with or without cross linker" and Plastomers, "Functionalized Polyethylene (PE)". Hot Mix Asphalt (HMA) stability has often been used to indicate the mix resistance to permanent deformation, which is caused mainly by the successive shear failures in the HMA, the stability of the HMA is evaluated in the laboratory using different tests and analysis methods that yield the HMA response to shear forces applied directly or indirectly on a specimen, these tests include the repeated shear test, frequency sweep shear test, and constant height creep shear test (measuring the mix stability during laboratory compaction using different versions of the [2]. Another approach developed by (Bahia et.al, 1998) based on gyratory compactor is used, the pressure distribution Analyzer (PDA) which is developed to Gyratory Load-cell Plate assembly (GLPA) by asphalt research group in Wisconsin University is used to measure and evaluate the resistance of mixture to distortion. In this study PDA is used to compare the stability of fine and coarse blends.

Objective

The specific objectives of this study are the following:

1- Show effect of Elstomer polymer "Styrene Butadiene Styrene (SBS) and Plastomer polymer "Functionalized Polyethylene (PE)" on the cohesion and adhesion of asphalt binder

2- Evaluate and compare the stability of fine blend passing through restricted zone (T.R.Z) and coarse blend passing below restricted zone (B.R.Z.) using pressure distribution analyzer.

3- Find effects of polymers on the stability of H.M.A.

Materials Polymers

Polymer means multiple "mer" unites, which can be linked together to form the polymers Link is formed by breaking the double carbon/carbon bond and allowing it to link with others to form. The physical structure of the polymers chain has a large effect on the mechanical properties of plastics. The number of monomers in each chain defines the degree of polymerization. The source of synthetic polymers many are produced from processing crude oil. They are commonly referred to as plastics. Properties depend on the polymer chain lengths, extent of cross-linking, radial compounds, and the production process.

Daurah asphalt is used as base binder and two types of polymers are used in this study, Elastomers "Styrene Butadiene Styrene (SBS) with or without cross linker" and Plastomers, new type of polymer developed by highway research group in Wisconsin University called "Functionalized Polyethylene (PE)".

Polymer Concentration

Initially, 2% polymer concentrations are selected for each polymer. Based upon results further polymer concentrations are determined, 4% of SBS and 3.5% of PE, for raising performance grade of Daurah asphalt binder two grades, then effect of these concentration on the stability of HMA, and cohesion or adhesion of asphalt binder.

Preparation of Polymer-Asphalt Mixes

To obtain SBS combination the initial mixing rate is about 250 rpm. Typically, the binder climbed the shaft of the mixer, and a spatula is used to prevent it from climbing into the mixer motor. The mixing rate is kept low enough to prevent the binder from climbing past the spatula. As the temperature of the binder rises, the mixing rate could be increased gradually. The mixing rate is increased every 10 minutes until the maximum rate of 1,000 rpm is reached for 4 to 4.5 hours and maintained the temperature of the sample at 180°C, which is necessary to obtain a uniform mixture, therefore, need to put heavy gas to prevent oxidation of binder. The polymers are added into the asphalt gradually for 0.5 hour. The temperature of the mixture is dropped immediately when the polymer are added, therefore, need to raise the temperature to 180°C. Mixing is completed when the modified asphalt no longer climbed the mixer shaft. a small spatula is dipped in the mix and smeared on clean, white paper. If the polymer grains are visible, the mixing process is incomplete. When the grains disappeared, the process is considered complete. Therefore, obtaining modifying asphalt binder with Functionalized Polyethylene (PE) polymer is easier than asphalt modifying with SBS because the temperature of mixing is 145°C for 1.5 hour, and no problem with oxidation.

Adhesion Testing

Adhesion can be measured with the pull-off tensile strength test by using the pneumatic adhesion tensile tester (PATTI). A schematic diagram of this device is shown in Figure 1a [4]. The asphalt is applied to a pull stub, which is then attached to the aggregate surface as shown in Figure 1*b*. The film thickness of asphalt is controlled by putting two pieces of 1⁄4- × 1⁄4- × 21⁄2-in. metal blocks under the pull stub. The space under both the pull stub and the aggregate surface is the film thickness of the asphalt specimen. PATTI transmits the air pressure to the piston, which is placed over the pull stub and screwed onto the reaction plate Figure 1a. The air pressure induces formation of an airtight seal between the piston gasket and the aggregate surface. When the pull stub is debonded from the aggregate surface, the pressure at which the cohesive or the adhesive failure occurs is measured and converted to the pull-off strength (kPa or psi), which can be used as an indicator of the adhesive bond strength of the asphalt binder.

The adhesion test is conducted at the ambient temperature (25°C). Two sources of aggregate, limestone and sandstone, are used to provide comparable asphalt–aggregate adhesion in this test to the adhesion characteristic of the asphalt mixtures, the aggregate surface is prepared from the slice of the asphalt mixture specimen produced from the same aggregate source.

Effect of Modified Binders on Adhesion Testing

The polymers are successfully used for modifying binder properties by changing their microstructure, enhancing the rheological properties, the damage resistance characteristics of asphalt binders and mixtures [1], Adhesion can be measured with the pull-off tensile strength test by using the pneumatic adhesion tensile tester (PATTI). The asphalt is applied to a pull stub, which is then attached to the aggregate surface. The air pressure induces formation of an airtight seal between the piston gasket and the aggregate surface. When the pull stub is separate from the aggregate surface, the pressure at which the cohesive or the adhesive failure occurs is measured and converted to the pull-off strength (psi), which can be used as an indicator of the adhesive bond strength of the asphalt binder. Studies by (Kanitpong and Bahia, 2005) indicated that this test is considered a rapid, low-cost, reproducible method for measuring the adhesion characteristics of asphalt binders to commonly used aggregate surfaces, and the cohesion and adhesion measurements of the asphalt binders are reasonable predictors of mixture performance in the lab, it is believed that the cohesion and adhesion testing of asphalt binder can be used as a tool to select desired asphalt binders to improve the resistance of asphalt mixtures to moisture damage and rutting.

