Australian Journal of Basic and Applied Sciences, 7(1): 105-116, 2013
ISSN 1991-8178

Effect of 20 Micron Filler Particle Size and Filler Type on Rheological and Performance Properties of Stone Mastic Asphalt-filler Mastics

[1]Ratnasamy Muniandy, [2]Eltaher Aburkaba

[1]Professor, [2]Department of Civil Engineering, Faculty of Engineering University Putra Malaysia (UPM) 43400 UPM, Serdang, Selangor Darul Ehsan, Malaysia.

Abstract: This paper evaluates the relative performance of a series of 20 micron filler particle size and filler type asphalt-filler mastics in terms of the two main distress modes associated with flexible asphalt pavements of permanent deformation and fatigue damage. The study makes use of the fundamental rheological binder testing using a dynamic shear rheometer (DSR), pavement performance prediction by means of the Superpave binder parameters, dynamic creep, temperature steps, and time sweep tests. The fundamental rheological data at given filler/asphalt ratio together with the permanent deformation and fatigue testing in the DSR all indicate an improved rutting and fatigue performance for the coarse (greater than 75 micron) asphalt-filler mastics compared to the fine (less than 20 micron) asphalt-filler mastics regardless filler type. In terms of filler type, ceramic waste filler found to be more effective on producing mastics that are more elastic and less susceptible to rutting and cracking than the control mastic.

Key words: 20 micron filler particle size; mastic rheological properties; Superpave binder parameters; mastics performance.

INTRODUCTION

The filler material passing the number 200 standard mesh sieve, usually comprise a major amount of the total aggregate in SMA pavement. This large portion of the mineral filler with asphalt binder contributes to the interlocking of the coarse aggregate and mineral fillers which are of the same mineralogical composition as coarse aggregates but have variations in surface roughness and angularity; usually show different capacities to adsorb a given type of asphalt component (Bardesi *et al*, 1999). The characteristics of mineral fillers such as particle size, gradation, shape of the particles can have a detrimental impact on asphalt mixtures because of their impact on mixture stiffness, air voids content, moisture sensitivity, and thus can have a significant effect on mixture performance (Dongre *et al*, 2002). The filler particles finer than 20 micron (μm) are a major factor governing the behavior of fillers as they possess the highest surface area and the presence of super fine filler (extremely fine particles) in the mix could be the main possible contributor to premature failure (cracking, stripping and brittleness) of hot mix asphalt. Also, the production of excess fines during the aggregate production process has made it necessary to re-evaluate the effect of such material on hot mix asphalt (Anderson *et al*, 2001).

(Kavussi and Hicks, 1997) in a study of four types of filler - limestone, quartz, fly ash and kaolin - attributed the higher stiffening potential of kaolin to the fineness and the surface affinity to bitumen. Also they indicated that as different filler possess different properties, they can alter the physical or chemical properties of the binder in different ways. (Anderson and Tarris, 1983) studied the effect of physico-chemical properties of the filler on performance. They also concluded that the mineral filler stiffens asphalt and that stiffening varies significantly between different fillers. (Anderson, 1987a) illustrated that the size of the fine affected rheological behavior but the source of the asphalt and the mineralogy of the fine also had a significant effect on rheological behavior. In another study, (Anderson *et al*, 1982) reported that fineness alone is not sufficient for defining how a fine will behave in an asphalt mixture. They concluded that different fillers and fines reacted differently with different asphalts. (Ward, 1979) study baghouse fillers from 16 different sources with a wide variety of particle size distribution, mineralogy and other physical properties, he indicated that fine dust, primarily 20 micron (μm) and finer, tended to combine with the bituminous binder and act as an asphalt extender. (Anderson and Geotz, 1973) examined the stiffening effect of a series of one-sized fillers ranging from 0.6 to 75 mm (passing No. 200 sieves). They concluded that both the size of the filler and bitumen binder composition had a significant influence on stiffening effect and that a proportion of the bitumen could be replaced by fine filler (<10 μm) but the mixtures produced were very sensitive to changes in the filler type.

Objectives and Scope:

Since Stone Mastic Asphalt (SMA) contains large amount of filler (8 -12 %) by total weight of aggregate, Still; the performance properties of asphalt-filler mastics in SMA pavement are considered to be unclear due to

Corresponding Author: Eltaher Aburkaba, Department of Civil Engineering, Faculty of Engineering University Putra Malaysia (UPM) 43400 UPM, Serdang, Selangor Darul Ehsan, Malaysia.
E-mail address: aztaher1955@yahoo.com

the various interaction effects of filler with asphalt binders, depending on the filler percentage, type and particle size and also, the traditionally employed approach of adding the amount of filler passing the 75 micron sieve without knowing the particle sizes (the gradation below the 75 micron) in the asphalt pavement design may not be the best scenario to maximize pavement performance when pavement distresses such as fatigue cracking, rutting, and moisture damage are considered all together. Appropriate use of filler size with local asphalt paving materials needs to be determined scientifically, not arbitrarily, therefore, the objectives of this study is to determine the influence and effects of fine particle size (finer than 20μm) and filler type on the asphalt-filler mastic rheological, viscoelastic and performance properties through selected Superpave binder tests. The data obtained from this study led to the evaluation of the influence and the effects of the filler fine particle size and filler type on rutting and fatigue cracking resistance at high and intermediate temperature respectively using the Dynamic Shear Rheometer (DSR) in accordance with AASHTO TP5-93 to perform dynamic (repeated) creep, temperature steps, and time sweep tests.

MATERIALS AND METHODS

Materials:

Since the performance of the fillers were of concern in this study, the commonly used 80/100 penetration grade soft binder was selected. This is to make sure there are no additional properties derived from additives if modified binders such as 60/70 and PG 76 were used. Four types of filler namely; Limestone (LS), Ceramic Waste (CW), Coal Fly Ash (CFA), and Steel Slag (SS) with two different particle sizes (passing 75 and 20 μm sieve) were used and evaluated for direct comparison. Fillers were crushed and ground to pass the standard sieve size 75 and 20 micron. The L0, C0, F0, and S0 represent the finest particle size (passing 20 micron sieve and retained on pan). L10, C10, F10, and S10 represent the coarsest (passing 75 micron and retained on 20 micron sieve). An important property of these filler combinations is that they possess different surface areas (the smaller the particle size the larger the surface area). This is important since the larger the surface area of particles the larger the amount of asphalt needed to coat such particles.

