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A simple interpretation of the effect of the polymer type on the properties of PMBs for road paving applications

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HIGHLIGHTS

- Characterization of a PMB requires different tests to be carried out.
- This preliminary laboratory effort is costly and time consuming.
- Flow curves are proved to be useful in interpreting the influence of polymer type.
- This can be helpful in selecting promising polymer/bitumen blends for production.

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ABSTRACT

The paper presents the results of the rheological characterisation of polymer-modified bitumen for paving applications. In order to find a simple interpretation of the influence of polymer type on the blends produced, in this study high density and low density polyethylene (PE) with different chemical properties were used, as well as ethylene-vinyl acetate. The chemical characteristics of the base bitumen and the polymers used were determined by means of SARA analysis and Fourier Transform Infrared Spectroscopy, FTIR, respectively. The morphology of the produced blends was investigated by means of fluorescent light optic microscopy, while the mechanical properties were investigated with both conventional tests and rheological measurements (dynamic mechanical analysis through frequency sweep test and viscosity measurements).

The analysis of the modified bitumens was carried out based on the chemical structure and crystallinity properties of the polymer used. The flow curves (viscosity vs shear rate), in particular, proved to be an initial indicator of the type of modification attained. This shows that simple tests can be helpful in predicting the internal structure of the polymer modified binders (PMBs) and thus in selecting promising polymer/bitumen blends of the PE family to be submitted to full characterization for production purposes.

1. Introduction

Polymer-modified bitumens have been widely used in road paving applications, and it is known to be a continual challenge in terms of producing PMBs with improved engineering properties. So far, there has not been any clear approach to finding a strategy for prevision of the final blend rheological properties in relation with the chemical structure of the bitumen and polymers. In order to provide a reliable description of material interaction, many different tests need to be carried out on the blend as well as on its components, but this is known to be costly and time-consuming.

Bitumen is well known to be a time-temperature dependent material that exhibits viscous behaviour at high temperatures and solid-like behaviour at low temperature. When used in road pavements, for producing asphalt mixtures, it is subjected to both high traffic volumes and seasonal temperature variation, thus consequent fatigue damage and accumulation of permanent deformation are of concern during pavements' service life. Therefore there is a continuous need to produce better material design for flexible pavements with regards to cost, maintenance and sustainability.

It has previously been seen that – depending on the type of modification -pavements with PMBs exhibit greater resistance to rutting and thermal cracking, as well as decreased fatigue damage, stripping and temperature susceptibility [1].

Polymers are used within a variety of end-use applications: consumer plastics, and goods, electronics, building and

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construction, electrical, and many others. Depending on the type of polymers, a successful bitumen modification may result in both a more flexible bituminous binder at low in-service temperatures and more rut-resistant pavements at high in-service temperatures.

In general, the most commonly used polymer-modified bitumens are 75% elastomeric modified binder and 15% plastomeric; the remaining 10% are either rubber or other modifications [2–4].

For many years now, the research community has been involved in deepening research activities in the field of asphalt modification with polymers for enhancing the overall performance of asphalt binders. The aim wasprimarily improving the consequent manufacturing processes, mix plant operations or laydown procedures, in order to meet both the increasing need for high-performance asphalt mixtures and other sustainability issues (i.e. reduction in energy consumption) [5]. Additionally, new specifications and testing methods, specifically valid for these innovative materials, will challenge the technologist's work in the next future.