Two types of stones are used in this test, limestone and sandstone, because the mineralogy of these stone is the same of the mineralogy of gravel aggregate that used in Iraq. Figure 2 depict tensile strength between limestone and different modified binders, it can be seen that tensile strength increase from 26% to 55% when use 2% and 4% of SBS respectively while increase from 54% to 76% when use 2% and 3.5% of PE respectively.

Figure 3 shows effects of modified binder on tensile strength for sandstone, it can be noticed that the strength increase 5% and 18% for asphalt binder modified with 2% and 4% of SBS respectively, and increase 29% and 51% for asphalt binder modified with 2% and 3.5% of PE respectively.

Figure 4 shows report displayed in PATTI test for 3.5% PE-sandstone (cohesion failure) while Figure 5 shows adhesion failure of 4% SBS modified binder.

Stability Of Hot Mix Asphalt

The stability of hot mix asphalt (HMA) is evaluated in the laboratory using different tests and analysis methods that yield the HMA response to shear forces applied directly or indirectly on a specimen. These tests include the repeated shear test, frequency sweep shear test, and constant height creep shear test [2]. Another approach developed by (Bahia et.al, 1998) based on measuring the mix stability during laboratory compaction using different versions of the gyratory compactor, the superpave gyratory compactor (SGC) is used to compact specimens for volumetric analysis, while recording density data throughout the compaction procedure, among various requirements for the design of asphalt mixtures. The number of gyrations representing different levels of density is the most important and unique to Superpave, it is specified for N_{ini} and requiring less than 89% G_{mm} representing construction densification, N_{des} at 96% G_{mm} to represent initial trafficking and basis for volumetric, N_{max} requiring less than 98% G_{mm}, representing the service life of the pavement, in accordance with predicted traffic ESALs based on a 20 year service life, Figure 6 show the superpave requirements of %Gmm versus Gyration, since the Superpave gyratory compactor (SGC) is a key component of the current design procedure and its use now widely understood, it would be desirable to utilize the equipment for the purpose of acquiring mechanical properties of the mixture in testing, the design of the SGC does not include a measure of the force, and there are multiple designs that vary in the details and the mechanism of achieving the angle during gyration. A corps of engineering in Wisconsin university developed the gyratory load-cell and plate assembly (GLPA), it is a simple tool that allows the measurement of the eccentricity of the resultant load applied by the gyratory compactor in real time during compaction, a two-dimensional distribution of shear resistance as measured on the top of the specimen, and low cost, independence of the gyratory machine design, and direct measurements on the sample [5]. The plate includes three load cells equally spaced on the perimeter of a double-plate assembly, which can be inserted in the sample of hot mix asphalt (HMA) in a typical gyratory mold, the load cells allow measuring the variation in distribution of force on top of the sample during the gyrations such that the position of the resultant force from the gyratory compactor can be determined in real time. Figure 7 the two-dimensional distribution of the eccentricity of the resultant load can be used to calculate the effective moment required to overcome the shear resistance of mixtures and tilt the mold to conform to the 1.25-degree angle [6], recently the GLPA device was further modified by FHWA to place the data collector within the plate. The new device has also been re-named as the Pressure Distribution Analyzer (PDA) as shown in Figure 8.

Volumetric Mixture -Design And Analysis

To find effects of the fine aggregate on the stability of the local asphalt mixture, two mixes (12.5mm nominal sieve size) are selected as shown in Figure 9, the first one passing below restricted zone (coarse blend), while the second one passing through restricted zone (fine blend).

The objective of the volumetric mixture design method is to select design binder content and blend by analyzing the densification of mixtures compacted in the gyratory compactor at a number of asphalt contents. All compaction in this study is conducted according to the Superpave asphalt mixture design procedure. The optimum asphalt binder content for design mixture is selected by considering mainly three parameters: air void, the percentage of G_{mm} (theoretical maximum specific gravity of mixture), and the percentage of voids filled with asphalt (VFA). Three asphalt contents (4.2%, 4.7%, and 5.2% for coarse blend) and (4.6%, 5.2%, and 5.8% for fine blend) are used to find the optimum asphalt content. Specimens satisfied superpave mixture requirements within this range of asphalt contents: air voids = 4%, $\%G_{mm}@N_{ini} < 89.0$, $\%G_{mm}@N_{max} \leq 98.0$, VFA = 65 to 75. The optimum value of the asphalt binder content for coarse and fine blends are founded 4.6 %, 4.8 % respectively as shown in Table 1.

Construction Densification Index (Cdi)

The Construction Densification Index (CDI) is defined as the area from the 8th gyration to 92% of G_{mm} in the densification curve as shown in Figure 10, it is theorized that CDI represents the work applied by the roller to compact the mixture to the required density during construction. The number of eight gyrations is selected to simulate the effort applied by a typical paver during the process of laying down the mixture, while the 92% of G_{mm} is the density at the completion of construction and the pavement is open to traffic, mixtures with lower values of CDI have better constructability and are desired; while too low value of CDI is an indication of a tender mixture and should be avoided.

Traffic Desification Index (TDI)

The Traffic Densification Index (TDI) is defined as the area from 92%, through 96% to 98% of G_{mm} in the densification curve as shown in Figure 10. After a pavement is opened to traffic at 92% of G_{mm}, it of the pavement. The 98% of G_{mm} is considered the critical density, at which the mixture is approaching the plastic failure zone. In the study, the effect of traffic at the design density, *or the amount of effort required* to densify the mixture between 92% and 96% of G_{mm} is not

Although the concept of using CDI and TDI appeared to be logical and useful, there were still some doubts about using the volumetric measurements without measuring force or stress in sample to evaluate mixture behavior, these concerns lead to the development of a PDA device that could be inserted on top of the mixture sample and could generate information about the stress distribution during compaction. Table 2 shows the values of CDI and TDI for the fine (T.R.Z) and coarse (B.R.Z) mixes using Daurah asphalt binder, it can be seen that the value of CDI for B.R.Z mix is too low (tender mix during compaction) and the value of TDI for fine mix increase by 40% more than the value of TDI for coarse mix.