Preparation of Asphalt-Filler Mastics:

During the development of the Superpave mix design system, researchers in the Strategic Highway Research Program (SHRP) simplified the criteria that govern the interaction between mineral filler and asphalt binder into a single parameter; the Dust/Asphalt ratio. First, asphalt binder and batches of fillers passing the 75/20 μm sieve were prepared and heated 20°C higher than the mixing temperature in order to facilitate mixing. The appropriate amount of asphalt was then added to produce a filler to asphalt (F/A) ratios by percentage by weight that was used in the mixtures (Table 1). The eight mastics were prepared by blending the filler with the original asphalt on a hot plate to provide uniform heating. A mechanical mixer module IKA Labortechnik, RW 20 DZM.n was used to blend the filler and asphalt binder at established mixing temperatures of 160°C. The appropriate mixing temperatures were determined in accordance with AASHTO T316 using the rotational viscometer. The mixing process was carefully performed to break down chunks of filler to ensure homogenous dispersion. An "X" shaped propeller was used to stir the filler-asphalt mastic, at speed of approximately 500 rpm for at least 30 minutes. The mixing temperature was kept constant to produce homogeneous mixtures during the mixing process. The mastic was continuously stirred as it cooled to prevent settling. At the end of the mixing operation, the mastic was used to prepare specimens for the RTFO, PAV and DSR tests.

A total of eight asphalt-filler mastic specimens were produced at different F/A ratio and aged through an accelerated aging process. The mastics were first aged by using the Rolling Thin Film Oven Test (RTFO) in accordance with AASHTO T 240 to simulate the short-term aging conditions. The Pressure Aging Vessel (PAV) was then used in accordance with AASHTO R 28 to simulate the changes in physical and chemical properties that occur in asphalt binder and mastics as a result of long term, in-service oxidative aging in the field. This method involved oxidation of asphalt binder and mastics in the RTFO followed by the oxidation of the residue in the PAV. The measured rheological properties consisted of complex shear modulus (G*) and phase angle (δ).

Table 1: Filler/Asphalt ratio for the eight mastics.

Filler/Mastic	Limestone		Ceramic waste		Coal fly ash		Steel slag	
type	L10	L0	C10	C0	F10	F0	S10	S0
F/A ratio	1.62	1.58	1.63	1.60	1.67	1.62	1.64	1.54

Experimental Program:

Rheological and Superpave Asphalt Binder and Mastics Tests:

The rheological characterization of asphalt binder has traditionally been based on measurements of viscosity, penetration, ductility and softening point temperature. These measurements are generally not sufficient to thoroughly describe the rheological and failure properties of asphalt binder needed to relate binder properties to mixture properties and to pavement performance. In order to accurately relate binder properties to pavement performance it is necessary to undertake more fundamental testing of binder/or mastic. At present the most commonly used method of detailed rheological testing of binders is by means of dynamic mechanical methods using oscillatory-type testing, generally conducted within the region of Linear Viscoelastic (LVE) response. These oscillatory tests are undertaken using Dynamic Shear Rheometers (DSR), which apply oscillating shear stresses and strains to samples of bitumen sandwiched between parallel plates at different loading frequencies and temperatures (Airey and Brown, 1998; Goodrich, 1988).

The Superpave binder specifications require the asphalt binder to be tested in three critical stages: (a) the first stage is represented by an original asphalt binder which has to be transported, stored, and handled prior to mixing with the aggregate, (b) the second stage is represented by the aged asphalt binder after hot mix asphalt production and construction (short-term aging), and (c) the third stage is represented by an asphalt binder which undergoes further aging during a long period of service. The DSR tests reported in this study were performed under the following test conditions:

(a) ***Superpave SHRP Asphalt Binder Parameters (AASHTO TP5);***

- Mode of loading: controlled stress
- Temperatures: 64, 58, and 52°C for un-aged and RTFO-aged binder, and 25, 22, and 19°C for PAV-aged (Performance grading of binder): to determine Complex Modulus (G*), Phase angle (δ), Rutting parameter (G*/sinδ), and Fatigue parameters (G*. sinδ).
- Frequency : 1.59Hz (10rad/sec) for un-aged, RTFO-aged, and PAV-aged
- Parallel plate geometries: 8mm diameter with 2mm gap for PAV-aged at intermediate temperatures, 25mm diameter with 1mm gap for un-aged and RTFO-aged at high temperatures, and
- Stress amplitude: within LVE response of τ =0.12, 0.22, and 50 kPa for un-aged, RTFO-aged, and PAV-aged respectively.

(B) Dynamic Rheological Analysis of Asphalt-Filler Mastic:

Rutting Parameter (G*/Sinδ):

The Strategic Highway Research Program (SHRP) researchers considered rutting as a stress controlled, cyclic loading phenomenon in determining the rutting parameter chosen for specification purposes. The specifications suggest that the complex modulus tests be performed on un-aged or on short term oven aged (RTFO-aged) binder and mastics at the temperature depending on the PG grade. A value of G*/sinδ less than 1kPa/or 2.2 kPa respectively indicates that the material is prone to permanent deformation (rutting).

- Mode of loading: Controlled Stress
- Temperatures: at high temperatures, 52°C
- Frequency : 1.59Hz (10rad/sec) on un-aged specimens
- Parallel plate geometries: 25mm diameter with 1mm gap
- Stress amplitude: within LVE response; shear stress, τ = 0.12 kPa for un-aged

Rutting Performance:

Binders subjected to repeated (dynamic) creep testing most accurately simulate the loading of pavements due to traffic and therefore can provide useful information and make up for the short comings that are found while using G*/sinδ as a rut indicator. Creep tests give important and practical information in regards to the viscoelastic and mechanical properties of asphalt binders (Herh *et al*, 1997). It is expected that flexible pavements should return to their original state after removal of applied load to avoid permanent deformation. The repeated creep test is typically performed by applying load for 1 second and waiting for 9 seconds before application of load again. Therefore, a loading cycle is completed in 10 seconds. The test procedure suggests that the tests be performed for 100 cycles (Bahia, 2001). The unrecoverable deformation at the end of each cycle is accumulated to identify permanent deformation at the end of one hundred cycles. A constant sheer stress is applied instantaneously (The loads can be varied to a range of magnitudes to identify the influence of load levels on the accumulated strain). The resultant deformation is measured as a function of time. The repeated creep tests are performed to identify compliance of the asphalt binder and accumulation of permanent strain due to load repetition. The dynamic creep tests are performed under the following conditions:

