

Evaluation of the Properties of Bituminous Binders Modified with Recycled Waterproofing Membranes (RWM)

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1 Introduction

The main purpose of waterproofing systems is to protect from water permeability and to improve the service life of structural elements, such as bridge decks [1]. Waterproofing products can be grouped under three main categories: sheet systems, liquid (sprayed) systems and mastic layers. The common aspect among these three solutions is the presence of polymers and bitumen [2]. Among waterproofing materials, bituminous waterproofing membranes (WM) have been the most common and widespread roofing and waterproofing products over the years. Bitumen modification with different polymers is necessary in order to meet performance and durability requirements [3, 4].

The two most employed polymers for WM modification are styrene–butadiene–styrene (SBS) copolymers and atactic polypropylene (APP) polymers. SBS polymers confer more elasticity on bitumen at ambient temperatures than do APP polymers and have rubber-like damping characteristics. For this reason, SBS polymer-modified WM are more suitable for cold climate applications than are APP polymer-modified products, whereas APP polymers confer more resistance at high service temperatures because the absence of the double bond possibly makes them prone to oxidation at elevated temperatures [5].

In a sustainable and ecological perspective, a few companies have developed recycling processes of waterproofing membranes (either coming from the production, the installation or the deconstruction of structures), saving up to 15% on the dumping costs. At the end of the treatment process, a part of the recycled waterproofing membranes (RWM) obtained

is incorporated into the formulation of new membranes, thus reducing the use of primary resources. The results showed that the substitution of 25% of virgin bitumen by the same amount of RWM in a binder formulation leads to a 13% decrease of the CO₂ eq. emissions [6]. However, other possibilities for RWM can be evaluated, especially in terms of bituminous materials such as hot mix asphalts (HMA) [7].

For this reason, the objective of this study is to evaluate RWM in bituminous binders suitable for road pavement materials. The research project covered a multi-scale experimental programme, but only the part related to bituminous binders is discussed in this chapter.

2 Materials and Testing Methods

The materials involved in this study are a plain bitumen used as a base binder for the addition of two types of RWM: SBS polymer-modified RWM (RWM_{SBS}) and APP polymer-modified RWM (RWM_{APP}).

2.1 Raw Materials

The bitumen used is a B70/100 bitumen and the main rheological properties are collected in Table 1. In addition, fatigue performance was evaluated according to the linear amplitude sweep (LAS) test (American Association of State Highway and Transportation Officials (AASHTO) T391–20).

RWM_{APP} is formed by a bituminous component modified with plastomers. It is used for any waterproofing applications with no specific requirements at low temperatures or ductility. RWM_{SBS} is modified with a thermo-elastomeric polymer that confers, under standard service conditions, similar properties to vulcanized rubber. Hence, RWM_{SBS} has higher ductility at low temperatures (up to –25 °C) and higher resistance to loads. The two types of RWM investigated were initially analysed in terms of bitumen and filler

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Table 1 B70/100 bitumen properties

Property	Standard	Unit	Value
Penetration	UNI EN 1426	dmm	83
Softening point	UNI EN 1427	°C	45.9
Brookfield viscosity at 160 °C	UNI EN 13302	Pa·s	0.090
Performance grade	ASTM D6373	–	63.6–23.8
	ASTM D8239	–	58V-22
Multiple stress creep and recovery test (MSCR) at 58 °C	J_{nr} (0.1 kPa)	UNI EN 16659	kPa ⁻¹
	J_{nr} (3.2 kPa)		kPa ⁻¹
	%R (0.1 kPa)		%
	%R (3.2 kPa)		%
Linear amplitude sweep (LAS) at 22 °C	Nf (2.5%)	AASHTO T391–20	–
	Nf (5.0%)		–
	Nf (15%)		–

Table 2 Bitumen content of RWM

RWM type	Bitumen content (%)	Filler and reinforcement content (%)
RWM _{SBS}	50.8	49.2
RWM _{APP}	48.7	51.3

content, aspects that were similar between the two materials (Table 2).