Resistive Effort

The resistive effort is a measure of the resistance of the mixture to compaction; usually calculate from the data acquired by PDA, in interpreting the data from SGC testing with PDA, a concept of resistive effort, denoted by (w), is the work done by SGC per unit volume per gyration, as defined in the following equation(Faheem , 2005):

continues to densify under traffic loads. The current mixture design procedure requires that the mixture be compacted to 96% of G_{mm} (4% air voids) at optimum asphalt content using N_{des} gyrations which the mixture is expected to reach under traffic during the early life emphasized. Instead, TDI is the amount of the total effort required to compact the mixture to a terminal density of 98% of G_{mm}. Mixtures with higher TDI values in this range are more desirable because it takes more traffic during their life span.

$$w = \frac{4eP\theta}{Ah} \quad \text{……(1)}$$

Where

W the resistive effort

e the eccentricity of resultant force

P the magnitude of resultant force

θ the angle of tilting (1.25°)

A the area of specimen

h the height of specimen at any given gyration.

The resistive effort curve is divided at 92% G_{mm} into a construction side and a traffic side. Under 92% G_{mm} it is desirable for the mixture to have a low resistive effort. This will enable the ease of compaction by the contractor. At above 92% G_{mm}, it is desirable for the resistive effort of the mixture to be high. The high level of resistive effort is an indicator of the high resistance of mixture to distortion under traffic, which will reduce rutting. To quantify the resistive efforts above and below 92% G_{mm}, the area under the resistive effort curve between N_{ini} and 92% G_{mm} is calculated and termed the compaction force index CFI, and the area between 92% and 98% G_{mm} is calculated and termed the traffic force index TFI. In this way, the CDI and TDI relate to the densification curve, and the CFI and TFI relate to the resistive effort curve. Figure 11 and 12 shows the resistive effort results for fine and coarse blends. Table 2 shows the CDI and TDI for coarse and fine blends, the values of CFI and TFI for fine and coarse mixes are presented in Table 3. It can be seen that the value of TFI for fine mix increase 80% more than the value of TFI for coarse mix because the percentage of the asphalt content for fine mix will increase and gives more contact area which leads to increase the value of shear resistance.

Effect Of Modified Binder On Construction Force Index (Cfi)

Construction force index (CFI) is related to the amount of work done to rise the density of the mix to 92%, and it is calculated after divided resistive effort curve at 92% G_{mm}, into a construction side and traffic side, under 92% G_{mm}, it is desirable for the mix to have low resistive effort as it will enable ease of compaction by the contractor, while above 92% G_{mm} it is desirable for the resistive effort of the mix to be high indicator of high resistance of mixture to distortion under traffic, which will reduce rutting. Figure 13 depicts the effect of different types of modifier of Daurah asphalt binder on CFI for 47 gyrations, it can be seen that CFI value is reduced about 68% as using 3.5% of Functionalized Polyethylene and reduced 42% as 4% of SBS modifier added to Daurah asphalt binder.

Conclusions

- The tensile strength between limestone and modified asphalt binders increase 26% to 55% as using 2% and 4% of SBS respectively while increase 54% to 76% when use 2% and 3.5% of PE respectively
- For sandstone the tensile strength increases about 5% and 18% for asphalt binder modified with 2% and 4% of SBS respectively, and increases 29% and 51% for asphalt binder modified with 2% and 3.5% of PE respectively.
- By analyzing densification curve, it can be seen that the value of TDI for fine mix higher 40% than the value of TDI for coarse mix, which gives more traffic during their life span, and the value of CDI for coarse mix is too low which meaning tender mix during compaction- The results obtained by PDA indicated that the value of TFI for fine mix increase by 80% than TFI value for coarse mix which give high level of resistive effort and high shear resistance of mixture to distortion under traffic- CFI is reduced by about 68% as using 3.5% of Functionalized Polyethylene and reduced 42% as 4% of SBS modifier added to Daurah asphalt binder, that gives good indication for contractors to use Functionalized Polyethylene modifier because the cost and time for compaction will reduce.

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Table 1 Shows %G_{mm} at Different Asphalt Content for Fine Blend.

No. of Gyrations	%Gmm at			% optimum Asphalt
	4.6	**5.2**	**5.8**	**4.8**
8	86.9	88.2	88.7	**87.3**
100	95.5	97.1	97.8	**96.0**
160	96.9	98.4	98.8	**97.4**

Table 2 values of CDI and TDI for Fine and Coarse mixes

Types of Mix	CDI	TDI
T.R.Z	**77**	**395**
B.R.Z	**5**	**283**

Table 3 values of CFI and TFI for Fine and Coarse mixes

Types of Mix	CFI	TFI
T.R.Z	267	1799
B.R.Z	98	999

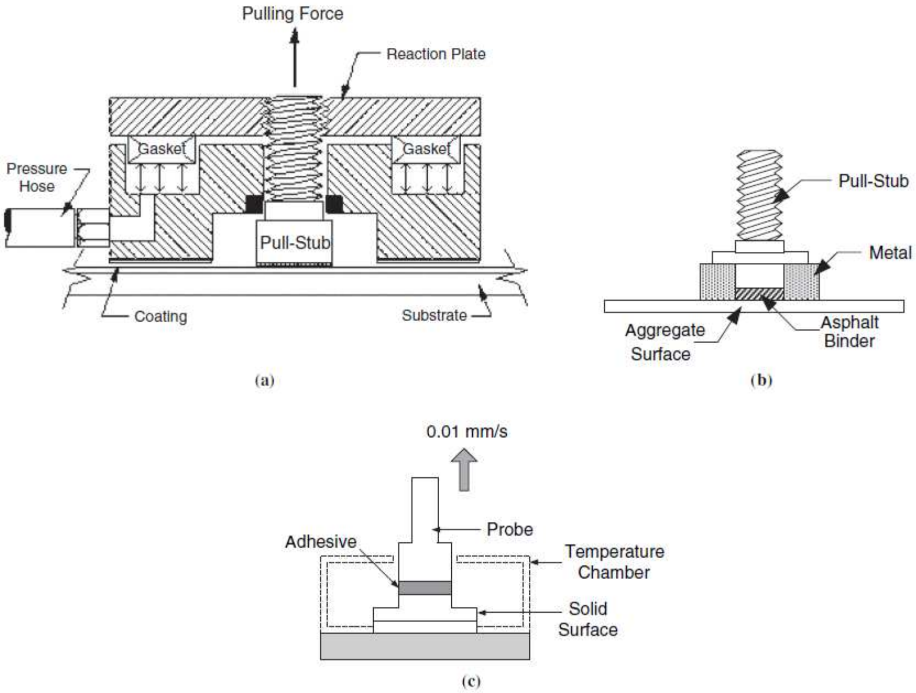


Figure 1 Schematic Diagram of the Device for Adhesion and Cohesion Testing of Asphalt Binders. (After Kanitpong and Bahia, 2005).