- Mode of loading: Controlled Stress, shear stress, τ = 2.2 kPa
- Temperatures: 52°C
- Frequency: 0.1 Hz on RTFO-aged (1 Hz for 10 second)
- Number of cycles: 100 (1second loading and 9 second unloading)

Effect of Temperature on Asphalt-Filler Mastics:

The temperature steps test was performed using DSR at high temperatures 46 - 82°C, the rutting parameters (G*/sinδ) and failure temperature on un-aged binder and mastics were determined using the following parameters;

- Temperatures: 46-82°C (Seven values)
- Frequency used: 1.59Hz (10rad/sec)
- Parallel plate geometries: 25mm diameter with 1mm gap for un-aged at high temperatures, and
- Stress amplitude: within LVE response; shear stress, τ = 0.12 kPa

Fatigue Parameter (G*.Sinδ):

To evaluate fatigue resistance of binder using G*.sinδ value as specified by SHRP. The specifications suggest that the complex modulus tests be performed on the long term oven aged (PAV-aged) binder and mastics at the temperature depending on the PG grade. A value of G*.sinδ greater than 5,000 kPa indicates that the material is prone to cracking. To determine the parameter for resistance to fatigue cracking for specification purposes, fatigue cracking was considered a strain controlled phenomenon.

- Mode of loading: Controlled Strain
- Temperatures: at intermediate temperatures, 20°C
- Frequency: 1.59Hz (10rad/sec) on PAV-aged
- Parallel plate geometries: 8 mm diameter with 2 mm gap
- Strain amplitude: within LVE response; strain level, **γ** = 1%

Fatigue Performance:

The fatigue parameter (*G**.sinδ) is measured in the linear viscoelastic range using small strains, this approach is unlikely to be useful in representing the effect of repeated cyclic loading and the changes in binder and mastic properties with accumulation of damage. The effort to develop a new test focused on simulating the fatigue phenomenon in a binder-only fatigue test such that damage behavior could be directly monitored (Bahia, 1999). The DSR was used to conduct what is called a time-sweep test. The test provides a simple method of applying repeated cycling of stress or strain loading at selected temperatures and loading frequency. The time sweep tests are performed under the following conditions:

- Mode of loading: Controlled Strain
- Temperatures: at intermediate temperatures, 20°C
- Frequency: 10 Hz on RTFO-aged
- Parallel plate geometries: 8 mm diameter with 2mm gap
- Strain amplitude: within LVE response; strain level, γ = 1%

The rheological properties of the binders and mastics were measured in terms of their complex shear modulus (stiffness), G*, phase angle δ (viscoelastic balance of rheological behavior) and the amount of work (energy) dissipated during each loading cycle (the less the energy dissipated the better resistance to fatigue and rutting). The work dissipated per loading cycle at a constant stress and constant strain can be expressed as follow:

$$W_c = \pi.\sigma_o\left(\frac{1}{G^*/\sin\delta}\right) \tag{1}$$

$$W_c = \pi.\varepsilon_0^2\left(G^*.\sin\delta\right) \tag{2}$$

Where:
W_c = work dissipated per load cycle,
$\sigma_\circ$, $\varepsilon_\circ$ = stress and strain applied during the load cycle
G* ,δ = complex modulus and phase angle

The lower the amount of energy dissipated per cycle, the lower the likelihood of fatigue cracking or any other damage phenomena to occur. The DSR rheological data for the eight mastics were then presented in the form of graphs of accumulated strain versus time and complex modulus versus number of cycles to failure.

RESULTS AND DISCUSSION

Superpave Asphalt Binder Performance Parameters:

The asphalt binder was graded in accordance with AASHTO M320/MP1 to verify the performance grade. Table 2 summarizes the results and properties of the base asphalt binder used in this study. From Table 2 it can be observed that the percentage of mass loss of RTFO residue, Rut-parameter (G*/sinδ) for un-aged, RTFO-aged and Fatigue parameter (G*.sinδ) requirements of the AASHTO MP1 of 1% maximum, 1 kPa minimum, 2.20 kPa, and 5000 kPa maximum respectively was fulfilled and the binder graded as PG52 - 22.

Table 2: Asphalt binder physical and rheological properties results.

Test	Measured Value	Standard used	Requirements
Un-aged binder Dynamic Shear, G*/sinδ, 52°C @ 10 red/sec, 1.59Hz (kPa)	1.15	AASHTO TP5	1 kPa minimum
Aged binder @ 10 red/sec, 1.59Hz, Mass Loss, RTFO, %	0.1 %	AASHTO TP5	1 maximum
RTFO aged residue G*/sinδ @ 52°C (kPa)	2.424	AASHTO TP5	2.20 kPa min.
PAV aged residue G*sinδ @ 22°C (kPa)	114.9	AASHTO TP5	5000 kPa max.
Creep Stiffness, S, m-value, test temp. @ 60 sec	Not tested	AASHTO TP1	300MPa max., 0.300 min.
Direct Tension, Failure strain, %	Not tested	AASHTO TP3	1 mm/minute

Dynamic Rheological Analysis of Un-Aged and Aged Asphalt-Filler Mastics:

One of the major outcomes of the SHRP asphalt research program was a performance-based asphalt binder specification which was designed to be applicable to both modified and unmodified asphalt binders, including binders with modifiers dispersed, dissolved or reacted with the base asphalt. A major objective of the asphalt research program was to identify and validate engineering properties that could be directly linked to the performance (the response to traffic loading and environment) of asphalt binders. The pavement distress modes that are considered in this study are rutting, caused by inadequate shearing resistance in the asphalt mixture, and load associated fatigue cracking.

Rutting Parameter:

The rheological properties of the un-aged asphalt-filler mastics were measured in terms of complex modulus (G*), and phase angle (δ). The permanent deformation rutting parameters (G*/sinδ) were then determined at a loading frequency of 1.59Hz in control stress mode at a reference high temperature of 52°C at which rutting is believed to be important. The SHRP rutting parameters (G*/sinδ) of the eight laboratory blended mastics are presented in Table 3 with higher values of G*/sinδ (behaves more like elastic solid) indicating superior rutting resistance. The values of the energy lost for asphalt-filler mastics presented in Table 3 were calculated using equation 1.

Table 3: Rutting parameter of un-aged mastics at temperature of 52°C.