2.2 Bituminous Blends and Testing Methods

The study evaluates the addition of RWM to the base binder B70/100 by the dry method, in the form of shredded material containing all the components (Fig. 1a, b). The RWM dosages studied were 10%, 20% and 30% by total bituminous blend mass for both RWM types. Blending operations were performed by means of a high-shear mixer for bitumen modification and an oil bath used to keep operating temperatures constant at 190 °C (Fig. 1c). The RWM and base binder were mixed for 1 hour, considered the time necessary to obtain an optimal RWM distribution, at a shear speed of 1800 RPM. A total of six bituminous blends were produced and studied (Table 3).

Empirical and Rheological Characterization

The six blends produced were initially characterized by empirical tests, such as needle penetration (UNI EN 1426), ring and ball softening point (SP) (UNI EN 1427) and Brookfield viscosity at 160 °C (UNI EN 13302). Furthermore, a rheological characterization was carried out by means of a dynamic shear rheometer (with plate–plate 25- and 8-mm

configurations) and a bending beam rheometer. The analysis involved $|G^*|$ complex shear modulus determination and analysis of the resulting master curves, determination of the performance grade (PG), multiple stress creep and recovery (MSCR) test performed at 58 °C and linear amplitude sweep (LAS) test performed at 22 °C. Short- and long-term ageing were simulated by the rolling thin-film oven test (RTFOT, UNI EN 12607–1) and the pressure ageing vessel (PAV, UNI EN 14769) procedures, respectively.

3 Results

3.1 Empirical Characterization

Figure 2 shows the results in terms of empirical tests. Needle penetration values are reported as an average of three measurements on one sample, whereas softening point temperatures and viscosity values are calculated on one sample. It is remarkable that the incremental dosage of RWM confers a stiffening effect, represented by a progressive decrease in the needle penetration value and an increase in softening point and viscosity. The effect of RWM addition is more critical for what concerns needle penetration and viscosity: in the first case, the results vary between 83 dmm of the penetration value for B70/100 and a minimum of 36 dmm (loss of 57%), whereas in the second case, viscosity varies between 0.090 Pa·s for B70/100 and 0.400 Pa·s (increase of 350%). On the other hand, softening point is less influenced by the addition of RWM, going from 46.0 °C for B70/100 to a maximum of 60.4 °C (increase of 30%). The addition of RWM_{APP} instead of RWM_{SBS} confers higher values of penetration and viscosity (only for dosages of 30%), whereas softening point values do not vary significantly.



Fig. 1 (a) RWM_{APP} ; (b) RWM_{SBS} ; and (c) a high-shear mixer

Table 3 Bituminous blends studied

Bituminous blends		Dosages by bituminous blend mass	
APP	SBS	B70/100 (%)	RWM (%)
RWM_{APP10}	RWM_{SBS10}	90	10
RWM_{APP20}	RWM_{SBS20}	80	20
RWM_{APP30}	RWM_{SBS30}	70	30

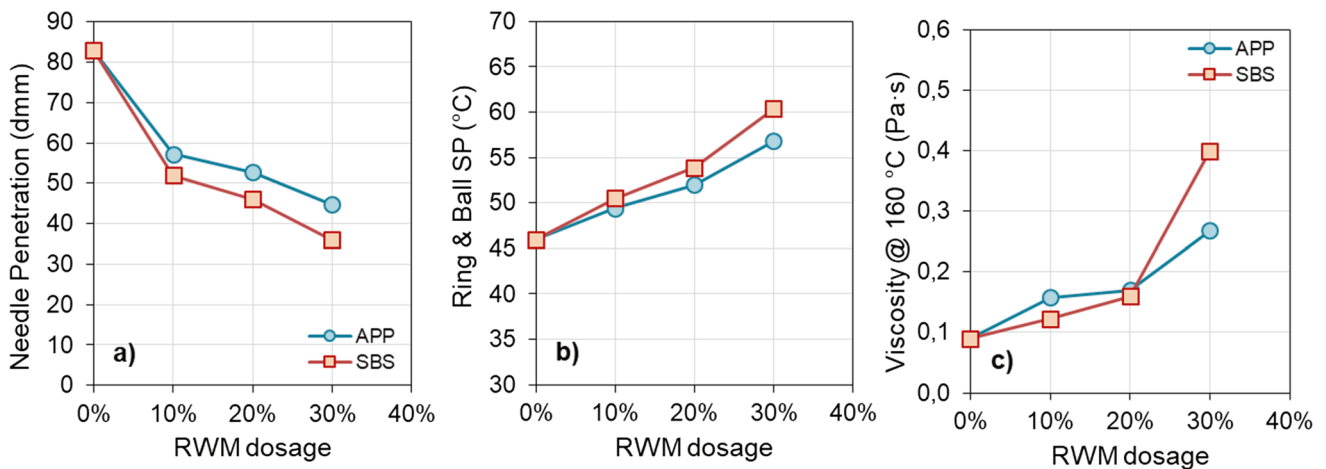


Fig. 2 Empirical tests results: (a) needle penetration; (b) SP; and (c) viscosity

