MODIFICATION OF THE ROLLING THIN FILM OVEN TEST FOR MODIFIED ASPHALT

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ABSTRACT

The Rolling Thin Film Oven Test (RTFOT) is a standard AASHTO test method to simulate the aging of asphalt plant mixes. However, it has been found to be inadequate for aging modified asphalts. Since modified asphalt is exposed to more severe conditions during construction than base asphalt, the RTFOT procedure should be more strictly applied than the current AASHTO T240-98 developed for base asphalt. This study investigated the modification of RTFOT temperature using six modified asphalts with various PG grades and sources. The modified RTFOT (MRTFOT) recommended by NCHRP 9-10 was also evaluated for comparison. SHRP grading and phase angle were employed as indicators of the extent of aging. It was found that the RTFOT conducted at elevated temperatures could produce modified asphalt flowing as a uniform film and achieve a better aging effect than the MRTFOT. From available data, 0.25 Pa.s is necessary for modified asphalt to flow and age adequately in the RTFOT. Also, a simple approach was proposed to determine the RTFOT temperature for modified asphalts: if un-aged modified asphalt is rated as PG70, then it should be aged at 173°C; if it is rated as PG 76 or a higher grade, then 178°C is recommended for the RTFOT. In this way, no additional test is necessary for choosing the RTFOT temperature for various modified asphalts.

Keywords: RTFOT, Modified asphalts, Temperature, Performance Grade, Viscosity, Phase angle, MRTFOT

1. INTRODUCTION

The Rolling Thin Film Oven Test (RTFOT) conducted at 163°C over a period of 85 minutes is the standard test (AASHTO T240) for the simulation of hot-mix asphalt aging. Though valid for unmodified asphalt, it has been proved to be inadequate for modified asphalt. One of the main problems with the RTFO procedure for modified binders is that modified asphalts, because of their high viscosity, will not roll inside the glass bottles during the test. To solve this problem, project NCHRP 9–10 was launched and an NCHRP 459 report (Bahia *et al*., 2001) report was published in 2001. In the report, a modified RTFOT (MRTFOT) was presented, using a steel rod 127 mm long and 6.35 mm in diameter. Metal rods placed in the RTFOT bottles caused modified asphalts to spread more evenly, thereby adequately aging the modified asphalts (Bahia *et al*., 2000). However, an evaluation of the MRTFOT method conducted by the Federal Highway Administration (FHWA) concluded that the use of metal rods reduced RTFO aging of modified asphalts and caused asphalt binder to drip out of the glass bottles (Hemsley, 1999; Satish *et al*., 2000). As a result, new methods such as the Modified German Rolling Flask (MGRF) and Stirred Airflow Test (Texas A&M Approach) emerged as alternatives to the RTFOT.

The latest research shows that MGRF aging is equivalent to RTFO (Satish *et al.*, 2004). Although the MGRF is less expensive, a fairly large investment is still required to purchase new equipment for RTFOT users, especially in developing countries. If the problems with the RTFOT could be addressed without having to develop completely new equipment, considerable savings in time and equipment could be achieved. This study tried to address the problem by modifying the oven temperature.

The primary problem with the RTFOT for modified asphalt lies in the high viscosity of modified asphalts. Under the RTFOT temperature of 163°C, the viscosity of modified asphalt is three- to tenfold that of conventional asphalt. Therefore, the temperature determined by the equiviscous principle is excessively high for some modified asphalts, which damages the asphalt binder, generates fumes, causes asphalt binder draindown, and may lead to a low asphalt binder content in some mixtures. Due to the above problems, still more research is needed to establish viscosity ranges for modified asphalt mixing temperatures.

The Chinese Technical Specifications for the Construction of Highway Modified Asphalt Pavements (JTJ 036-98, 1999) recommends that the construction temperature of modified asphalt mixtures should be 10°C – 20°C higher than that of conventional asphalt mixtures. As the global climate becomes warmer and traffic volume becomes heavier, high rutting-resistant modified asphalt is increasingly popular for roads. The mixing temperature of these asphalt mixtures has to be elevated to 180°C or even higher.