Mastic type	G* kPa	Δ °C	Rutting Parameter G*/sinδ (kPa)	Ranking	Work dissipated per load cycle (kN/m^2)
L10	3.86	59.7	4.47	4	0.01012
L0	3.80	68.3	4.09	8	0.01055
C10	4.17	49.9	5.45	2	0.00829
C0	3.91	61.7	4.44	5	0.01018
F10	3.32	46.9	4.55	3	0.00994
F0	3.26	52.3	4.12	7	0.01097
S10	4.34	51.8	5.52	1	0.00819
S0	4.24	73.6	4.42	6	0.01023

It can be seen from Table 3 that the filler particle size and filler type influenced the rheological properties and work dissipated per load cycle of asphalt binder differently. In fact, Figure 1 shows that the type of filler and the particle size have different effects on the same asphalt binder due to the filler properties and physical chemical reactions between the two materials.

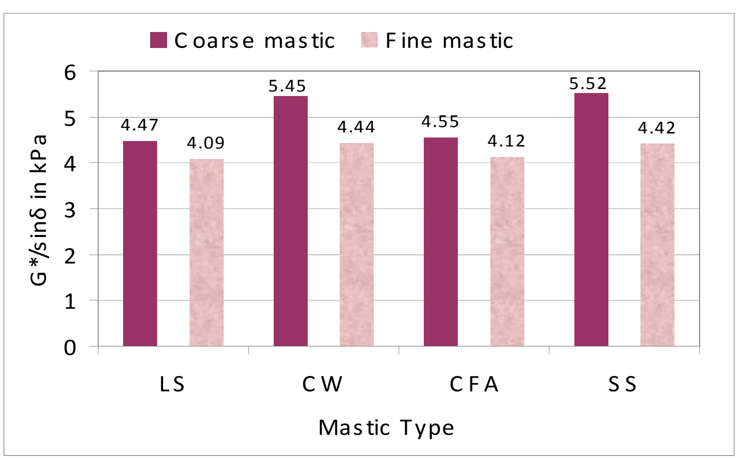


Fig. 1: Rutting parameter (G*/sinδ) of un-aged mastics at temperature of 52°C.

The particle size of the filler show a relatively consistent increase in *G** and decrease in sinδ regardless the filler type (Table 3). The test results showed that the complex modulus (G*) increases with the increase of particle size (i.e. at given F/A ratio the coarse particle size of the filler regardless the filler type has caused the highest stiffening effect while fine particle size filler gave the lowest G* values) and also, the energy dissipated (lost) per load cycle decreases as the filler particle size increase. This kind of behavior is expected since the higher the F/A ratio the stiffer the mix (less free asphalt). However, the coarser particle of steel slag (S10) and ceramic waste filler (C10) show a more pronounced increase in *G** and decrease in sinδ, which improved (reduced) temperature susceptibility regardless the type. Similar results were seen for the coarse particle size filler mastics (F10 and L10) which indicated a general trend, that at the given F/A ratio, filler fraction and binder content, coarse particle size caused the most stiffening and superior performance of the two filler particle sizes used. This results demonstrates that complex modulus (G*) alone is not sufficient to characterize asphalt binder/or mastic, phase angle (δ) is also need.

Fatigue Parameter:

Using the hypothesis that a reduction in both fatigue parameter (G*·sinδ) and the work dissipated per load cycle will correspond to improved fatigue resistance, the fatigue parameters along with the energy dissipated per load cycle (equation 2) and the ranking of the asphalt binder and the eight mastics at temperature 20°C were calculated and presented in Table 4 and graphically in Figure 2.

The G*·sin δ values in Table 4 and Figure 2 indicate that the proprietary C10 should have far superior fatigue performance compared to the laboratory blended mastics followed by (F10, L10, C0, S10, F0, L10, and L0) mastics which indicated a general trend for this study regardless the filler type, that the coarse particle size of the asphalt-filler mastics caused the most resistance to fatigue cracking at intermediate temperature. In terms of filler type, the rankings indicate that, the ceramic waste and coal fly ash filler tended to perform better and produced mastic having the highest fatigue resistance than the other fillers (steel slag and limestone) regardless the particle size.

Table 4: Fatigue parameter of PAV-aged mastics at temperature of 20°C.

Mastic type	G* (kPa)	Δ (°C)	Fatigue Parameter, G*.sinδ (kPa)	Ranking	Work dissipated per loading cycle (kN/m^2)
L10	62.1	67.6	57.41	3	0.01803
L0	145.0	81.5	143.4	8	0.04503
C10	25.9	55.9	21.45	1	0.00674
C0	91.4	70.3	86.05	4	0.02702
F10	38.7	74.6	37.31	2	0.01172
F0	97.6	78.9	95.77	6	0.03007
S10	117.0	49.9	89.49	5	0.02809
S0	119.0	63.4	106.0	7	0.03328

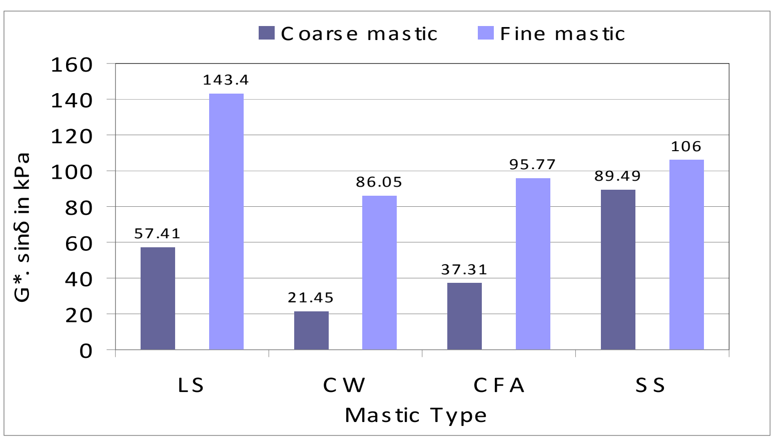


Fig. 2: Fatigue parameter (G*.sinδ) of PAV-aged mastics at temperature of 20°C To be changed according to table 4.