3.2 Rheological Characterization

Figure 3 shows the results obtained from complex shear modulus $|G^*|$ and phase angle δ measurements. The reference temperature adopted is 20 °C, and the analysed temperature range is from −10 °C to 70 °C. The addition of RWM in plain bitumen confers higher stiffness and lower phase angle values at low frequencies (high temperatures). The higher the RWM dosage, the more visible is the influence on stiffness and phase angle values.

Considering the same amount of RWM in the bituminous blend, RWM_{APP} has a higher stiffening effect compared to RWM_{SBS} and a different behaviour in terms of phase angle δ . In case of RWM_{APP} , it is possible to observe a higher influence of the filler contained in the blend (decrease of the phase angle at high temperatures), whereas in case of RWM_{SBS} , the influence of SBS polymers on the phase angle at high temperatures is more visible, especially with RWM dosages equal to 20% and 30%.

Table 4 displays continuous PG classification of the bituminous blends studied, according to both classification

systems (ASTM D6373 and ASTM D8239). In general, the addition of RWM improves high temperature performance, by an increase in the maximum service temperature. At the same time, the minimum service temperature is penalized by an increase from -23.8 °C of B70/100 to -8.3 °C considering the introduction of RWM. It is reasonable to assume that the presence of the filler and other constituents contained in RWM confers lower ductility and higher stiffness to the bituminous binder at low service temperatures.

Table 5 shows results in terms of the MSCR test performed at 58 °C at two stress levels, 0.1 kPa and 3.2 kPa, subsequently to the short-term ageing simulation. The results related to B70/100 are reported in Table 1. The use of RWM in plain bitumen is generally beneficial, decreasing the non-recoverable creep compliance value and improving the aver-

age elastic recovery at both stress levels and highlighting both the influence of the filler and the presence of polymers.

In particular, the parameters studied with the MSCR test, i.e. J_{nr} and $\%R$, improve with the progressive addition of RWM from 10% to 30%. Furthermore, RWM_{SBS} performs better than RWM_{APP} , especially in terms of elastic recovery due to the presence of elastomers.

Figure 4 depicts LAS test results in terms of shear stress vs. shear strain curves and of dissipated energy. The stress-strain curves represent the stiffness and hardness of bitumen in the initial phase, i.e. up to the maximum shear stress, and the ductility and resistance to damage in the second phase, i.e. the descending part of the curve.

Bituminous blends with RWM_{APP} are characterized by higher shear stress in the first part compared to RWM_{SBS} , due