To simulate the aging of asphalt during the construction period effectively, the RTFOT temperature should conform to, or be equivalent to, the on-site mixing temperature. But in the laboratory, RTFOT bottles containing samples have the same temperature as the asphalts inside them. By contrast, on-site aggregate temperature is typically 10°C – 20°C higher than that of the asphalt so that the light asphalt fractions evaporate easier on contacting hotter aggregate. Moreover, the field conditions to which asphalt is subjected are more severe than those offered by the RTFOT in the laboratory. The flow of the binder in the RTFOT bottle relies on the action of gravity as the bottle rotates, in contrast to the high shear coating of the aggregate in a pug mill where the thin binder films are quickly formed (AUSTROADS Modified Binder Test, 2003). To compensate for this difference, which reduces the aging severity of the test procedure, elevated temperatures are feasible for laboratory aging simulation. This study experimented with a wide range of modified binders using the RTFOT at three temperatures.

2. OBJECTIVE

The objective of this study was to propose a tentative RTFOT temperature for modified asphalts, reducing the problems of assessing short-term aging of modified asphalts in the Superpave specification without developing completely new equipment.

3. EXPERIMENTAL DESIGN

Six asphalt binders were included in the study, which varied in PG grade (from PG 64 to PG 82) and modifier type used (SBS, EVA modified, representative of elastomer and plastomer). Four of them were produced in the laboratory by the small-scale high-shear mixer, while the other two were production asphalts, namely Styrelf and Luxiang asphalt. For the purpose of comparison, three asphalts were also aged with the MRTFOT. Each test was run in triplicate.

Four laboratory-produced modified asphalt binders were all made from the same base asphalt, PG 58-28.

The modifiers and the test plan are listed below:

- Yanshan 4303 SBS modified binder: RTFOT (3 temperatures)
- D1192 SBS block copolymer modified binder: RTFOT (3 temperatures)
- D1101 SBS block copolymer modified binder: RTFOT (3 temperatures), MRTFOT
- Esso EVA modified binder: RTFOT (3 temperatures), MRTFOT.

Two finished asphalts from modified asphalt suppliers:

- Luxiang SBS modified binder: RTFOT (3 temperatures), MRTFOT
- Styrelf SBS asphalt binders: RTFOT (3 temperatures).

Physical properties, such as complex shear modulus, G*, and phase angle, δ,. were measured on all original and aged materials using the Dynamic Shear Rheometer.

4. MATERIAL PREPARATION

The polymer contents of the four laboratory-produced asphalts were the same, 4% by mass of base asphalt. The base bitumen was heated to 140°C. Polymer was then added and manually mixed for 15 minutes. The temperature of the oil bath was elevated to 180°C while the high-shear mixer operated at 10 000 r/min to achieve high-speed shearing for 4 hours. When the polymers could no longer be seen with the naked eye, the asphalt binder was transferred to the oven at 140°C and subjected to mechanical agitation, no more than 600 r/min with a propeller for 16 hours – long enough for the polymer to be finely dispersed and developed in the asphalt binder as tiny particles of 4 – 6 μm. The experimental results indicated that these polymers were compatible with the base asphalt and the modified asphalts met the requirements of the SBS I-D type.

Table 1. High-temperature performance grade of modified asphalts.

Rutting factor, G*/sinδ , kPa	**Temperature**	**Yanshan 4303**	**D1101**	**D1192**	**Esso**	**Luxiang**	**Styrelf**
Original asphalt binder, kPa	64°C	2.45	1.84	2.17	4.98	/	/
	70°C	1.28	1.05	1.26	3.00	2.32	/
	76°C	0.7	0.57	0.71	1.78	1.57	4.17
	82°C	/	/	/	1.04	0.97	2.38
	88°C	/	/	/	0.73		1.44
163°C, 85 min RTFOT residue, kPa	64°C	3.55	3.25	4.08	5.08	3.71	/
	70°C	1.88	1.74	2.23	3.23	2.39	/
	76°C	/	1.00	1.19	1.94	1.63	4.96
	82°C	/	/	/	/	/	2.57
	88°C	/	/	/	/	/	1.75
PG High-temperature grade		PG64	PG64	PG70	PG70	PG70	PG82

The SHRP high-temperature performance grades of all the asphalts are shown in Table 1. With one exception, namely D1192 modified asphalt, the PG from every 163°C RTFOT residue is always lower than that of the corresponding original asphalt. This occurred primarily because modified asphalt is hard to age adequately in the RTFOT at the traditional temperature, a small property change leading to a grade shift. It is therefore necessary to investigate the effect of oven temperature on short-term aging.