Asphalt-filler mastics performance test:

Dynamic creep Test:

The dynamic (repeated) creep tests were performed using the Dynamic Shear Rheometer (DSR) at a constant stress level of 220 Pa for one second followed by rest period of nine seconds, which considered being one cycle. During rest period, the specimen recovers some of the strain that was developed during the 1-s stress period before it is loaded again (Button, 2004). A total of 100 creep cycles were performed on the RTFO aged asphalt-filler mastics at a temperature of 52°C. The permanent strain is then accumulated for 100 cycles or 1000 seconds to determine and compare the resistance of asphalt-filler mastics to permanent deformation (rutting) under repeated loading that is meant to simulate traffic loading. Figure 3 and Figure 4 show that the accumulated (total) strain was influenced by the particle size and type of the filler used, decreasing with the increase in the particle size of the filler. Smallest values of total strain were obtained for mastics with ceramic waste with coarse particle size mastic, followed by the coal fly ash, limestone (control filler), and steel slag. The increase in accumulated strain was significantly less for coarse ceramic waste (C10) filler mastic.

In addition, the test results at the end of 100 cycles for the eight filler mastic are shown in Table 5. The results indicate that the accumulated strains increase with decrease in filler particle size at a given F/A ratio. The test results suggest that fine particle size of steel slag (S0) filler mastic had maximum accumulated strains while coarse particle size ceramic waste (C10) filler mastic had minimal accumulated strains. The permanent deformation ranking of the eight asphalt-filler mastics has also been included in Table 5 as a function of accumulated strain with lower value of accumulated strain percent at the end of 100 cycles indicating superior rutting resistance.

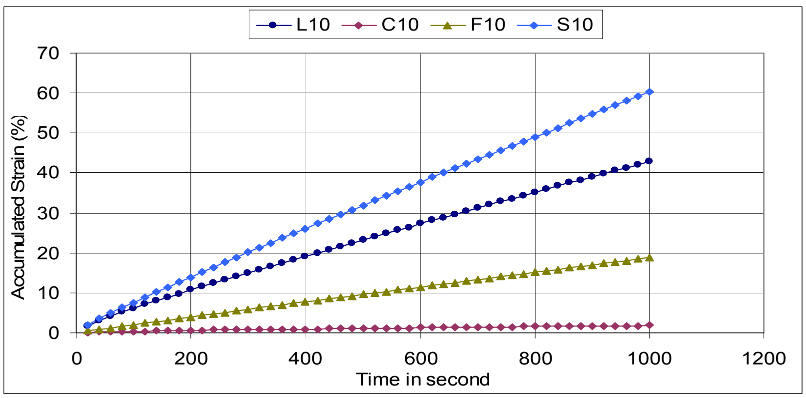


Fig. 3: Results of the accumulated strain under repeated creep testing for four coarse particle size filler mastics at 1 s loading and 9 s unloading (52°C, 220 Pa).

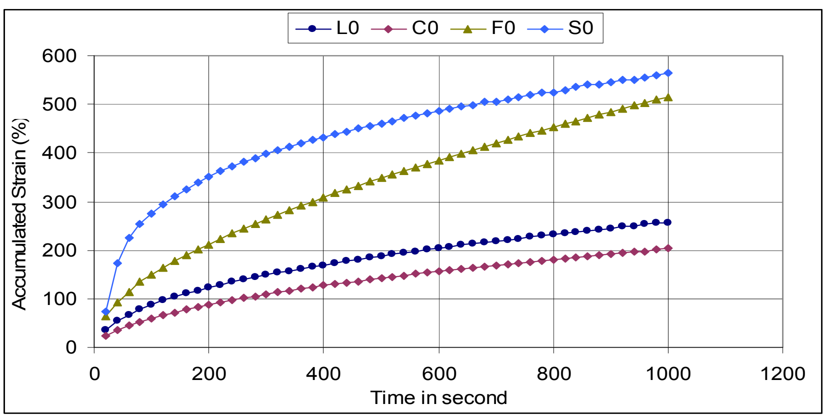


Fig. 4: Results of the accumulated strain under repeated creep testing for four fine particle size filler mastics at 1 s loading and 9 s unloading (52°C, 220 Pa).

Table 5: Accumulated strain at the end of 100 cycles and ranking for the eight filler mastics at reference temperature of 52°C.

Mastic type	Accumulated Strain (%)	Ranking
L10	42.90	3
L0	257.00	7
C10	1.80	1
C0	203.00	5
F10	18.80	2
F0	515.00	6
S10	60.40	4
S0	565.00	8

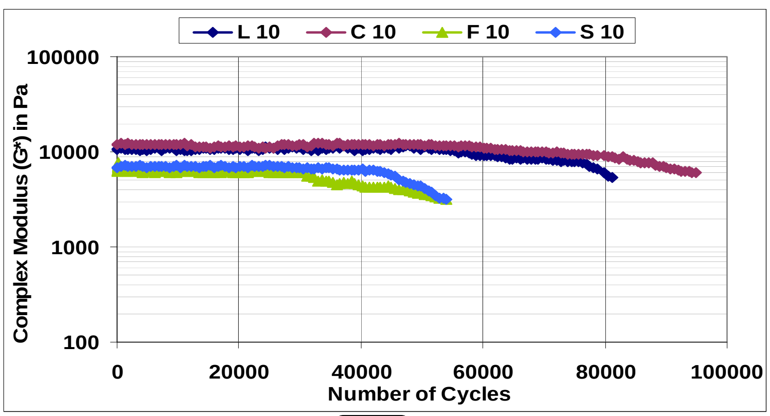
In general, regardless the filler type the repeated creep results in Table 5 confirm that, the asphalt-filler mastics with the coarse particle size exhibited less deformation and show superior performance in comparison to filler mastics with the fine particle size at a given F/A ratio. In terms of filler type ceramic waste show superior performance followed by coal fly ash, limestone, and steel slag asphalt-filler mastic. It can be inferred that coarser particle size filler could improve better the resistance of asphalt pavements to rutting phenomenon compared to the finer particle size of mineral filler at a given F/A ratio.

