Ardaman & Associates, Inc.

Geotechnical, Environmental and
Materials Consultants

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City of Orlando
Engineering/Streets and Drainage Bureau
Public Works Department
400 South Orange Avenue
Orlando, Florida 32801-3302

Attention: Mr. Rick Howard, P.E., City Engineer

Subject: Report of Phase II Pavement Rejuvenation Study
Various City Streets
Orlando, Florida

Gentlemen:

As requested and authorized, Ardaman & Associates, inc. has completed engineering and testing services for Phase II of this pavement rejuvenation study. Phase I of this project included obtaining pavement samples prior to treatment with the rejuvenating agent and developing this testing program to evaluate the rejuvenating agent and provide data to assess the application period.

BACKGROUND

The City has been treating low volume streets with Reclamite®[1] asphalt rejuvenating agent for about 10 years. An initial application is typically made within one year after placement of the asphaltic concrete for an overlay. Reapplication is scheduled at a period of about 6 years. The intent of this program is to reverse the effects of "aging" (sometimes referred to as weathering or oxidation) by reintroducing portions of the asphaltic cement lost as a result of weathering. With aging, oxidation occurs and, in effect, reduces the petrolenes fraction[2] of the asphaltic cement. Increasing the petrolenes fraction improves the ductility of the asphaltic cement and therefore pavement durability.

Specifications developed for pavement rejuvenators and prior testing by others have concentrated on verifying that the rejuvenating products decrease the viscosity (or increase the penetration) of the asphaltic cement. Viscosity is measured on asphaltic cement extracted from cores obtained prior to treatment and after treatment with a rejuvenating agent. There is not much information available regarding critical values of viscosity, penetration or ductility that would indicate when the pavement is likely to develop cracks. SHRP-A-369 indicates that, in previous studies, penetration

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[1] Manufactured by Golden Bear Division, Witco Corporation, P.O. Box 456, Chandler, AZ 85244. Supplied by Pavement Technology, Inc., Westlake, OH.

[2] Asphalt consists of four basic components: asphaltenes (A), Polar aromatics (PA), napthene aromatics (NA) and saturates(S). The latter three components, PA, NA and S are referred to as the petrolenes fractions.. Asphaltenes are soluble only in the presence of polar and napthene aromatics, which act as media to disperse the dissolved asphaltenes. The saturates develop the setting characteristics of the entire solution.

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less than 10 and ductility less than 20, measured at 25°C, were established to be the limits at which pavements start to show cracking.

TESTING PROGRAM

This study included field sampling and laboratory testing. The field sampling was performed in two phases. In Phase I, initial field samples were obtained from eight city streets[3] in mid-February 1997 prior to application of the rejuvenating agent in July/August 1997. The sample locations are presented in our report dated May 30, 1997, which is included in Appendix I. Four of the streets were selected for continued testing in Phase II. Additional samples were collected from locations near the pretreatment cores for each street after application of the rejuvenating agent. Testing to measure rheological properties was performed by PRI Asphalt Technologies, Inc. of Tampa, Florida, as a subconsultant to Ardaman, on the following samples:

Phase IIA:

- pretreatment core samples obtained in Phase I ;
- post treatment core samples obtained to compare with pretreatment conditions;

Phase IIB:

- virgin asphaltic cement from a local distributor; and
- asphaltic cement from a local distributor treated with Reclamite.

Dynamic shear and stiffness testing was performed on samples of these materials before and after artificial aging for 5 time intervals based on procedures and performance graded asphalt binder specifications established by the Strategic Highway Research Program (SHRP) as part of the Superpave™ (*Sup*erior *Per*forming Asphalt *Pave*ments) system. The testing program and procedures are further described in the following subsections.

Superpave™ Specification

This project used the Superpave specification as a basis for evaluating the performance of asphalt binder with and without rejuvenating agent, subjected to various degrees of field and laboratory-simulated aging. The following brief discussion explains the concepts of the Superpave system. The Asphalt Institute Publication No. SP-1, SUPERPAVE Performance Graded Asphalt Binder Specification and Testing, is a concise readable document which we recommend as a reference for more details regarding Superpave.