5. DETERMINATION OF TEST TEMPERATURE

Superpave mixture design requires that gyratory specimens be mixed and compacted at equiviscous binder temperatures corresponding to viscosities of 0.17 and 0.28 Pa.s, respectively. This approach provides reasonable temperatures for unmodified binders. However, some modified binders have exhibited unreasonably high mixing and compaction temperatures when using this technique. Estimation of the proper mixing and compaction temperatures involves developing a temperature-viscosity relationship for the binder (ASTM D2493*, Calculation of Mixing and Compaction Temperatures*)

It is found that the double logarithm of viscosity (from the Brookfield Rotating Rheometer) has good linear correlation with temperature (see Figure 1). From this linear relationship, it is easy to obtain the mixing temperature at which asphalt viscosity is 0.17 Pa.s (see Table 2). Generally speaking, the higher the PG of an asphalt, the higher the computed temperature from the equiviscous principle. Taking into account equipment safety in the case of the RTFOT and field practice, 173 °C and 178 °C were selected as temperatures comparable to the standard 163°C. The viscosities at different temperatures are presented in Table 2.

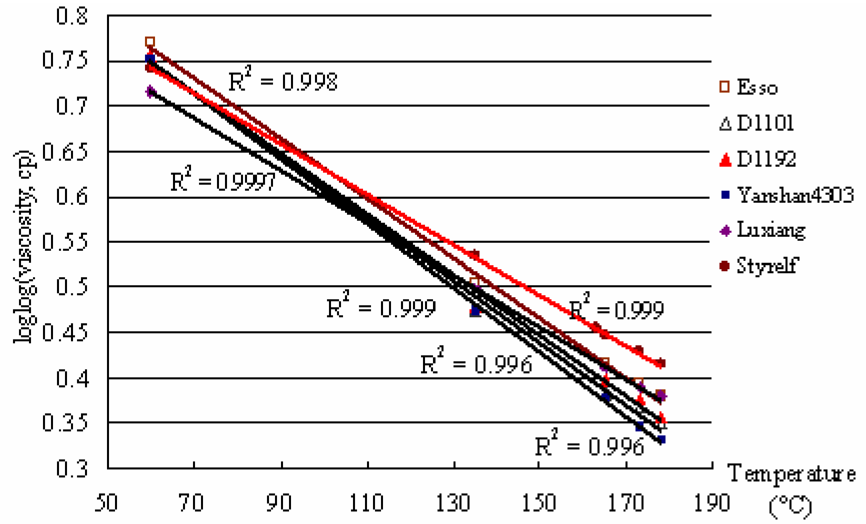

Figure 1. Relationship between viscosity and temperature.

Table 2. Modified asphalt viscosities and equiviscous temperatures.

Asphalt binder		Esso	D1192	D1101	Yanshan 4303	Luxiang	Styrelf
Viscosity Pa.s	60°C	766	522	456	501	163	331
	135°C	1.56	1.02	0.94	0.95	1.41	2.65
	165°C	0.401	0.315	0.243	0.258	0.375	0.63
	163°C	0.434	0.382	0.271	0.276	0.424	0.71
	173°C	0.296	0.239	0.163	0.216	0.283	0.48
	178°C	0.251	0.186	0.14	0.171	0.251	0.403
Equiviscous temperature of 0.17 Pa.s		187°C	178°C	171°C	174°C	186°C	200°C

6. RESULTS AND ANALYSIS

The continuous grades of asphalt binders were interpolated from the linear regression equation (R^2 > 0.99) of the rutting factor ($G^*/\sin\delta$) and grading temperatures in the logarithm co-ordinate. The grading results are shown in Figure 2.

