ANALYSIS OF ASPHALT-BASED ROOF SYSTEMS USING THERMAL ANALYSIS

Ralph M. Paroli and Ana H. Delgado

Institute for Research in Construction,
National Research Council of Canada
Ottawa, Ontario, Canada K1A 0R6

Keywords: Thermal analysis, roof membrane, asphalt, modified bitumen

INTRODUCTION

Asphalt has been used in the construction of roads and houses for thousands of years. The properties of asphalt has rendered it quite useful in roofing and waterproofing applications. The most popular use of asphalt in industrial roofing is in the form of a built-up roof or modified-bituminous sheet. This type of roof consists of asphalt, reinforcement and aggregate which is used to protect the asphalt from ultraviolet rays. All materials have their weaknesses and asphalt is no exception. A good asphalt (e.g., low asphaltene content) must be used to ensure the quality and low-temperature performance of roofing asphalts. Polymer additives can be added.

The criteria for choosing a polymer additive are: (a) the viscosity of the asphalt should not be significantly altered (b) It must be sufficiently compatible with the asphalt so as to avoid any phase separation during application (even at high temperatures). (c) It must improve some of the mechanical properties of the asphalt such as resistance to permanent deformation, fracture and high-temperature. In low-temperature environments, the polymer must be able to enhance the low-temperature flexibility and lower the glass-transition temperature (T_g) of the asphalt. Two commonly used polymer additives are styrene-butadiene-styrene block copolymer (SBS) and atactic polypropylene (APP). The exact amount of polymer added depends on the polymer and desired property. For example, 10-15% of SBS is sufficient to yield a continuous phase in the asphalt.

Roofing membranes have been used for many years. In the past, the testing of various roofing materials was simple because of the accumulated experience and also because of the lack of variety. Today, with the variety of additives, it is quite difficult to compare them solely on the basis of mechanical properties. This is especially true since the mechanical properties of these materials are not only related to macroscopic behaviour but also at the molecular level which is controlled by chemical composition and molecular arrangement.

Thermal analysis is a technique that can provide some insight as to why some roofing materials do not perform properly. In the past seven years, quite a few papers have been published using these techniques for roofing (see references 1-10 and references therein). Thermogravimetry (TG) can be used to monitor weight loss due to weathering and/or aging. Dynamic mechanical analysis (DMA) can be used routinely to determine the glass transition temperature. Together, DMA and TG can provide a measure of the degradative factors which can lead to the correlation between accelerated weathering and actual field performance. The objective of this study is to demonstrate the utility of TG and DMA in establishing the durability of modified-bituminous roof membranes.

EXPERIMENTAL

Composition of Modified Bitumen Membranes.

Four commercially-available, polymer-modified bituminous roofing membranes were obtained and labelled as SBS1, SBS2, SBS3 and APP1. A typical composition for the roofing membrane samples used in this study is given in Table I. The quantities will vary from product to product. It should be noted that the granules, reinforcement and polyethylene account for between 36 and 40% of the total weight of a cap sheet but are excluded from the percentages listed in Table I.

Sample Preparation

Each material was cut into seven pieces of about 150 x 250 mm. One piece was used as a control, three were placed in an air-circulating oven preheated at 80 °C, and the remaining three were placed in an air-circulating oven set at 100 °C, for heat-aging. One piece of each material was removed from the oven, after 1, 7, and 28 days. Specimens were cut out for tensile testing and thermal analyses.

Thermogravimetry (TG)

The weight-loss of each roofing sample was monitored by thermogravimetric analysis using a Seiko Instruments Inc. STA 320 interfaced to a HP-900 Workstation. A piece of approximately 20 mg of sample was cut without including granules. The analyses were carried out at temperatures between 20 °C and 600 °C using a nitrogen gas flow of 150 mL min^{-1} and from 600 °C to 1000 °C under air. The scanning rate was 20 °C min^{-1}. Throughout this study the derivative TG (DTG) curve was used as it provided the desired quantitative data (see Fig. 1). The data are tabulated in Table II as a function of heat-aging temperature and exposure-time.