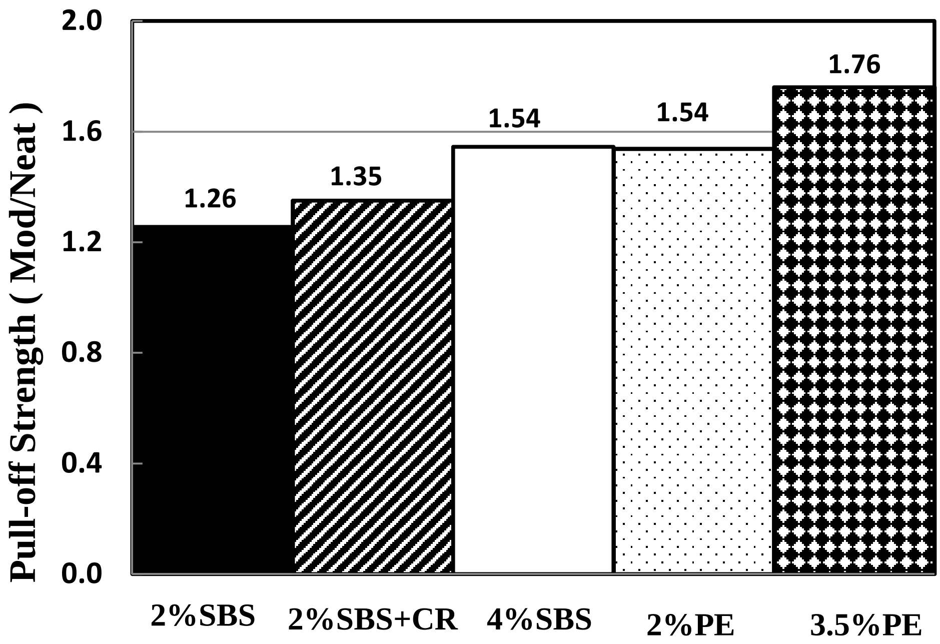


Figure 2 Effects of Modified Binder on Tensile Strength for Limestone

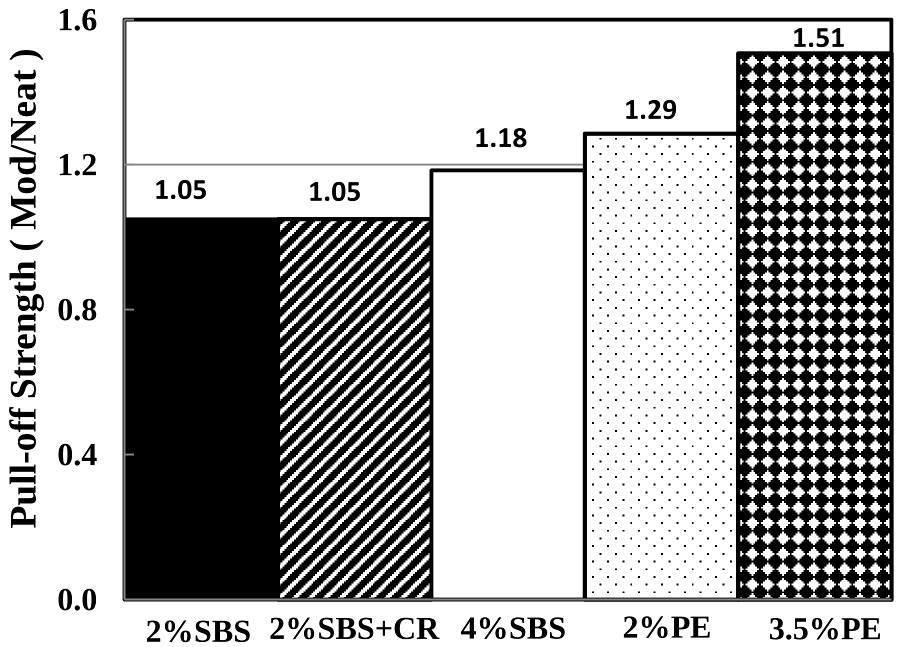


Figure 3 Effects of Modified Binder on Tensile Strength for Sandstone

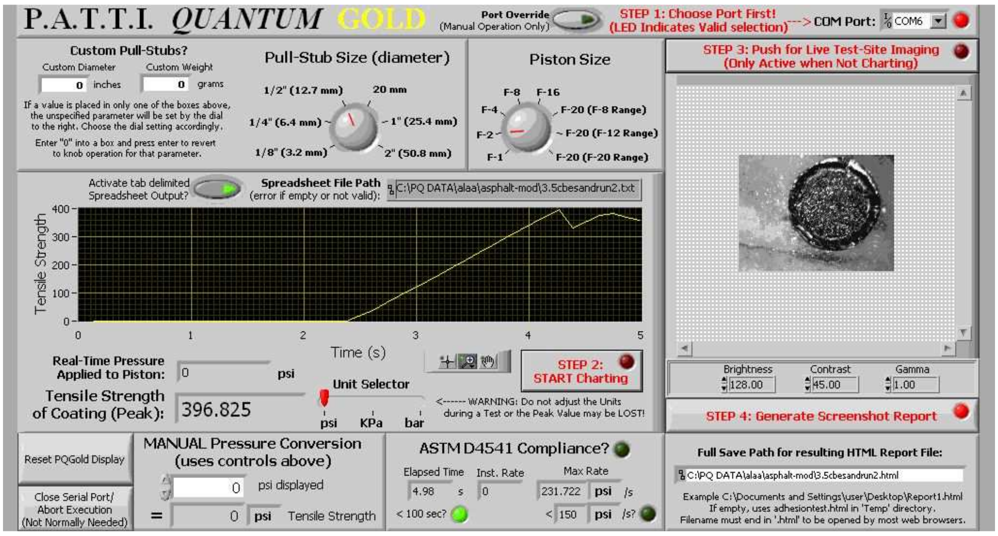