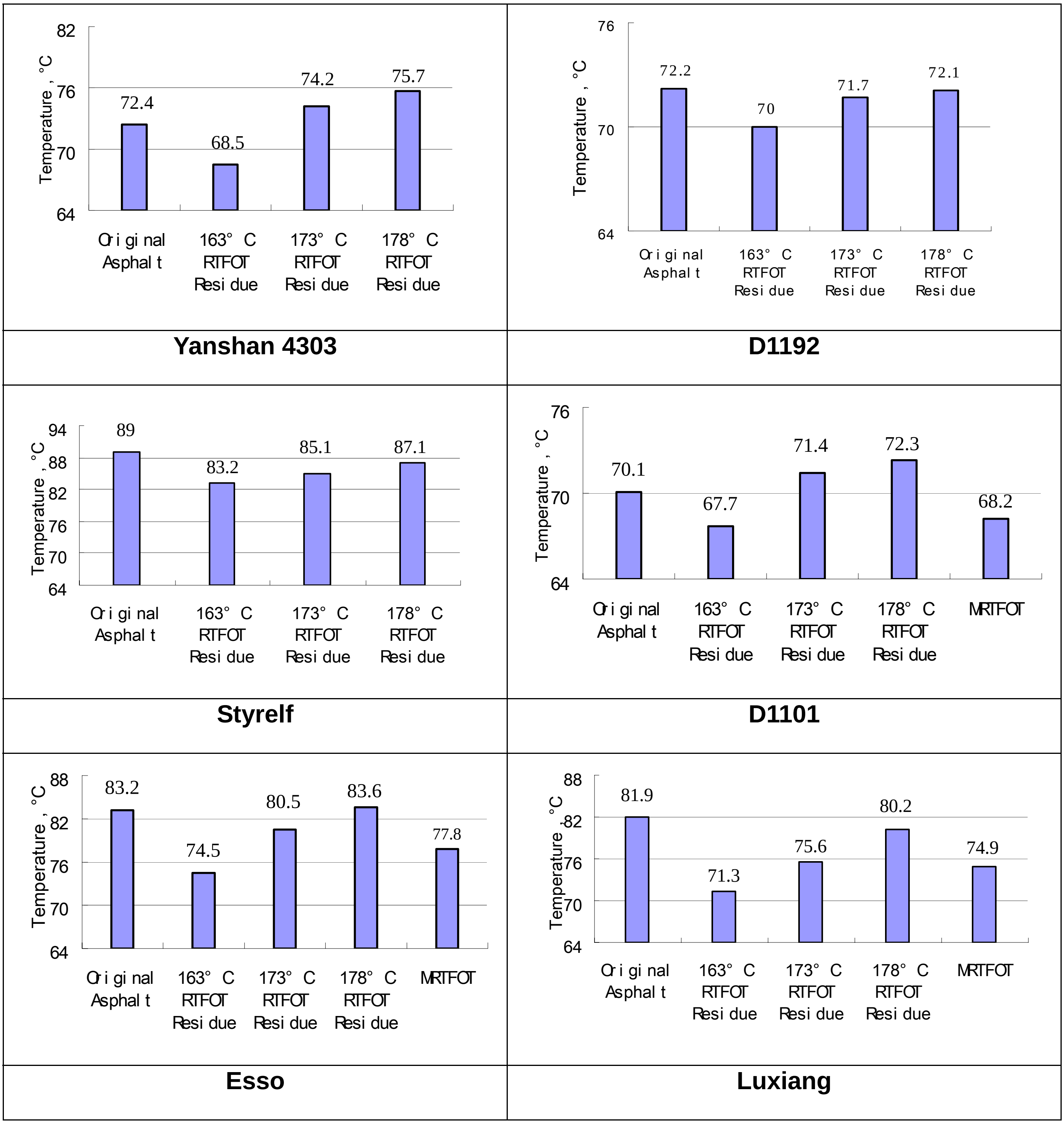

Figure 2. Continuous grading under different conditions.