Dynamic Mechanical Analysis (DMA)

The glass transition temperature of the membranes was obtained using a Rheometrics RSA II (software version 3.0.1) dynamic mechanical analyzer equipped with a mechanical cooling device. The following experimental profile was used for this study:

Geometry:	3-point bending
Sample width:	8 - 10.5 mm
Sample thickness	3.5 - 4.0 mm
Sample length	48.00 mm
Sweep type	Temp. steps
Frequency:	1 Hz (6.28 rad/sec)
Temperature Range:	-100 °C to +30 °C
Heating Rate:	2.0 °C/min
Soak Time:	2.0 min
Strain:	2×10^{-2} %

Typical DMA curves are shown in Fig. 2. The glass transition temperature, T_g, (α-transition values) was obtained from the average of at least two and no more than four specimens from the same sample. The values are reported as the maximum in the loss modulus (E") vs temperature curve. It is also possible to use the maximum of the tanδ peak vs temperature curve, however, it was found that the E" curve gave a better correlation with traditional mechanical data (e.g., tensile and elongation). The glass transition temperatures of the various samples are summarized in Table III.

RESULTS AND DISCUSSION

Three SBS (styrene butadiene styrene) modified membranes and one APP (atactic polypropylene) modified membrane were selected. The granules on the SBS modified membranes should be taken into account during analysis because they account for approximately one-third of the total weight and are not affected by high temperatures. Their presence minimizes the weight loss detected during the actual experiment. For this reason, the granules were removed from the SBS samples prior to testing. The APP modified membrane did not contain granules.

The results of the TG show that the polymer-modified bitumens are not affected by short term exposure to temperatures of 80 and 100 °C. But two samples show a large loss of weight after being heated in an oven for

28 days at 100 °C. The weight loss for SBS1 and SBS2, as determined by TG, is much less after 28 days of heating at 100 °C than it was at 7 days. Thus, weight was lost in the oven during the aging. This demonstrates that this technique can be useful in determining the relative stability of modified bituminous membranes. It is likely that changing the conditioning by heating the membrane in an oven for six months at 80 °C would provide a better reading on the long term durability of these membranes. In the field, loss of protective granules, which is a problem, will also expose the bitumen to UV radiation and accelerate the overall rate of deterioration of the membrane.

Generally, the glass transition temperature of control SBS modified membranes is in the -48 to -50 °C range. Heat aging, however, gradually raises the T_g to around -30 °C. On the other hand, the APP modified sample appears to be unaffected by heating as its T_g remains constant at -30 °C. Most samples also showed a another transition around -15 °C. While the component responsible for this transition is still unknown; its existence, however, might indicate that installing SBS-modified membranes in sub-zero temperature, using hot asphalt, as specified by the manufacturers could cause problems. It should be noted that all manufacturers call for their membranes to be unrolled and allowed to relax prior to installation.

CONCLUSIONS

The modified bituminous membranes, because of their low softening temperature and their complex chemical composition, provide results that are more difficult to interpret than the previously published EPDM and PVC membranes. The results, nevertheless, appear to be quite reliable when compared to the performance of these membranes in the field.

The results have shown that APP-modified material had a warmer glass transition temperature than the SBS-modified. The APP-modified bitumen, however, was more heat resistant than the SBS-modified ones.

The heating-aging temperature of 100 °C is not recommended because of the low softening point of the asphalt. A heat-aging temperature of 80 °C for six months could be preferable to assess the relative durability.

Loss of weight resulting from heat-aging affects the performance of modified bituminous membranes and appears to be an important factor in determining service-life. Little weight loss (~5%) after aging/weathering is indicative of stability to the aging program.

REFERENCES

1. C. G. Cash, Single Ply Roofing Technology: ASTM STP 790, pp. 55-64, (1982).
2. D. Backenstow and P. Flueler, *Proceedings, 9th Conference on Roofing Technology*, National Roofing Contractors Association, Rosemont, IL, pp. 54-68, April 1987.
3. R. M. Paroli, O. Dutt, A. H. Delgado, M. Mech, Thermochimica Acta, **182**, 303-317, (1991).
4. G. D. Gaddy, W. J. Rossiter, Jr., R. K. Eby, *Proceedings, 1991 International Symposium on Roofing Technology, pp.* 502-507, 1991, F. Kocich, editor, National Roofing Contractors Association, Rosemont, IL.
5. G. D. Gaddy, W. J. Rossiter, Jr., R. K. Eby, *ASTM STP 1136*, 168-175, (1991).
6. R. M. Paroli, O. Dutt, A. H. Delgado, H. K. Stenman, Journal of Materials in Civil Engineering **5**(1), 83-95, (1993).
7. K. Oba, and F. Björk, Polymer Testing, **12**, 35-56 (1993).
8. J. J. Penn, R. M. Paroli, Thermochimica Acta, **226**, 77-84 (1993).
9. I. S. Rodriguez, O. Dutt, R. M. Paroli, N.P. Mailvaganam, Materials and Structures, **26**(160), 355-361 (1993).