Figure 4 Report Displayed in PATTI Test for 3.5% PE-Sandstone

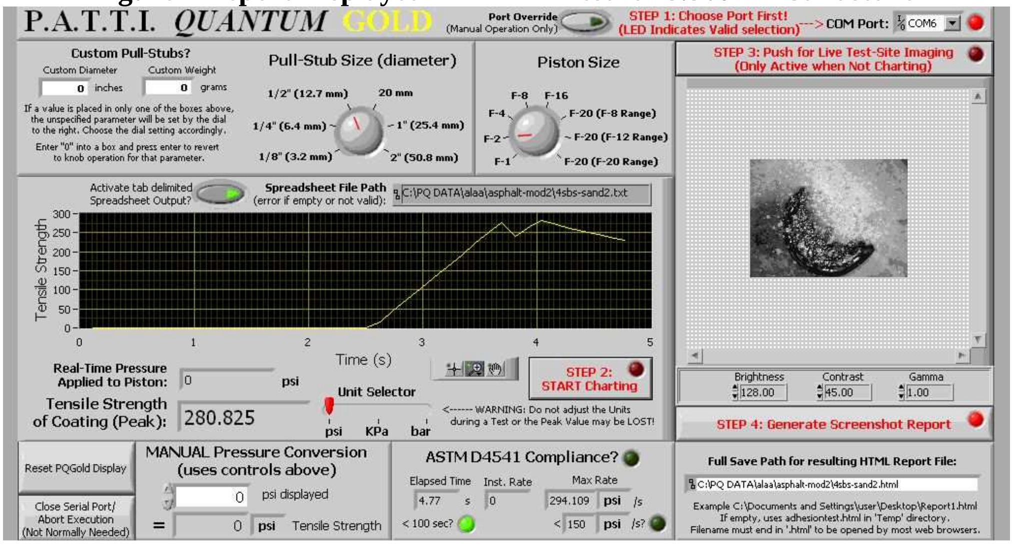


Figure 5 Report Displayed in PATTI Test for 4%SBS-Sandstone

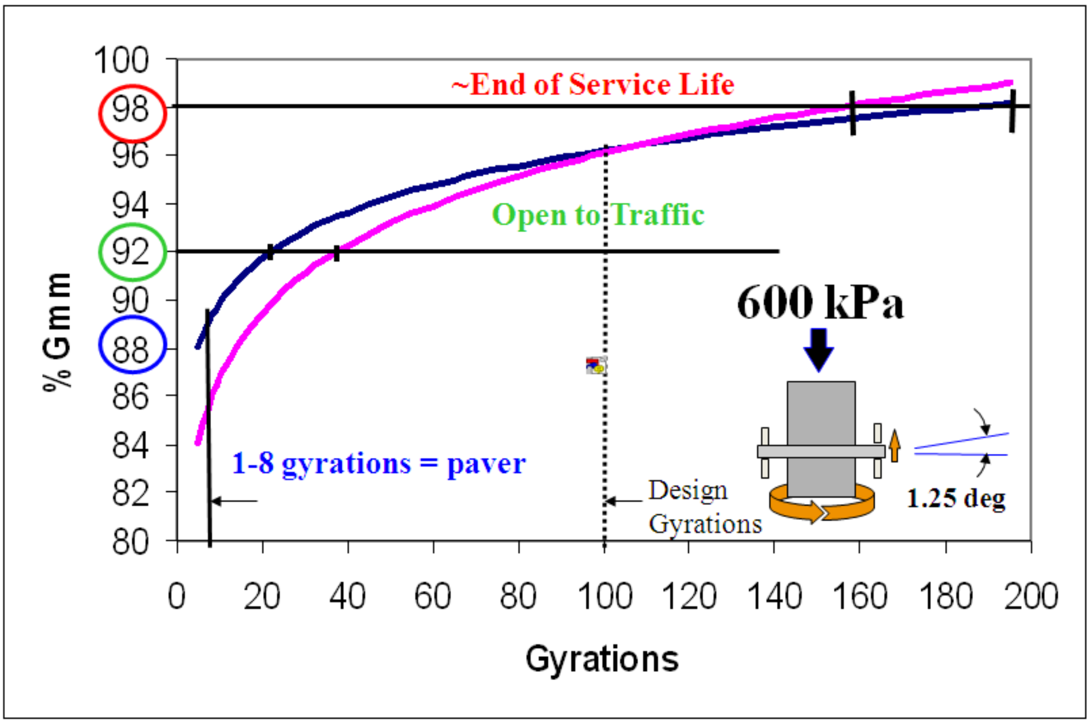


Figure 6 Superpave Requirements for %Gmm versus Gyration after (Faheem, 2005)