The MRTFOT results are slightly higher than the standard RTFOT data, but still lower than the results from the 173°C RTFOT residues. The MRTFOT could not solve the problem of the one-grade shift still remaining for three asphalts.

As the RTFOT temperature increases, the rutting factors from the RTFOT residues increase, thus raising the high temperature grade and making it closer to the original asphalt grade. For each binder, the rutting factors for the 173°C RTFOT residue are higher than the 163°C RTFOT result, and they have higher rutting factors at 178°C than at 173°C RTFOT.

On the whole, the 173°C RTFOT result is the closest to the original asphalt grade for two modified asphalts, D1101 and Yanshan 4303, whereas the 178°C RTFOT residues have the most similar result to the original asphalt grade for the other four asphalts. The result is basically consistent with the equiviscous temperature sequence in Table 2. The more approximate to the equiviscous temperature, the more consistent is the result with the original asphalt grading RTFOT residue. Furthermore, the effect of RTFOT temperature is also related to the temperature sensitivity of the asphalt. For example, in Figure 1, Esso modified asphalt is more sensitive than the Luxiang and Styrelf asphalts. Therefore, elevating the RTFOT temperature is more effective for Esso asphalt. However, when viscosity under high temperature decreases enough for the modified asphalt to flow uniformly in the bottles, the RTFOT residue could have a good grading result. From the above limited data, 0.25 Pa.s could be considered as the maximum viscosity for asphalt to flow and age adequately in the RTFOT.

The effect of aging temperature on the phase angle, δ,. was analysed from their relationship curves, as shown in Figures 3 and 4. To consider the phase angle change before and after aging, the phase angle of the original asphalt binder was included. Arabic numerals 1, 2, 3 and 4 in the horizontal co-ordinate denote the original asphalt binders, and 163°C, 173°C and 178°C the respective RTFOT residues.

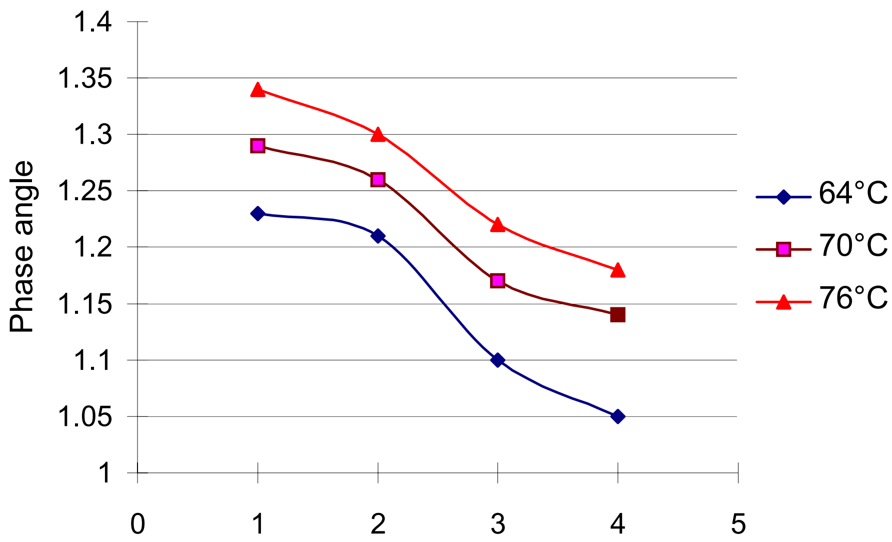

Figure 3. Esso modified asphalt phase angle under different conditions.

For each asphalt binder (e.g. Figure 3), the phase angle increased with the elevation of the DSR test temperature, indicating the increased viscous component. The aging process also decreased the phase angle and increased the elastic response. This was mainly due to the oxidative hardening of the asphalt binders. Since trends in the change of δ with different aging conditions were consistent at different DSR test temperatures for one particular asphalt, it was possible to compare the change tendencies of different asphalts at the selected temperature of 76°C, as shown in Figure 4.