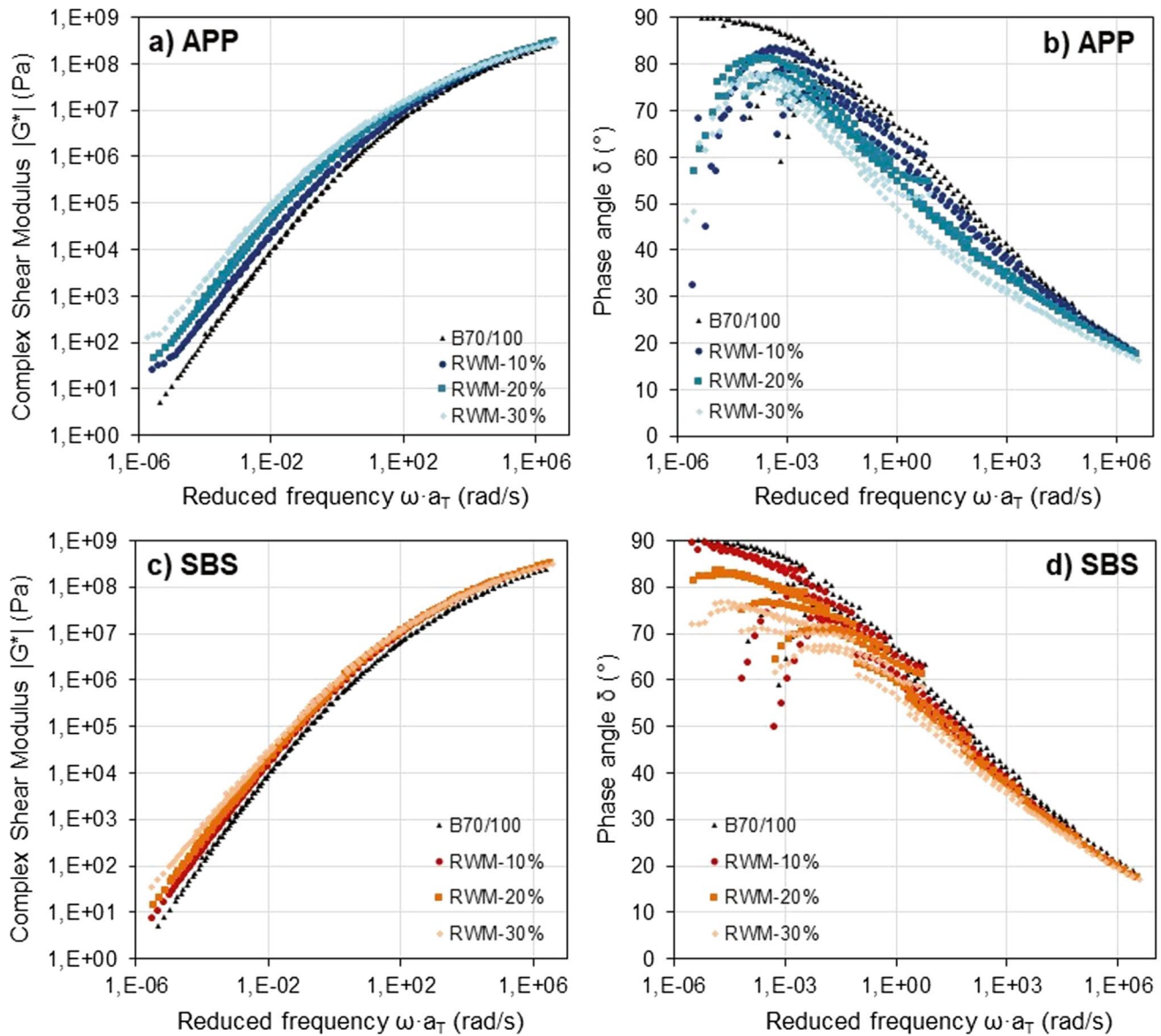


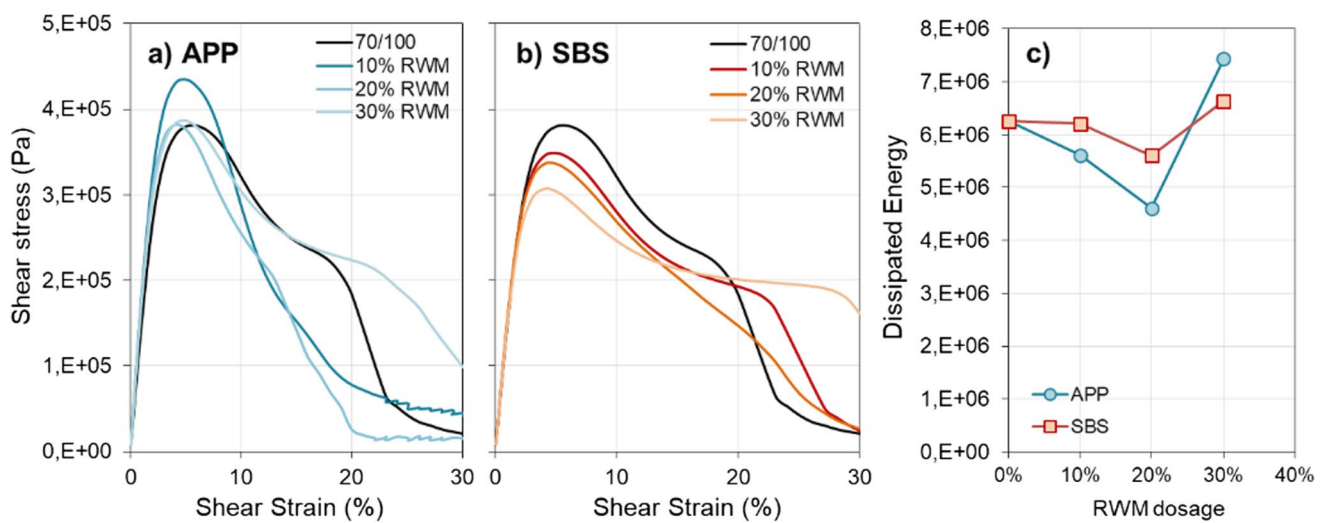
Fig. 3 Master curves ($T_{REF} = 20$ °C): (a) Complex shear modulus $|G^*|$ for RWM_{APP} ; (b) phase angle δ for RWM_{APP} ; (c) complex shear modulus $|G^*|$ for RWM_{SBS} ; and (d) phase angle δ for RWM_{SBS}