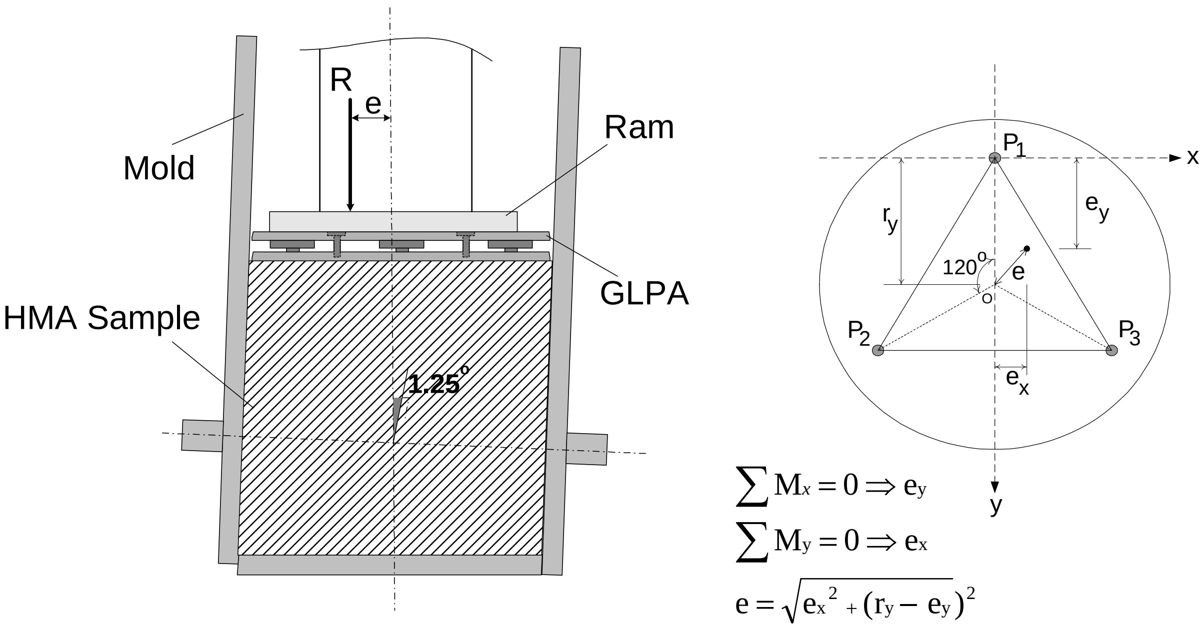


Figure 7 Measurement of the Eccentricity of the Resultant Load applied by the Gyratory Compactor (Gular, 2000)

Figure 8 The Pressure Distribution Analyzer (PDA) Shear Plate Used in the SGC Compaction Mold

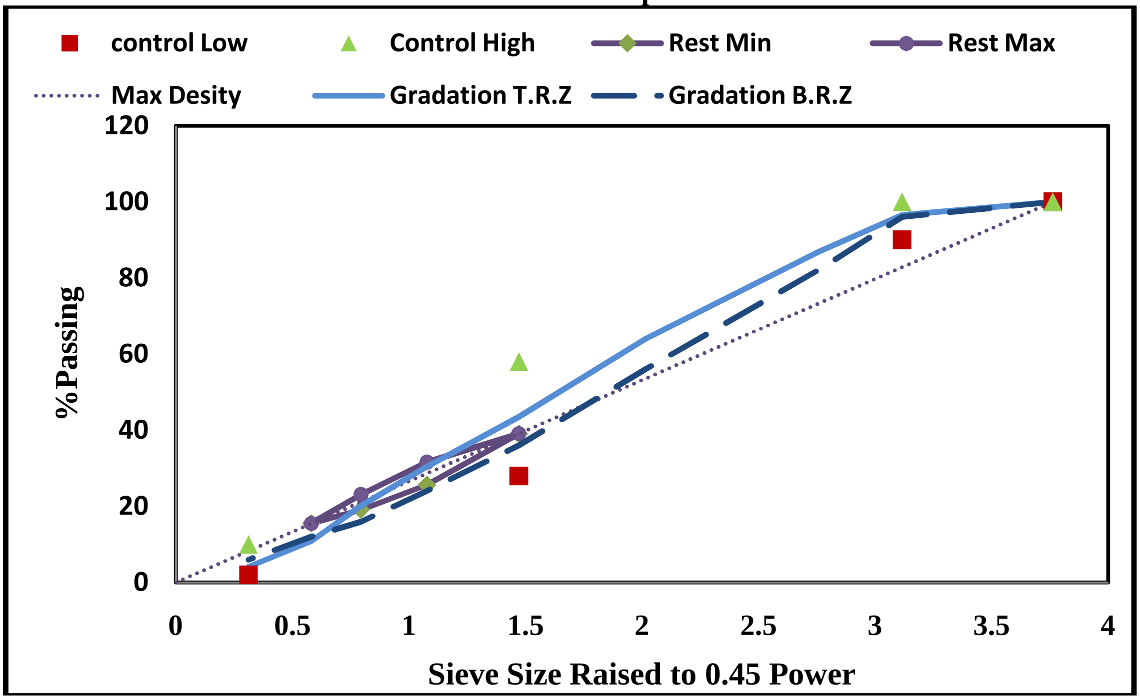


Figure 9 Coarse and Fine Blends (12.5mm nominal sieve size).

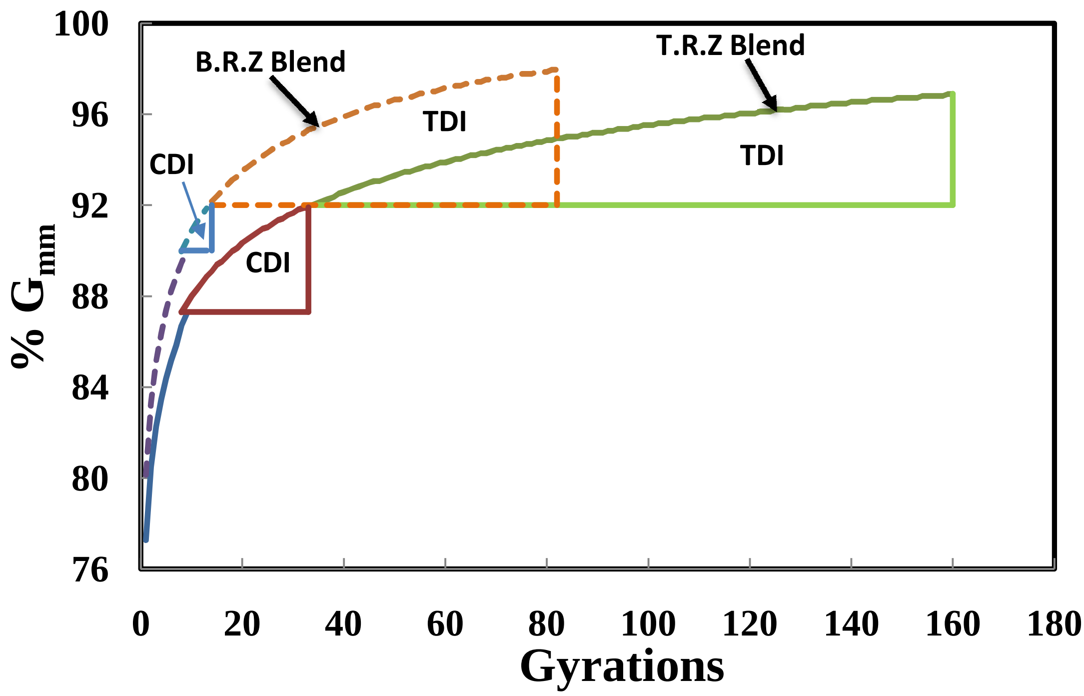


Figure 10 Shows CDI and TDI for Coarse and Fine Blends.