Time Sweep Test:

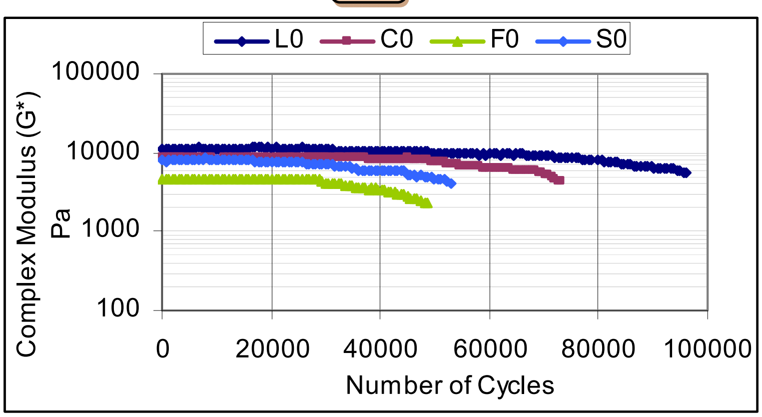
In this study time sweep test was performed on RTFO aged eight asphalt-filler mastics to simulate the effect of mixing and compaction. The testing was conducted at 20°C, a strain level of 1%, which is small enough to develop fatigue damage and not to cause any nonlinear damage, was selected and applied to each 8-mm diameter and 2-mm thick DSR specimen with constant loading frequency of 10Hz in control strain mode to determine the fatigue life of the asphalt-filler mastics. The number of cycles to failure (fatigue life) was determined from a set of complex modulus (G*) versus time in seconds plots, the time in seconds was calculated at 50% of initial G_i*, the number of cycles to failure was then determined by multiplying the time at 50% of initial G_i* by the frequency (10 Hz) as presented in Table 6 and Figure 5 (a, b, and c).

Table 6: Fatigue Performance and ranking of RTFO-aged filler mastics.

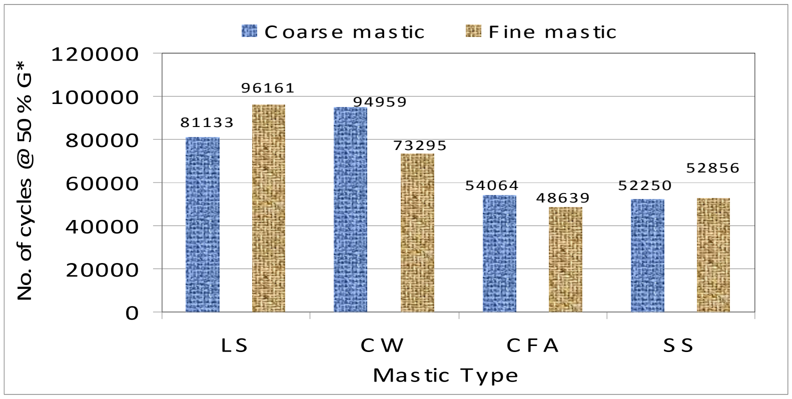
Mastic	Initial (Gi*) (Pa)	Time @ 50% of Initial (Gi*) (seconds)	No. of Cycles @ 50% of (Gi*)	Ranking
L10	10,560.00	8113.30	81,133.00	3
L0	11,220.00	9616.10	96,161.00	1
C10	12,060.00	9495.90	94,959.00	2
C0	8,480.00	7329.50	73,295.00	4
F10	6,300.00	5406.40	54,064.00	5
F0	4,560.00	4863.90	48,639.00	8
S10	7,020.00	5225.00	52,250.00	7
S0	8,280.00	5285.60	52,856.00	6



a



b



c

Fig. 5: (a, b) Time sweep test results at 10 Hz, 20°C, and 1% strain (mastics were RTFO-aged) and (c) number of cycles to failure for the eight mastics at 50% G*.

Figure 5 (a, b) shows the initial G_i* values are slightly different and the mastics show significantly different fatigue behavior. Four of the mastics (L0, C10, L10, and C0) showed high resistance to fatigue after more than 70,000 cycles, while the other mastics showed non-significant variation in fatigue life when it was defined as the number of cycles to the initial G_i* value by 50 percent. Furthermore, Figure 5 indicate that (C10) should have far superior fatigue performance compared to laboratory blended steel slag, coal fly ash mastics, and the control mastic (L10). Depending on the filler type, the Superpave binder/mastics parameter ranks the fatigue performance of the coarse particle size to be significantly higher than that of the fine size particle mastics at a given F/A ratio for ceramic waste and coal fly ash filler and the other way around for limestone and steel slag.

In general, the data obtained from time sweep tests showed satisfactory performance of fine particle size asphalt-filler mastics (L0 and S0), while the data from fatigue parameter (G*.sinδ) tests showed significantly poor performance of fine particle size asphalt-filler mastics. This phenomenon may be due the aging effect since the former test conducted on RTFO aged specimens (short term aging), while the later conducting on PAV aged specimens (long term aging). However, the overall predicted performance of fine asphalt-filler mastics is questionable since the finer particle size asphalt-filler mastics exhibited more brittleness and hardening with loading frequency and at low temperature and this in turn will cause significantly poor long term performance. The finding indicated that the effect of filler type on the fatigue properties of the mastics at tested temperature may lessen as the particle size decreases as demonstrated by coal fly ash (F0) and ceramic (C0) asphalt-filler mastic.

Effect of Temperature on Asphalt-Filler Mastics:

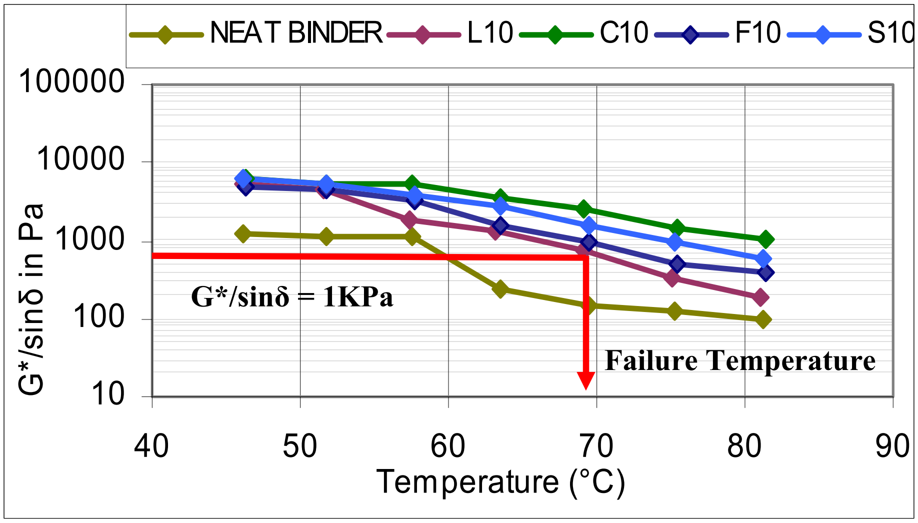
Temperature Steps Test:

The SHRP rutting parameters (G*/sinδ) for the un-aged penetration grade asphalt (80/100) and the eight laboratory blended asphalt-filler mastics are presented in Table 7. The parameters have been determined at high and intermediate temperature of 46°C to 82°C with increment of 6°C. The loading frequency used in the specification was selected as 1.59 Hz (10 rad/s). The permanent deformation ranking of the asphalt binder and eight asphalt-filler mastics has also been included in the Table 7 as a function of the asphalt binder and mastics rutting parameters (G*/sinδ) at 52°C and failure temperature at G*/sinδ = 1kP with higher values of G*/sinδ (behaves more like elastic solid) and higher failure temperature indicating superior rutting resistance.