There are many studies [6–8] available on the compatibility of polymer bitumen blends but there are many difficulties in generalizing the criteria that rule the compatibility between bitumen and polymers, mainly in terms of bitumen composition (chemical nature complex and not constant), polymer type and polarity. The fact is that the physical and mechanical characteristics of the final polymer-bitumen blends cannot be easily predicted since they greatly depend on many factors, such as the components' characteristics and the production procedures. Thus, a full mechanical and chemical characterization of both the blend and its components is crucial for understanding the effectiveness of the modification as well as the expected properties of the polymer/bitumen blends produced. Therefore, the overall objective of this work is to provide a simple tool for interpreting the effect of the chemical structure and morphology of some polymers on the final properties of PMBs. Although many papers and reviews have been published on this subject, in this work the effect of modification is simply interpreted on the basis of the flow curves. In fact it is known that the shape and the values of the flow curves of blends are determined by the molecular structure of the components as well as by their interactions. It is proved that in this study that the flow curves of the polymer/bitumen blends provide results that are connected with the amount of crystallinity and polarity of the polymers used.

2. Materials and methods

2.1. Base bitumen

Conventional bitumen having a 50/70 penetration grade with representative parameters shown in Table 1 was used as the base material for the modification of the blends studied in this paper. The selection of this specific binder was due the fact that it is of one of the most widely used to in Southern Italy, both neat bitumen and base binder for polymer modification, thanks to its high aromatic component, as shown in Table 2.

Table 1
Conventional properties of the base bitumen.

Characteristics	Units of measurement	Values
Grade		50/70
Penetration	dmm	68
Softening point	°C	50.5
Fraas breaking point	°C	−12
Ductility	mm	over 100
Increase in Softening point (after RTFOT)	°C	3.5
Penetration (after RTFOT)	dmm	64.7

Table 2
Base asphalt SARA analysis.

Saturates	2.4%
Aromatics	55.6%
Resins	25.4%
Asphaltenes	16.6%

Table 3
Polymers used in this work.

Sample code	Polymer	Commercial name	Producer
LDPE	Low density polyethylene	FC30	Versalis
HDPE	High density polyethylene	MP94	Versalis
EVA	Ethylene-vinyl acetate copolymer	ML60	Versalis

For classification of the bitumen SARA analysis was performed following the IP 469–01 standard with the Thin layer chromatography-flame ionization detector IATROSCAN. The results are shown in Table 2.

Based on the bitumen composition the colloidal index (CI) was calculated as follows (Eq. (1)).

$$CI = \frac{Asphaltene + Saturates}{Resins + Aromatics} = 0.234 \quad (1)$$

In general, a lower CI value will lead to a more compatible system [7,9]. Taking into account its high aromatic fraction, the binder used in this study can be considered a good base bitumen for modification. Furthermore, it is wide spread and available in southern Italy, it shows a consistent composition with time and it is adequate for both, use as a neat bitumen and a base for modification. For the mentioned reasons only this bitumen was used in order to simplify the interpretation and to limit the complexity and the variability of the polymer/bitumen blends to be studied.

2.2. Polymers

The polymers used for this work are shown in Table 3 together with the commercial name and the producer.

In Table 4 the values of the melt flow index (MFI) evaluated at 190 °C and of the crystallinity degree of these polymers are reported. For the EVA sample, the vinylacetate content is stated as well.

HDPE, EVA and LDPE were used as received. LDPE was processed (P-LDPE) in a Brabender mixer at 210 °C for 30 min at a rotational speed of 64 rpm. Finally, LDPE and EVA were blended in the same mixer but in milder processing conditions, at 180 °C for 10 min at a rotational speed of 64 rpm. The EVA content in the blend was 20% wt/wt.

2.3. Bitumen/Polymer mixing protocol

Polymer modified bitumen samples (PMB) were prepared by mixing the components (for comparison purposes the 5% wt/wt of polymer was select for all the polymer, since this is a typical percentage of modification) in the laboratory with a Silverson mixer equipped with a static and dynamic head assuring high shear action. A PMB sample was also prepared by using 2.5% of HDPE, in order to highlight the effect of the polymer content on the final blend's properties. The bitumen was heated at 180 °C in the oven and then transferred into a thermostatic bath provided with double walls. The bath temperature was constantly kept at 180 °C. The duplex head of the high shear mixer was totally immersed into the hot bitumen and a constant shear of 3500 rpm (gradually