The Superpave specification addresses the following aspects of binder performance with the corresponding testing procedures listed:

Handling/Pumping — Rotational Viscometer
Permanent Deformation and Fatigue Cracking — Dynamic Shear Rheometer
Thermal Cracking — Bending Beam Rheometer or Direct Tension Tester.

The Superpave system uses new parameters such as the complex shear modulus and the phase angle between stress and strain in place of viscosity and penetration. The complex shear modulus,

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[3]Per the City, the streets that we studied were generally resurfaced in 1990. Reclamite was applied in 1991 and again in 1997.

G*, is the ratio of total shear stress ($\tau_{max} - \tau_{min}$) to total shear strain ($\gamma_{max} - \gamma_{min}$). The time lag between stress and strain is related to the phase angle, δ. For a perfectly elastic material, an applied load causes an immediate response; thus the phase angle is zero. For a viscous material (such as asphalt at mixing temperatures) the phase angle approaches 90°. Asphalt binders are viscoelastic at normal pavement temperatures and behave somewhere between these two extremes. For a more detailed explanation of these parameters refer to SP-1.

The Superpave binder specification tests asphalt binders in conditions that simulate the three critical stages during the binder's life:

- transport, storage and handling
- mix production and construction
- long-term aging.

Only long-term aging-related parameters are relevant for this project.

The original binder material represents the condition during transport, storage and handling. The Rolling Thin Film Oven (RTFO) test simulates mixing and placement of asphalt binder. The Pressure Aging Vessel (PAV) procedure simulates long-term in-service aging. The standard PAV 20-hour exposure corresponds to 5 to 10 years of field aging. This relationship is approximate and there are many contributing factors that make it difficult to reliably extrapolate for the field equivalency of greater or lesser PAV exposure times.

An excerpt from Table 1 of SP-1, provided as Exhibit 1, shows the performance graded asphalt binder specification. The performance grade (PG) evaluated for Orlando is PG 64-22. The 64 (°C) corresponds to the maximum pavement design temperature and the -22 (°C) corresponds to the minimum pavement design temperature. One important distinction between currently-used asphalt specifications and the Superpave specification is that the required physical properties remain constant for all of the performance grades. However, the temperatures at which these properties must be reached vary depending on the climate in which the binder is expected to be used. The applicable temperatures for Orlando are shaded.

EXHIBIT 1

Table 1. Performance Graded Asphalt Binder Specification

Performance Grade	PG 46			PG 52							PG 58					PG 64					
	-34	-40	-46	-10	-16	-22	-28	-34	-40	-46	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40
Average 7-day Maximum Pavement Design Temperature, °C [a]	<46			<52							<58					<64					
Minimum Pavement Design Temperature, °C [a]	>-34	>-40	>-40	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-40
Original Binder																					
Flash Point Temp, T48: Minimum °C	230																				
Viscosity, ASTM D 4402: [b] Maximum, 3 Pa·s (3000 cP), Test Temp, °C	135																				
Dynamic Shear, TP5: [c] G*/sin δ, Minimum, 1.00 kPa Test Temperature @ 10 rad/sec, °C	46			52							58					64					
Rolling Thin Film Oven (T 240) or Thin Film Oven (T 179) Residue																					
Mass Loss, Maximum, %	1.00																				
Dynamic Shear, TP5: G*/sin δ, Minimum, 2.20 kPa Test Temp @ 10 rad/sec, °C	46			52							58					64					
Pressure Aging Vessel Residue (PP1)																					
PAV Aging Temperature, °C [d]	90			90							100					100					
Dynamic Shear, TP5: G*sin δ, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16
Physical Hardening [e]	Report																				
Creep Stiffness, TP1 [f] S, Maximum, 300 MPa m-value, Minimum, 0.300 Test Temp, @ 60 sec, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30
Direct Tension, TP3: [f] Failure Strain, Minimum, 1.0% Test Temp @ 1.0 mm/min, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30