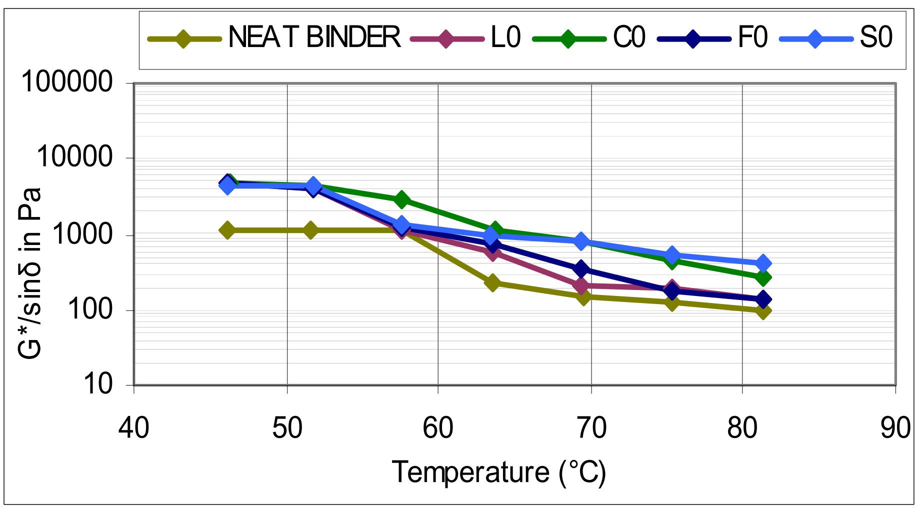
Table 7: Rutting parameters of un-aged asphalt binder and mastics at various temperatures.

Mastic type	Rutting parameter (G* / sin δ) kPa on un-aged binder and mastics@1.592Hz (10rad/s)							Failure Temp.@ 1kP (°C)	Ranking by Failure Temp. and G*/sinδ @ 52°C	
	46 °C	52 °C	58 °C	64 °C	70 °C	76 °C	82 °C			
Binder	1.18	1.15	1.1	0.232	0.152	0.126	0.101	57.8	9	9
L10	5.12	4.47	1.88	1.283	0.762	0.342	0.192	66.4	4	4
L0	4.74	4.09	1.16	0.587	0.217	0.196	0.137	62.4	7	8
C10	6.3	5.45	5.19	3.584	2.514	1.432	1.011	81.5	1	2
C0	4.8	4.44	2.97	1.133	0.778	0.443	0.262	65.7	5	5
F10	5.09	4.55	3.1	1.534	0.923	0.487	0.211	68.8	3	3
F0	4.64	4.12	1.23	0.731	0.336	0.182	0.132	61.8	8	7
S10	6.09	5.52	3.93	2.784	1.453	0.997	0.593	75.8	2	1
S0	4.57	4.42	1.39	0.993	0.783	0.534	0.412	63.5	6	6

The DSR rheological data for the un-aged penetration grade neat asphalt (80/100) and the twelve mastics were then presented in the form of isochronal plots (Fig. 6) of complex modulus, G*, and phase angle, δ, at various temperature (42 – 82 °C) and at a loading frequency of 1.59Hz under control stress mode.



(a)



(b)

Fig. 7: Rutting parameter and failure temperature at 1kPa of asphalt binder and mastics for (a) coarse filler particle size (b) fine filler particle size.

In general, greater G*/sinδ values have been obtained for the steel slag (S10) and ceramic (C10) asphalt-filler mastics and lower values for coal fly ash and the control mastic of limestone with the relative increases in G*/sin δ being higher at the lower and intermediate temperature below 64°C. The coarser size particles of steel slag mastics (S10) and ceramic waste mastics (C10) displayed the higher G*/sinδ and higher failure temperature values and were therefore ranked higher than the coal fly ash in terms of their potential rutting resistance. On the other hand, the fine size particles displayed lower G*/sinδ and lower failure temperature values regardless filler type.

In terms of filler type, the rankings indicate that the steel slag and ceramic mastics tended to perform better than the control and the other mastics at low and high temperatures. The G*/sinδ did follow the same trend for all of the proportion tested. In addition, the predicted permanent deformation performance of the eight mastics was greatly above the conventional penetration grade asphalt binder.

The failure temperature of the un-aged asphalt binder and the eight mastics was measured from the DSR temperature steps test at G*/sinδ (Rutting Parameter) corresponding to 1000 Pa and the results and PG-Grading of asphalt-filler mastics are presented in Table 8 and graphically in Fig. 7. Greater failure temperature values have been obtained for the coarse particle size of the ceramic waste and steel slag filler mastics (C10, S10) compared to the control mastics of limestone while coal fly ash mastics perform much the same as limestone mastics. Also, the coarse particle size asphalt-filler mastics show a gradual change with temperature while the fine particle size asphalt-filler mastics show a rapid decline with temperature (Fig. 7). The increment of failure temperature is very important to improving the high performance of asphalt-mastic. It will help to reduce the high temperature deformation and rutting damage of asphalt pavement. The results in Table 8 confirm once again that, the coarse particle size show superior performance than the fine particle size regardless filler type.

The DSR Superpave asphalt-filler mastic properties test results in Table 8 indicated that the (L10, F10, and C0) increased the high temperature stiffness by two grades, (S10) increased by three grades, (C10) increased by four grades, and the testing on the (L0, F0, S0) indicated that the high temperature grade was one grade higher than the base asphalt binder. A general trend was observed that, coarse filler particle size mastics regardless the filler type was performed significantly higher than that observed for the fine filler particle size mastics.

Table 8: PG-grading of asphalt-filler mastics.

