

Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binders

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The Rolling Thin Film Oven (RTFO) Test is utilized to simulate aging that occurs in asphalt binders during hot mix asphalt production. The test oxidizes the asphalt binder and is compared to actual aging that occurs during hot mix asphalt production and laydown.

There is concern that aging in the RTFO may be affected by the elevation of the laboratory where the test is conducted. This is important since many asphalts are produced at refineries at low elevations but are sold into markets at higher elevations. Therefore, it is possible the owner-agencies testing these asphalts may get different test results if elevation affects physical properties after RTFO aging.

This study analyzed the results of asphalt tests after RTFO aging for 73 laboratories ranging in elevation from 0 to 6600 feet mean sea level. Seven grades of asphalt were analyzed. Physical properties evaluated after RTFO aging included dynamic modulus, G*; phase angle δ, the ratio of dynamic modulus and the sin of the phase angle, and G*/sin δ..

Results of this analysis indicate a statistically significant difference between RTFO aging for asphalts tested at low elevations compared to higher elevations.

Keywords: Asphalt binders, asphalt aging, rolling thin film oven aging

Background

The Rolling Thin Film Oven (RTFO) Test (AASHTO T240) is utilized to simulate aging that occurs in asphalt binders during hot mix asphalt production. The test exposes a thin film of asphalt binder to heat and moving air for a specified time and a specified temperature. This results in oxidation of the asphalt binder which can be compared to actual aging that occurs during hot mix asphalt production and laydown. After aging in the rolling thin film oven the asphalt binder is subjected to various laboratory tests to measure physical behavior. Behavior is then evaluated to determine whether the asphalt binder is sufficiently resistant to premature oxidative hardening.

Recently, there has been concern that aging in the RTFO may be affected by the elevation of the laboratory where the test is conducted (RMAUPG 2011). This may be of much practical significance since many asphalts are produced at refineries at low elevations where quality control testing is conducted to determine specification compliance. If, however, these asphalts are sold into markets at higher elevations, it is possible the owner-agencies testing these asphalts may get different test results if elevation affects physical properties after RTFO aging. Although it is logical that elevation would affect oxidative aging due to reduced oxygen in the atmosphere as elevation increases, how much of an effect has never been reported in the literature.

This study analyzed the results of asphalt tests after RTFO aging for 73 laboratories across the U. S. ranging in elevation from 21 feet mean sea level to 6901 feet mean sea level. Seven grades of asphalt were analyzed ranging from PG64-22 to PG 76-28. The data was compiled by the Western Cooperative Test Group as part of scheduled round robin tests conducted annually to assess the utility of the tests being evaluated. Physical properties evaluated after RTFO aging included dynamic modulus, G*; phase angle, δ; the ratio of dynamic modulus to the sin of the phase angle, G*/sin δ; and each of these three parameters tested at a temperature 6C below the low temperature range of the asphalt grade being evaluated. That is, for a PG64-22 binder, the test data was collected at -28C. This was done as a matter of convenience since this temperature was used to collect multiple stress creep recovery (MSCR) data for each asphalt. In addition, the ductility of the asphalts was analyzed.

Literature Review

There has been a significant amount of research conducted describing the effects of oxidative aging on asphalt binders. For example, analysis of the asphalt aging process during the refining process and into construction was reported by Mercado et al (2005). This research evaluated factors having a detrimental impact on dynamic modulus and phase angle including storage time and temperature, contamination, and modification. Others (Epps, et al 2002) have studied changes in physical properties of asphalt binders at the hot mix facility including contamination with binders of different grades, storage time, and storage temperature. The Fourier Transform Infrared Spectroscopy (FTIR) test has been used to identify asphalt binder functional groups by measuring the absorption of various infrared light wavelengths by an irradiated sample (Jemison et al, 1992) to better understand and explain RTFO-DSR test results. Colbert et al (2011) used simulated aging techniques to analyze potential low temperature cracking of aged asphalts. Recycled Asphalt Pavement (RAP) and artificially-aged asphalt binders were characterized. RTFO and the Pressure Aging Vessel (PAV) were used to age binders, and the Asphalt Binder Cracking Device (ABCD) was used to investigate low temperature binder properties. The relationship between asphalt compatibility, flow properties, and oxidative aging was reported by Pauli and Huang (1997). Embrittlement of asphalt pavemenst was shown to be impacted by changes in the flow properties of the binder. The colloidal-suspension model of asphalt was introduced to investigate asphalt composition changes after oxidation. Corbett separation (ASTM D4124-09) was used to categorize unaged and aged samples. The Christensen-Anderson-Marasteau (CAM) model was modified to create master curves for asphalt composition change in rheological properties after oxidation. Gandhi et al (2010) hypothesized that asphalt oxidation impacts the flow properties of the material in an embrittled state.

One study for NCHRP (Holsinger, 2005) evaluated the precision and bias of RTFO aging on physical test results, but did not segment test results with respect to elevation.

Experimental Method

The data analysis presented in this paper was provided by the Western Cooperative Test Group (WCTG). WCTG was formed in the 1960's with the Wyoming Highway Department Materials Testing Laboratory and several of the asphalt refineries in Wyoming. The group now includes member laboratories from all over the U. S, Canada and Central America according to the website (WCTG.org, 2013). WCTG is an organization that provides information and assistance to promote mutual understanding between users and producers of asphalt materials with an objective to improve the utilization of standardized testing of asphalt materials. Round robin binder tests are conducted every year among the laboratories in order to evaluate the utility of various existing and potentially new binder tests. These round robin test results were used in this study to evaluate the effects of elevation change on RTFO aging.