Notes:

a. Pavement temperatures can be estimated from air temperatures using an algorithm contained in the Superpave™ software program or may be provided by the specifying agency, or by following the procedures as outlined in PPX.

b. This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

c. For quality control of unmodified asphalt cement production, measurement of the viscosity of the original asphalt cement may be substituted for dynamic shear measurements of G*/sin δ at test temperatures where the asphalt is a Newtonian fluid. Any suitable standard means of viscosity measurement may be used, including capillary or rotational viscometer (AASHTO T 201 or T 202).

d. The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures 90°C, 100°C or 110°C. The PAV aging temperature is 100°C for PG 64- and above, except in desert climates, where it is 110°C.

e. Physical Hardening – TP 1 is performed on a set of asphalt beams according to Section 13.1 of TP 1, except the conditioning time is extended to 24 hrs ± 10 minutes at 10°C above the minimum performance temperature. The 24-hour stiffness and m-value are reported for information purposes only.

f. If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness is between 300 and 600 MPa, the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The m-value requirement must be satisfied in both cases.

The testing program is further described in the following subsections.

Phase IIA: Core Testing

Pretreatment Core Samples

We tested four of the 16 core samples obtained in Phase I of this study to measure the viscosity of the asphaltic concrete. The samples were selected from sunny and shaded locations both from the wheel path and outside the wheel path. The following table describes the test sample locations:

Test Sample Location	Wheel Path	Outside Wheel Path
Sunny	**Ross Place** (**NW,RP,W1** and W2*)	**Lucerne Terrace** (**SW,LT,C1** and C2*)
Shaded	**Church Street** (**NE,CS,W1** and W2*)	**Mack Avenue** (**SW,MA,C1** and C2*)

* Samples obtained as reserves.

The testing involved trimming the top ¼- to ½-inch of the cores and extracting the asphaltic cement using toluene and Rotavapor distillation (ASTM D5404-93). The extracted asphaltic cement was then subjected to testing. The rheological properties were measured using a Dynamic Shear Rheometer (DSR) under three different conditions where the shear rate and temperature were varied. Two of the tests measured viscosity at a temperature of 25°C using the DSR in sliding plate viscometer mode. One test was performed with a shear rate of 0.05 reciprocal seconds (1/sec) and a second with a shear rate of 0.001 (1/sec). The third test was performed at a temperature of 64°C with a shear rate of 10 radians/sec using the Superpave DSR protocol (AASHTO TP5) for binder. The testing was performed from July 23-30, 1997.

Post Treatment Core Samples

We obtained three additional cores from each of the selected streets on which pretreatment testing was performed adjacent to the locations where cores were previously obtained. They are referenced as follows:

Test Sample Location	Wheel Path	Outside Wheel Path
Sunny	**Ross Place** (**NW,RP,W3**, W4* and W5*)	**Lucerne Terrace** (**SW,LT,C3**, C4* and C5*)
Shaded	**Church Street** (**NE,CS,W3**, W4* and W5*)	**Mack Avenue** (**SW,MA,C3**, C4* and C5*)

* Samples obtained as reserves.

Again the cores were trimmed to obtain the top ¼- to ½-inch of material. The asphaltic cement was extracted and distilled as described above. The extracted asphaltic cement was subjected to testing as described above for the pretreatment samples.

Phase IIB: Asphalt Cement Testing

Virgin (neat) asphalt cement (AC-30) was obtained from an asphaltic cement producer and was tested both with and without the rejuvenating agent Reclamite.

Virgin Asphaltic Cement

It should be recognized that different sources of asphaltic cement may have different aging characteristics. We therefore attempted to obtain asphaltic cement used in past City of Orlando resurfacing projects. The asphaltic cement was obtained from a local distributor, Marathon Oil Company, Tampa, Florida, which has provided asphaltic cement for many of the City's resurfacing projects.