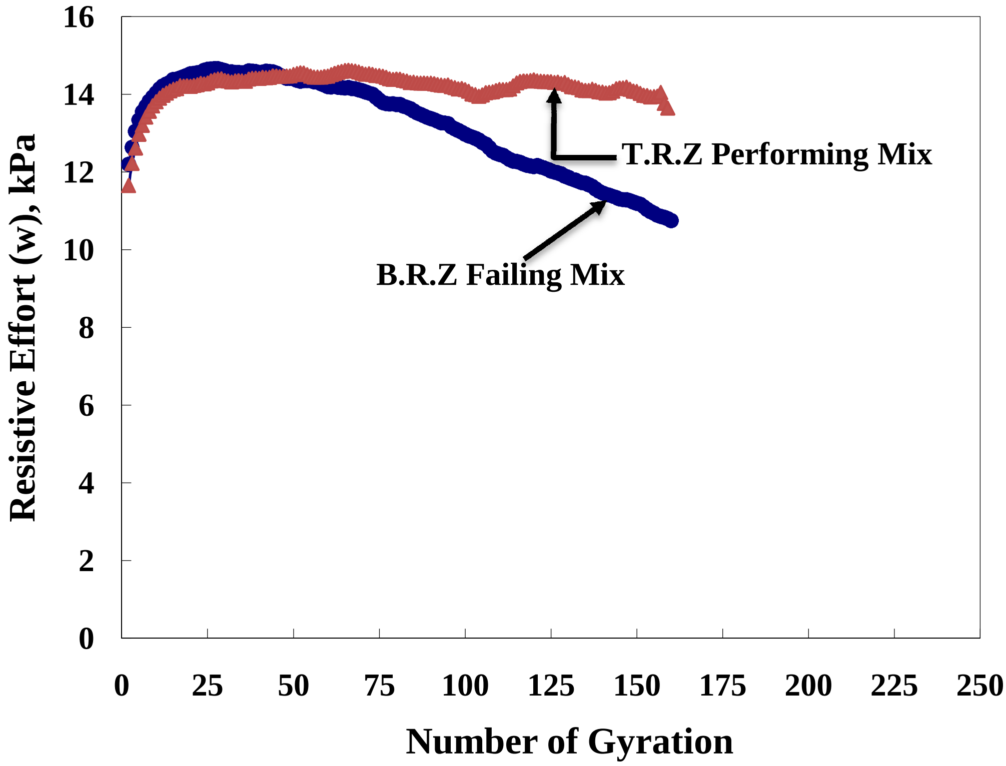
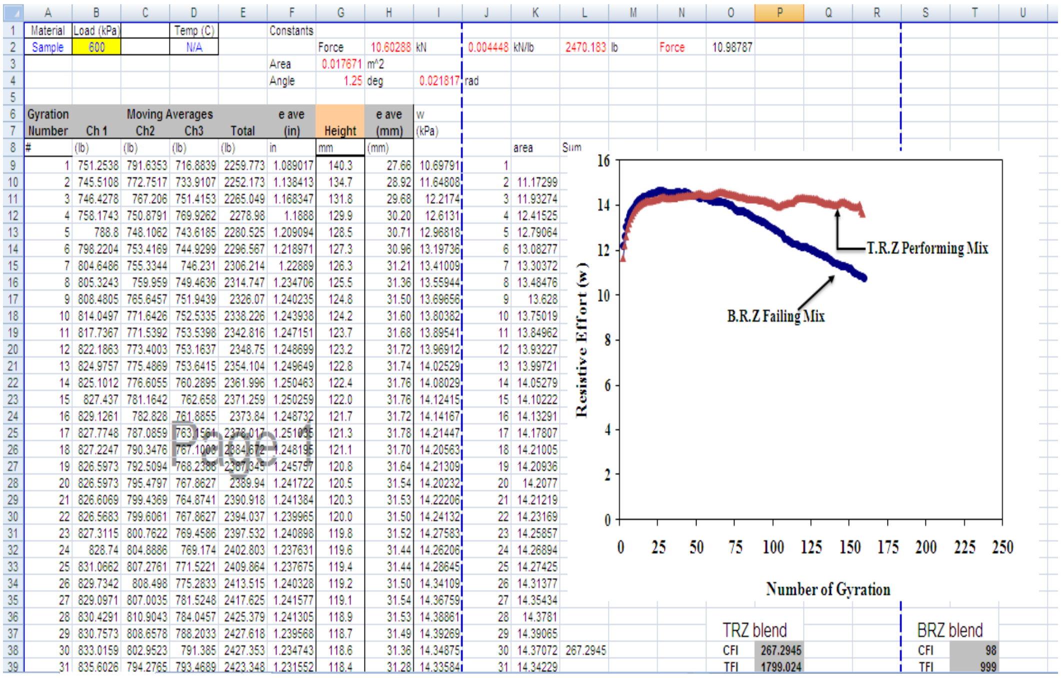


Figure 11 Shows CDI and TDI for Coarse and Fine Blend.