Mastic Type	LSD		CWD		CFA		SSD	
	L10	L0	C10	C0	F10	F0	S10	S0
DSR Temperature at1kPa	66.4	62.4	81.5	65.7	68.8	61.8	75.8	63.5
SHRP PG (High Temperature)	64	58	76	64	64	58	70	58

Conclusions:

To investigate the effect of filler type and particle size on performance properties of asphalt binder and mastics, eight mastics were produced in the laboratory with filler to asphalt ratios by percentage by weight that was used in the mixtures, using four types of filler and two particle size (coarse and fine). A series of selected Superpave binder tests were conducted using DSR. Mastics were artificially aged through an accelerated aging process (RTFO and PAV). The rheological properties (G* and δ) together with performance prediction parameters (G*/sinδ and G*.sinδ), dynamic creep, temperature steps, and time sweep tests of rutting at high temperature and the fatigue cracking at intermediate temperature properties were evaluated. From the test results, the following conclusions were drawn for the materials used in this study:

1. At given F/A ratio the coarse particle size of the filler seems to lead to better rutting resistance and fatigue cracking properties than the fine size particle does.
2. The filler type was found to have a significant effect on both rutting parameter (G*/sinδ) fatigue parameter (G*sinδ). The improvement in rutting resistance and fatigue life due to addition of filler is much greater for the ceramic mastic than for the other filler types. This indicates that the physico-chemical interaction between asphalt binder and filler is dependent on the type of materials.
3. At given F/A ratio the coarse particle size of the filler regardless the filler type has caused the highest stiffening effect while fine particle size filler gave the lowest complex modulus (stiffness) values.
4. The energy dissipated per load cycle decreases as the filler particle size increased.
5. The results from dynamic creep test indicated that, the accumulated strains increases with decrease in filler particle size at a given F/A ratio regardless filler type.
6. The data obtained from time sweep tests showed satisfactory performance of fine particle size asphalt-filler mastics, while the data from fatigue parameter (G*.sinδ) tests showed significantly poor performance of fine particle size asphalt-filler mastics.
7. Greater failure temperature values have been obtained for the coarse particle size compared to the fine particle size asphalt-filler mastics.
8. The coarse particle size asphalt-filler mastics show a gradual change with temperature while the fine particle size asphalt-filler mastics show a rapid decline with temperature.
9. At given F/A ratio and depends on filler type, performance grading (PG-Grading) indicated that the coarse filler particle size mastics increased the high temperature stiffness up to four grades, while the fine filler particle size mastics increased the high temperature grade by one grade higher than the base asphalt binder.
10. The results showed that variation of filler particle size and type can lead to considerable changes in rheological and performance of mastic. Filler particle size and filler type for mix design should be determined based on the overall performance of mastic.

ACKNOWLEDGMENTS

The author wish to thank the Highway and Transportation Engineering unit at University Putra Malaysia (UPM), for their insight and guidance.

REFERENCES

AASHTO., T316-04, 1995. Viscosity determination of asphalt binder using a rotational viscometer. American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., USA.

AASHTO., T240-03, 1995. Effect of heat and air on a moving film of asphalt (rolling thin-film oven test). American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., USA.

AASHTO., R28, 1995. Accelerated aging (oxidation) by means of pressurized air and elevated temperature. American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., USA.

AASHTO., TP5-93, 1993. Standard test method for determination of rheological properties of asphalt binder using a dynamic shear rheometer. American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., USA.

AASHTO., M320, 1993. Standard specification for performance graded asphalt binder. American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., USA.

Airey, GD. and SF. Brown, 1998. Rheological performance of aged polymer modified bitumen's". Journal of the Association of Asphalt Paving Technol.; 67: 66-100.

Anderson DA, WH. Goetz, 1973. Mechanical Behavior and Reinforcement of Mineral Filler-Asphalt Mixtures. Proceedings of the Association of Asphalt Paving Technologists; 42: 37-66.

Anderson, David A., Y. M. Le Hir, J-P Planche, and D . Martin, 2001. Zero Shear Viscosity of Asphalt Binders. Transportation Research Board, 80th Annual Meeting, Washington, DC.

Anderson, DA, 1987a. Guidelines for Use of Dust in Hot Mix Asphalt Concrete Mixtures. Proc. Association of Asphalt Paving Technologists; 56: 492-516.

Anderson DA, JP. Tarris, 1983. Characterization and specification of baghouse fines. Proc. Association Asphalt Paving Technologists; 52: 88-120.

Anderson, DA, TW. Kennedy, 1982. Development of SHRP binder specification. Journal of the Association of Asphalt Paving Technologists; 62: 481-507.

Bardesi, A,B., Brule, JF. Corte, E. Diani, A. Gerritsen, G. Lefebvre, JP. Planche, D. Sybilski, A. Stawiarski, F. Verhee, S. Watkins, 1999. Use of modified bituminous binders, special bitumens and bitumens with additives in pavement applications. Technical Committee Flexible Roads (C8), World Road Association (PIARC).

Bahia, HU, DI. Hanson, M. Zeng, H. Zhai, 2001. Characterization of Modified Asphalt Binders in Superpave Mix Design. NCHRP Report 459, Transportation Research Board, Washington DC.

Bahia, HU, H. Zhai, S. Kose , and K. Bonnetti, 1999. Non-linear Viscoelastic and Fatigue Properties of asphalt Binders. Journal of the Association of Asphalt Paving Technologists; 68: 1-34.

Button, Joe W., 2004. New Simple Performance Tests of Asphalt Mixes.

E-C068, ISSN0097-8515, Transportation Research Board, Washington D.C.

Dongre, Raj and JD. Angelo, 2002. Evaluation of Dfferent Parameters for Superpave High Temperature Binder Specification Based on Rutting Performance in the Accelerated Loading Facility at FHWA. Transport Research Board, 81st Annual Meeting, Washington, DC.

Goodrich, JL, 1988. Asphalt and polymer modified asphalt properties related to the performance of asphaltic concrete mixes. Proc. Assoc. Asphalt Paving Technol.; 57. p 116–175.

Herh, Peter KW, M. Steven , Cole, Kaj Hendman, and KS. Bruce Rudolph, 1997. Dynamic Shear Rheometers. Pave the Way for Quality Asphalt Binders. Viscotech DSR.

Kavussi A, RG. Hicks, 1997. Properties of Bituminous Mixtures Containing Different Fillers. J. Assn. of Asphalt Paving Technologists; 66. p 153-186.

Ward RG, JM. McDougal, 1979. Bituminous Concrete Plant Dust Collection System, Effect of Using Recovered Dust In Paving Mix. Research Report FHWA/WV-79-003, Charleston, WV, West Virginia Department of Highways, USA.