Samples of this asphaltic cement were subjected to artificial aging using the RTFO Procedure (AASHTO T240 or ASTM D 2872) followed by the AASHTO PP1 protocol in a Pressure Aging Vessel (PAV). A 20-hour time of exposure in the PAV is used to simulate 5 to 10 years of aging. For this testing, we obtained samples after 10, 15, 20, 25, and 30 hours of exposure in the PAV. Samples from each of the exposure time increments were subjected to dynamic shear and bending beam rheometer (BBR) stiffness testing (AASHTO TP1) to measure rheologic properties.

Treated Asphaltic Cement

The asphalt cement was treated with Reclamite at a ratio corresponding to the manufacturer's recommended application rate—0.06 gallons per square yard or 0.153 parts Reclamite emulsion[4] to 1 part AC. Treated asphalt was also tested at a much higher application rate of rejuvenating agent—0.35 parts Reclamite concentrate to 1 part AC, which is equivalent to 1.05 parts Reclamite emulsion to 1 part AC—to test whether high dosage had undesirable effects on pavement properties. Table 1 provides the calculations for the ratios of Reclamite to asphalt cement used in the testing. The testing procedures (including aging) performed for the virgin AC were repeated for the treated samples.

RESULTS

One purpose of this project was to identify test procedures that would effectively identify the appropriate time intervals and dosage for the City to apply rejuvenating agent. In order for this approach to work the specification parameter must

(i) approach a limit signaling impending cracking at some level of (simulated) aging;
(ii) be susceptible to improvement with the rejuvenating agent.

The specification parameters/tests for in-place binder in the first column of Exhibit 1 represent potentially useful indicators.

Phase IIA: Core Testing

Viscosity

The results of viscosity testing are presented in Table 2 and Figure 1. Testing data are included in Appendix II. For the centerline (C) samples, the viscosity decreases an average of 45 percent between pretreatment and post treatment. For the traffic area/wheelpath (W) samples, the

[4] Reclamite is recommended to be diluted 1 part concentrate to 2 parts water.

viscosity decreases an average of 3 percent. However, the Church Street sample tested at a shear rate of 0.001 (1/sec), shows a 78 percent decrease in viscosity. Without this result there appears to be little change in viscosity for the samples obtained from the wheelpath.

Superpave Binder Specification

The results of DSR testing are presented in Table 2 and Figure 2. Testing data are included in Appendix II. $G^*/\sin\delta$ decreases an average of 37 percent between pretreatment and post treatment for the centerline samples and increases an average of 11 percent for the wheelpath samples. All of the measured values are comfortably above the Superpave specification of 2.20 kPa, with or without treatment.

Rheological analysis of extracted and recovered asphalts provided the following results:

Centerline asphalt samples (C's) exhibited reduced binder viscosity and complex shear modulus (G^*) with the Reclamite treatment. Centerline binder viscosities are higher than traffic lane binder viscosities. This observation is attributed to the stearic hardening (molecular structuring) that is allowed to occur in the non-traffic areas of the pavement. Traffic areas, on the other hand, are stressed by vehicular loads, "working" the binder and aggregate, which retards the molecular structuring (a reversible phenomenon). The stearic hardening hypothesis may explain why pavements first exhibit distress/cracking in the non-traffic areas.

Extracted and recovered asphalt from the traffic areas (W's), exhibit similar rheological properties with or without the Reclamite treatment. It is hypothesized that the binder and Reclamite blend together by different modes in the traffic and non-traffic areas. Additionally, the traffic areas constantly "work" the treated binder, which may influence:

- the compatibility of the asphalt and Reclamite;
- susceptibility to hydraulic actions of rain water;
- the relative permeability of the pavement.

Penetration of the Reclamite is probably higher in the non-traffic areas relative to the traffic paths. In addition, the rate of penetration reportedly decreases with successive applications of Reclamite. This is the second time that the pavements in this study have been treated.

Additional testing may better explain the differences observed between the centerline and traffic areas.