Material	Load (kPa)	Temp (C)	Constants						
Sample	600	N/A	Force	10.60288	kN	0.004448	kN/lb	2470.183	lb
			Area	0.017671	m^2				
			Angle	1.25	deg	0.021817	rad		

Gyration Number #	Moving Averages Ch 1 (lb)	Ch2 (lb)	Ch3 (lb)	Total (lb)	e ave (in) in	Height mm	e ave (mm) (mm)	w (kPa)		area	Sum
1	751.2538	791.6353	716.8839	2259.773	1.089017	140.3	27.66	10.69791	1		
2	745.5108	772.7517	733.9107	2252.173	1.138413	134.7	28.92	11.64808	2	11.17299	
3	746.4278	767.206	751.4153	2265.049	1.168347	131.8	29.68	12.2174	3	11.93274	
4	758.1743	750.8791	769.9262	2278.98	1.1888	129.9	30.20	12.6131	4	12.41525	
5	788.8	748.1062	743.6185	2280.525	1.209094	128.5	30.71	12.96818	5	12.79064	
6	798.2204	753.4169	744.9299	2296.567	1.218971	127.3	30.96	13.19736	6	13.08277	
7	804.6486	755.3344	746.231	2306.214	1.22889	126.3	31.21	13.41009	7	13.30372	
8	805.3243	759.959	749.4636	2314.747	1.234706	125.5	31.36	13.55944	8	13.48476	
9	808.4805	765.6457	751.9439	2326.07	1.240235	124.8	31.50	13.69656	9	13.628	
10	814.0497	771.6426	752.5335	2338.226	1.243938	124.2	31.60	13.80382	10	13.75019	
11	817.7367	771.5392	753.5398	2342.816	1.247151	123.7	31.68	13.89541	11	13.84962	
12	822.1863	773.4003	753.1637	2348.75	1.248699	123.2	31.72	13.96912	12	13.93227	
13	824.9757	775.4869	753.6415	2354.104	1.249649	122.8	31.74	14.02529	13	13.99721	
14	825.1012	776.6055	760.2895	2361.996	1.250463	122.4	31.76	14.08029	14	14.05279	
15	827.437	781.1642	762.658	2371.259	1.250259	122.0	31.76	14.12415	15	14.10222	
16	829.1261	782.828	761.8855	2373.84	1.248732	121.7	31.72	14.14167	16	14.13291	
17	827.7748	787.0859	763.1561	2378.017	1.251035	121.3	31.78	14.21447	17	14.17807	
18	827.2247	790.3476	767.1008	2384.672	1.248195	121.1	31.70	14.20563	18	14.21005	
19	826.5973	792.5094	768.2388	2387.345	1.245757	120.8	31.64	14.21309	19	14.20936	
20	826.5973	795.4797	767.8627	2389.94	1.241722	120.5	31.54	14.20232	20	14.2077	
21	826.6069	799.4369	764.8741	2390.918	1.241384	120.3	31.53	14.22206	21	14.21219	
22	826.5683	799.6061	767.8627	2394.037	1.239965	120.0	31.50	14.24132	22	14.23169	
23	827.3115	800.7622	769.4586	2397.532	1.240898	119.8	31.52	14.27583	23	14.25857	
24	828.74	804.8886	769.174	2402.803	1.237631	119.6	31.44	14.26206	24	14.26894	
25	831.0662	807.2761	771.5221	2409.864	1.237675	119.4	31.44	14.28645	25	14.27425	
26	829.7342	808.498	775.2833	2413.515	1.240328	119.2	31.50	14.34109	26	14.31377	
27	829.0971	807.0035	781.5248	2417.625	1.241577	119.1	31.54	14.36759	27	14.35434	
28	830.4291	810.9043	784.0457	2425.379	1.241305	118.9	31.53	14.38861	28	14.3781	
29	830.7573	808.6578	788.2033	2427.618	1.239568	118.7	31.49	14.39269	29	14.39065	
30	833.0159	802.9523	791.385	2427.353	1.234743	118.6	31.36	14.34875	30	14.37072	267.2945
31	835.6026	794.2765	793.4689	2423.348	1.231552	118.4	31.28	14.33584	31	14.34229	

TRZ blend		BRZ blend	
CFI	267.2945	CFI	98
TFI	1799.024	TFI	999

Figure 12 Results Obtained and Calculated using PDA and Excel Software

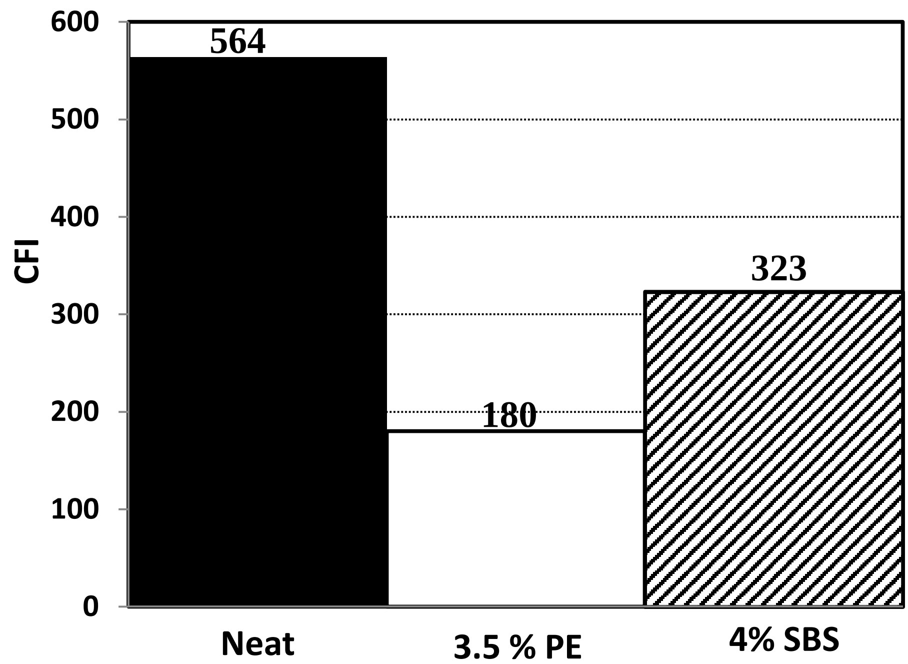


Figure 13 Effects of Modified Daurah Asphalt Binder on CFI