Table 4 Performance grade (PG) of the bituminous blends studied

APP	PG	SBS	PG
RWM _{APP10}	58E-10 (66.8–12.3)	RWM _{SBS10}	58E-16 (66.3–17.3)
RWM _{APP20}	58E-16 (71.6–11.3)	RWM _{SBS20}	58E-10 (69.6–13.6)
RWM _{APP30}	58E-16 (76.5–8.3)	RWM _{SBS30}	58E-10 (73.7–12.6)

Table 5 MSCR test results

	J_{nr} (kPa ⁻¹)		%R			J_{nr} (kPa ⁻¹)		%R	
Load (kPa)	0.1	3.2	0.1	3.2	Load (kPa)	0.1	3.2	0.1	3.2
RWM _{APP10}	0.41	0.47	24	13	RWM _{SBS10}	0.39	0.45	29	19
RWM _{APP20}	0.18	0.23	38	24	RWM _{SBS20}	0.20	0.23	44	35
RWM _{APP30}	0.06	0.07	49	38	RWM _{SBS30}	0.08	0.10	62	53

**Fig. 4** LAS test results ($T = 22$ °C): (a) Stress–strain curve for RWM_{APP}; (b) stress–strain curve for RWM_{SBS}; and (c) dissipated energy

to the higher stiffness (see Fig. 3), whereas in the second part, bituminous blends with RWM_{SBS} show a higher ductility and better resistance to the increasing shear strain. To better represent the dissipated energy and analyse the fatigue properties, the area under the stress–strain curve was calculated by the trapezoidal rule and shown in Fig. 4c. It is highlighted that with 10% and 20% of RWM addition, fatigue performance is penalized compared to that of the base binder B70/100, whereas with 30% addition of RWM, the dissipated energy is higher.

4 Conclusions

Waterproofing membranes are widely used for applications in civil engineering infrastructures. While it is already possible to reuse RWM in the bituminous membrane production process, the objective of this study was to evaluate the introduction of RWM (up to 30%) with SBS and APP polymers in

a plain bitumen employed for road pavement material production. The programme involved the bituminous binder rheology investigation, and the following conclusions can be listed:

- From the empirical characterization, it is possible to observe the stiffening effect conferred by RWM introduction, especially in terms of needle penetration and viscosity. This aspect is confirmed from the analysis of the shear complex modulus $|G^*|$ master curves.
- RWM lead to better properties in terms of permanent deformation and elastic recovery, regardless of the dosage. Bituminous blends with 30% of RWM are characterized by a higher resistance to fatigue damage if compared to plain bitumen.
- RWM with SBS polymers globally showed better properties compared to those containing APP polymers, particularly in terms of elastic recovery.

- The use of RWM penalizes the binder rheological properties at low temperatures, by increasing the minimum service temperature of the bituminous blend PG.

The results obtained encourage the possibility of reusing aged bituminous waterproofing membranes in asphalt materials, thus reducing the virgin binder by up to 30%. On the other hand, future studies and efforts should investigate how to improve the properties of bituminous binders containing RWM at low service temperatures without affecting the same at high service temperatures.

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