Phase IIB: Asphalt Cement Testing

The results of testing are presented in Table 3 and Figures 3, 4 and 5. Testing data are included in Appendix II. The dynamic shear rheology (DSR) has been expressed in kPa @ 64°C (147.2°F) as a function of $G^*/\sin\delta$, which defines an asphalt's stiffness at a frequency equivalent to vehicular traffic. Since asphalt is a non-Newtonian thermoplastic material (more fluid at high temperature, and brittle at cold temperature), rheological measurements such as $G^*/\sin\delta$ provide information on the asphalt's ability to withstand stresses induced by vehicular traffic and/or climate conditions, while the creep stiffness measured assesses the material's flexibility/pliability at cold service temperatures, after aging, when it is in its most brittle state.

If an asphalt is too fluid at the high service temperatures, it may deform by rutting. If it is too stiff at cold temperatures, it will crack when stresses are induced. Therefore, the asphalt binder must possess a combination of properties to provide a long and successful service life.

Dynamic Shear Rheometer

Reclamite reduced the complex modulus of the treated asphalt binder. The degree of complex modulus reduction is dosage-dependent, see Table 3. The virgin AC-30 sample without aging is fairly close to the minimum specification value of 1.00 kPa and is actually lower than the 2.20 kPA required after the sample has been subjected to the Rolling Thin Film Oven procedure. Otherwise, the untreated binder is comfortably above the specification value after aging. The sample treated with Reclamite at the manufacturer's recommended amount is near the specified minimum without aging. This would indicate that the Reclamite should not be added to this unaged asphalt cement.

The high dosage Reclamite samples fail to meet the specification criteria even after aging, which would indicate that this amount of rejuvenating agent is excessive.

Reclamite tended to reduce the rate of aging, as measured at 64°C. This implies that Reclamite, itself, has good aging characteristics. At the Reclamite recommended dosage of 0.153 parts per 1.0 part asphalt, the rheological properties of the treated asphalt after $PAV_{20hours}$ (5 - 10 years of service life) were equivalent to $PAV_{10\,hours}$ of the untreated binder (3 - 5 years of service life).

Bending Beam Rheometer

Creep stiffness (S) data @ -12°C (10.4°F), assess the binder's response to thermally induced stress at the coldest expected temperature for the geographical region. Normally done on PAV-aged samples, the Superpave binder requirements are a maximum S of 300 MPa (300,000 kPA) with a corresponding minimum m-value of 0.300.

Reclamite lowered the stiffness and increased the m-value (see Table 3). However, the results for the untreated AC-30 show that it comfortably meets the S specification and meets the m-value specification even after 30 hours of PAV aging.

Again, the degree of reduction of the creep stiffness and increase of the m-value are dosage-dependent.

As an approximation, the m-value of Reclamite-treated asphalt (recommended dosage), after $PAV_{30hours}$ (8 - 12 years of field aging), was equal to the untreated asphalt after $PAV_{10\,hours}$ (3 - 4 years of service life).

Aging

The purpose of developing typical aging curves for Orlando streets is to project when pavements will fail to meet specifications and problems such as cracking can be expected to develop. Coupled with other information such as the effectiveness of rejuvenating agents added at various stages of the aging cycle, these curves would allow the City to develop a pavement management and monitoring strategy.

The dynamic shear test results in Figure 3 show that the majority of the post treatment cores tested would have values comparable to the virgin asphalt (AC-30) tested with an exposure time of 15 to less than 30 PAV hours. This is roughly equivalent to 5 to 12 years of aging in the field. The pretreatment cores had values similar to the virgin asphalt for exposure time of 10 to more than 30 PAV hours.

The average G*/sin δ for the pretreatment cores is 14.8 kPa. The average for the post treatment cores is 11.7 kPa. The slope of the aging curve for treated AC-30 (at the manufacturer's recommended application rate) is 0.249 kPa/PAV hour. At this rate, post treatment binder would return to pretreatment values after 12 PAV hours or roughly 3 to 6 years. This would suggest that a reapplication time of 6 years might be appropriate. Additional testing as described in the following section is necessary to support this finding.