Asphalts analyzed in this study were PG 64-22, PG 64-28, PG 64-34, PG 70-22, PG 70-28, PG 76-22 and PG 76-28. These binders were provided by nineteen asphalt suppliers. A total of 73 laboratories conducted the tests over a period of one year.

Properties measured after RTFO aging were the complex modulus, G*; the phase angle, δ; G*/sin δ; G* at -6C, phase angle at -6C; G*/sin δ at -6C; and ductility. G*, δ, and G*/sin δ were measured at the appropriate temperature for the asphalt grade being tested and at 6C below this temperature, hence the -6C designation. This was done out of convenience since multiple stress creep recovery tests were also conducted on these asphalts at this temperature, allowing a second temperature for measurement of G*, δ and G*/sin δ.

The significant amount of data analyzed in this study was first organized with respect to laboratory elevation and grouped in 500 foot elevation increments. This was done initially for analysis purposes to determine effects. However, this arbitrary stepwise grouping was abandoned in favor of a continuous analysis utilizing each individual laboratory elevation as a function of each of the seven dependent variables and conducting a regression analysis on the result.

Presenting all the data requires seven tables and occupies several pages of space not affordable here. Therefore, a summary of the results of the statistical analysis of this sizable database is presented below.

Results

The data was regressed to determine the effect of elevation (x-axis) on the dependent variable (y-axis) for each PG binder. A slope of zero for such a regression would indicate that elevation has no effect on the dependent variable. Although presenting each of the resulting 45 graphs and corresponding regression analyses would be desirable (the PG64-22 was not tested for G* @ -6C, δ @ -6C, G*/sin δ @ -6C, or ductility), limited space precludes this. Therefore, a summary of all 45 regression analyses is presented in Table 1.

Table 1 is a summary of the regression statistics indicating the probability that the slope of the regression line for each dependent variable is zero with respect to elevation. Table 1 also shows what the slope of the regression line is when the probability of the slope being zero is less than 5 percent ($\alpha = 0.05$). The slopes shown in Table 1 represent the change in the value of the dependent variable for each 1000 foot increase in elevation. Shaded cells in Table 1 are the combinations that are statistically significant at $\alpha < 0.10$.

Example 1

To illustrate how to interpret Table 1 look at the dependent variable G* for the PG64-22 binder. Table 8 indicates the chances that elevation does not affect G* is equal to $\alpha = 0.009$ or 0.9 percent. From Table 1, the slope of this relationship is -0.058. This means that if the value of G* at sea level is 3.660 then the expected value of G* for the same asphalt at 6000 feet above sea level would be 3.660-(0.058 * 6) = 3.66-0.348 =3.312.

Table 1

Regression Statistics for All Binders and Dependent Variables

Dependent Variable		Binder							Avg	s
		64-22	64-28	64-34	70-22	70-28	76-22	76-28		
G*	Pr>F	0.009	0.400	0.002	0.170	0.005	0.027	0.100		
	Slope	-0.058		-0.057		-0.049	-0.039		-0.050	0.009
δ	Pr>F	0.006	0.029	0.070	0.340	0.004	0.094	0.037		
	Slope	0.097		0.155		0.127	0.111	0.158	0.130	0.027
G*/sin δ	Pr>F	0.017	0.077	0.007	0.208	0.278	0.030	0.014		
	Slope	-0.056	-0.060	-0.083			-0.054	-0.077	-0.066	0.013
G* @ 6C below	Pr>F		0.158	0.002	0.171	0.072	0.022	0.098		
	Slope			-0.095		-0.113	-0.051	-0.054	-0.078	0.031
δ @ 6C below	Pr>F		0.023	0.132	0.394	0.017	0.216	0.078		
	Slope		0.321			0.150		0.114	0.195	0.111
G*/sin δ @ 6C below	Pr>F		0.014	0.003	0.143	0.143	0.059	0.086		
	Slope		-0.079	-0.131			-0.054	-0.078	-0.086	0.032
Ductility	Pr>F		0.655	0.050	0.950	0.460	0.596	0.365		
	Slope			1.280						

Example 2

The effect of elevation on δ for the PG76-28 was 0.158 per 1000 feet elevation change. Table 8 indicates the chances that elevation does not affect δ is equal to $\alpha = 0.037$ or 3.7 percent. So, for a δ of 58.87 at sea level, the expected value for δ at 6000 feet above sea level would be 58.87+(0.158 * 6) = 59.82.

Analysis

Of the 45 regression analyses conducted on the WCTG data to determine if elevation has an effect on the dependent variables G*, δ, G*/sin δ and ductility after RTFO aging, a total of 26 combinations were statistically significant at $\alpha < 0.10$ and 19 combinations were significant at $\alpha < 0.05$. Interestingly, six of the seven PG binders were affected by elevation change for most of the dependent variables except the PG 70-22, which was not affected by elevation change. Also, ductility was not affected by elevation except for the PG64-34 binder. And, although statistically significant at a = 0.05 for the PG64-34, all the other binders showed highly non-significant results.

Conclusions

1. This preliminary analysis indicates that laboratory elevation above sea level has an effect on the dynamic shear rheology of PG asphalt binders after rolling thin film oven aging.
2. The elevation effect was statistically significant in 26 out of 45 combinations analyzed.
3. The elevation effect appears to be significant enough to warrant further investigation and possibly revision of test procedures to avoid the possibility of rejecting materials for non-conformance to specifications when, these materials may, in fact, meet specifications.

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