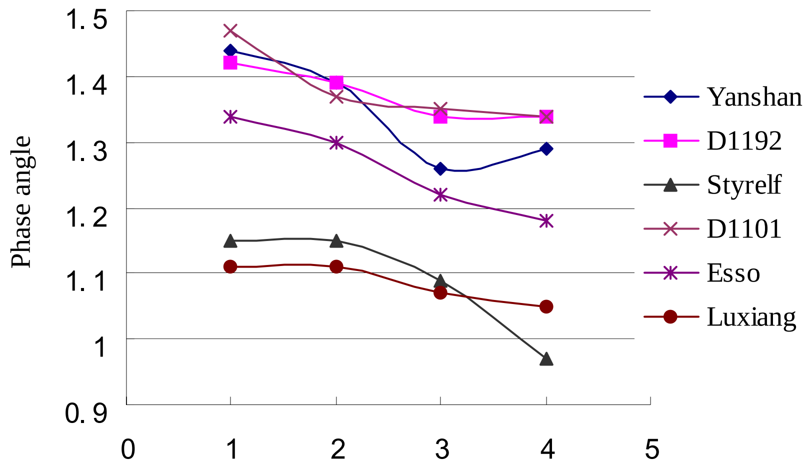

Figure 4. Phase angle change at 76°C under different conditions.

It is clear that the RTFOT temperature has a significant influence on the phase angle, δ. For the Esso, Luxiang and Styrelf modified asphalts, the change in δ between the original asphalt and the 163°C RTFOT residue was very slight and the 178°C RTFOT residue had the smallest δ, i.e. maximum elastic response. These three asphalts were aged adequately at 178°C RTFOT. D1192 modified asphalt had the same δ for the 173°C RTFOT and 178°C RTFOT residues. An extra 5°C increase for RTFOT seemed redundant. Although the 178°C RTFOT residue of the D1192 asphalt had the closest grading to the original asphalt result, the difference between the 173°C RTFOT and 178°C RTFOT results was quite small. As a result, the D1192 asphalt could have an RTFOT temperature of 173°C. The Yanshan and D1101 asphalts had very small or even negative increases in δ from 173°C elevated to178°C as the RTFOT temperature.

In summary, for the original PG70 asphalt, 173°C is suitable as RTFOT temperature. On the other hand, for the original asphalts PG76, PG 82 or a higher grade, 178°C is feasible and practicable. If permitted, the viscosity principle mentioned above should also be adopted to further verify the reasonable RTFOT temperature. However, 0.25 Pa.s was based only on the results of this study; still more experimental data and mechanical analysis are necessary to validate the final viscosity critical value.

7. CONCLUSIONS AND RECOMMENDATIONS

Six modified asphalts were aged under different RTFOT temperatures and their properties were evaluated and analysed.

The following conclusions were drawn from this study:

- RTFOT temperature has a significant effect on the aging process. Elevating the oven temperature properly could subject modified asphalt to adequate short-term aging without having to introduce new equipment.
- The double logarithm of viscosity has a strong linear correlation to temperature for modified asphalts. The equiviscous temperature of 0.17 Pa.s is a bit high for some modified asphalts. From this study, the maximum viscosity limit of 0.25 Pa.s could be tentatively considered for determining the equiviscous principle of RTFOT temperature. But there is still more work to be done to verify this critical value.

- For the original PG70 asphalt, the RTFOT temperature should increase by 10°C, i.e. RTFOT at 173°C; for the original asphalts of PG76, PG 82 or a higher grade, another 5°C increase is necessary. In other words, the RTFOT should be carried out at 178°C. If permitted, the viscosity principle mentioned above should also be followed to further verify the proper RTFOT temperature.
- The MRTFOT results are slightly higher than standard the RTFOT data but still lower than the results from the 173°C RTFOT residues. The modified test could not achieve the same good effect as the elevation of the RTFOT temperature.
- The aging treatment decreases the phase angle. The change tendency of the phase angle confirms the simple approach (point 3 above) to determining the RTFOT temperature for modified asphalts.

8. REFERENCES

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