10. "Thermal Analysis Testing of Roofing Membrane Materials: Interim Report of the Thermal Analysis Task Group", *Conseil International du Batiment pour la Recherche l'Etude et la Documentation (CIB) W.83 and Réunion Internationale des Laboratoires d'Essai et de Recherche sur les Matériaux et les Constructions (RILEM) 120-MRS Joint Committee on Membrane Roofing Systems*, September 1993.

11. K. Oba, Flat roofs: Investigation of heat welding Techniques for polymer-modified bituminous roofing membranes. Dissertation, Royal Institute of Technology. Sweden (1994).

12. R. M. Paroli, O. Dutt, T. L. Smith, B. J. Whelan, Roofing Research and Standards Development: Volume 3, ASTM STP 1224, Thomas J. Wallace and Walter J. Rossiter, Jr., Eds., American Society for Testing and Materials, Philadelphia, 1994, pp.139-147.

Table I Typical matrix composition of SBS modified membranes

Ingredients	% by weight	Function
Bitumen	66 - 74	Waterproofing agent
Rubber modifier	11 - 16	Imparts elastomeric properties
Filler	11 - 18	Provides rigidity

Table II TG data for modified bituminous membranes

Heating Schedule		Weight Loss (%)			
Temp (°C)	*Days*	*SBS1*	*SBS2*	*SBS3*	*SBS4*
unheated		71.8	78.4	55.5	78.2
80	1	69.1	80.6	57.3	78.8
80	7	71.6	71.9	54.8	78.8
80	28	70.3	70.8	55.3	77.0
100	1	70.3	74.8	57.6	74.0
100	7	69.2	73.0	55.1	75.9
100	28	36.3	29.9	52.1	73.8

Table III Glass Transition Temperature (T_g) of Modified Bitumens

Heating Schedule		Tg (°C) for Samples			
Temp (°C)	*Days*	*SBS1*	*SBS2*	*SBS3*	*APP1*
Unheated		-50	-50	-48	-30
80	1	-50	-50	-46	-30
80	7	-40	-50	-46	-30
80	28	-40	-48	-50	-30
100	1	-40	-40	-50	-30
100	7	-40	-40	-48	-30
100	28	-30	-30	-30	-30

Figure 1. Typical TG/DTG curves for a polymer-modified bitumen roof membrane.

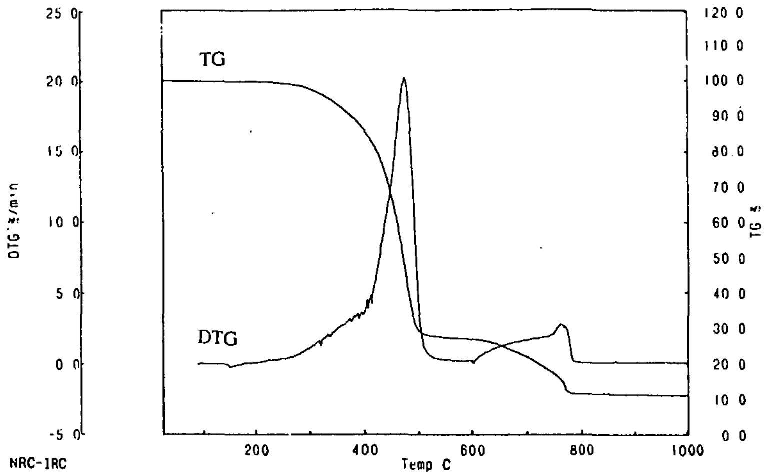

Figure 2. Typical DMA curves for a polymer-modified bitumen roof membrane.