We were unable to develop satisfactory aging curves for in-place asphalt pavement representative of the current practice of the City of Orlando from the available data. The G*/sin δ values for the street cores—post treatment and pretreatment—corresponded to well aged (5 to 12+ years) virgin AC-30. This might be explained by differences between the actual paving material and the reference material. It is known that recycled asphalt is typically combined with new binder in resurfacing projects. This would explain higher DSR values for the pavement cores than for the reference AC-30. Running additional tests as recommended below would give us more points to correlate.

RECOMMENDED ADDITIONAL TESTING

Dynamic shear rheometer (DSR) testing at 25°C (77°F) should be performed on post treatment cores (and pretreatment cores, if available) for the four locations tested in Phase IIA. This testing should also be performed on the reference AC-30 material with a range of aging times up to 30 PAV hours. The purpose of this testing would be to establish whether asphalt cements typically used in Orlando meet the Superpave binder specification to prevent fatigue cracking at intermediate operating temperatures. The DSR testing performed thus far was targeted at achieving a minimum specified G*/sin δ value to avoid permanent deformation at high temperature. All of the cores tested were comfortably above this limit, so there is no need to consider this test further. Phase IIB testing has shown that, even with aging, the virgin AC-30 met the criteria for DSR at 64 °C and flexural creep stiffness and m-values at -12°C from the bending beam rheometer (BBR) testing.

Other testing that should be considered is aging and treating rather than treating and aging the AC-30. Reclamite would be added to virgin asphalt cement samples at increments of 10, 15, 20, 25 and 30 PAV hours. These treated samples would then be subjected to DSR testing at 25°C and BBR testing at -12°C.

Application/mixing rate for the Reclamite per the manufacturer's recommendation would appear to be appropriate for this additional testing.

Testing of the annual cores should include DSR testing at 25°C and possibly BBR testing at -12°C, if funding permits.

OVERALL FINDINGS

The results of this study suggest the following general findings:

- Reclamite®, at the specified application rate, imparts favorable properties to neat asphalt binders.

  When Reclamite was added to neat asphalt binder the complex modulus and stiffness were decreased. The asphalt binder viscosity and complex modulus from the cores decreased with the application of Reclamite at the specified rate. These values in the tested samples were not decreased to the degree that they were too low. However, over application could yield pavement susceptible to rutting at high temperatures.

- The application rate on the order of 0.06 gallons per square yard appears to be appropriate for a treatment period of about 6 years.

  The results of the laboratory testing on the neat asphalt binders suggest that the recommended application rate for Reclamite is appropriate for the conditions in which the City of Orlando is using it. The results of testing on artificially aged asphalt binder found that the complex modulus of the binder treated with the recommended dosage returned to pretreatment values after about 12 hours of PAV exposure (equivalent to 3 to 6 years of aging). Therefore, a treatment period of 6 years is within the range predicted by the test results. However, we note that the asphalt binder in the pavement in-place is probably substantially different than that used in the testing. The resurfacing program includes recycled asphalt and may include modifiers which could not be practically included in a testing program. The dosage rate used should be correlated to the pavement to be treated.

- The data suggest that the dosage rate for a relatively new pavement will be different than for a highly oxidized pavement.

  If Reclamite is applied to a new pavement, the application rate should be limited to avoid creating a low viscosity which allows ruts to develop under high temperatures. The data shows that the recommended application rate causes the complex modulus to decline to 1.163 kPa for unaged asphalt binder. This value should be at least 2.2 kPa to avoid rutting under high temperatures. Highly oxidized pavement can tolerate a higher level of treatment before reaching a level where rutting can be a problem. Also the older pavement may be less abscrptive.

- The results of the core testing are variable and suggest that treatment is not as effective in the wheel path as it is in the remainder of the pavement.

  The average binder viscosity from the wheel path cores was less than the average for the centerline cores.