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Chemical and rheological analysis of modified bitumens blended with "artificial reclaimed bitumen"

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HIGHLIGHTS

- Several blends of virgin modified and artificial reclaimed bitumens were analyzed.
- Chemical (FT-IR) and rheological analyses were carried out.
- Viscosity, rutting and fatigue resistance and healing capability were evaluated.
- Artificial reclaimed bitumen does not penalize material performances.
- Results encourage the use of high percentage of Reclaimed Asphalt.

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ABSTRACT

Bitumen characteristics are fundamental for the development of good performance in asphalt mixtures, particularly when the mix includes Reclaimed Asphalt (RA) as aged bitumen can strongly affect the properties of the final bituminous phase. In this study three modified bitumens with different contents (1.8%, 2.8% and 3.8%) of SBS polymer were selected. Blends of these bitumens with various percentages of an artificial reclaimed bitumen (itself polymer modified), long-term aged in laboratory, were analyzed. A chemical characterization together with classical and innovative rheological tests were performed. The chemical investigation conducted using FTIR analysis showed that different percentages of artificial reclaimed bitumen included in the blends influence the final SBS amount. Rheological tests demonstrated that the addition of the artificial reclaimed bitumen does not penalize the final bituminous blend characteristics thereby indicating that the maximum amount of Reclaimed Asphalt incorporable in a mixture (according to the highest percentage of artificial reclaimed bitumen investigated) does not appear to be limited by the rheological characteristics of the final bituminous phase.

1. Introduction

Over the last few decades, road infrastructures have increased considerably as a result of the extensive construction of new roads necessary to satisfy the constant growth in traffic volume. As a consequence, at present, many pavement structures have reached the end of their service life, and often require drastic maintenance to restore acceptable structural and functional performance. These rehabilitation activities imply the availability of large amounts of Reclaimed Asphalt (RA) from old pavements, that can be reused for the production of new asphalt mixtures, with significant economic and environmental benefits. In this context, the current growth in demand for aggregates and bitumens and the corresponding limited supply are inducing construction companies to considerably increase the amount of RA incorporated in the mixes [1–3]. In this sense, the hot recycling process is the most widespread technique. Since bitumen is a thermo-dependent viscoelastic material, during mixing plant production at high temperatures it undergoes a considerable decrease in viscosity, thereby allowing both the coating of the aggregate with the virgin binder and the reactivation of a certain part of the bitumen contained in the RA [4]. Thus, the bituminous phase in the hot recycled mix consists of a blend of virgin and reclaimed bitumen. However, the further exposure of RA to high temperatures may lead to extra oxidation of its bitumen, in addition to the aging it has already undergone during its service life [5]. This phenomenon causes significant changes in the chemical and mechanical properties of the bitumen [6,7] affecting its ability to react and combine with the virgin binder, as investigated by many researchers [8,9]. Moreover, nowadays the increasing quantity of RA which already includes modified bitumens further complicates the analysis, requiring the

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evaluation of polymer integrity and the estimation of polymer contribution after aging. In this context, particular attention must be paid to the chemical and rheological characterization of the bituminous phase of hot recycled asphalt mixes, in order to provide a comprehensive picture that relates the structure of the material to its mechanical behaviour.

2. Objectives

The overall objective of this study is to understand how the oxidation process undergone by RA could modify bitumen characteristics and polymer integrity in order to predict the effects of high percentages of RA on the performance of hot recycled mixtures. Moreover, it contributes towards establishing whether there is a threshold for the amount of RA incorporable in a reclaimed mixture and which combination of virgin/aged binder could be the best solution in terms of performance for a flexible pavement. To that end, various bituminous blends obtained by mixing several virgin binders and an artificial reclaimed bitumen were investigated.

3. Materials

The virgin binder used in this study include three bitumens modified with different amounts of SBS (Styrene Butadiene Styrene) polymer. In particular, three levels of modification (in percentage by bitumen weight) have been used with the same base bitumen B. According to the percentage of polymer incorporated, the virgin bitumens are codified as soft S (1.8%), medium M (2.8%) and hard H (3.8%) and their basic properties are summarized in Table 1 together with the characteristics of the base bitumen B.

The artificial reclaimed bitumen R was obtained by subjecting bitumen H to long-term aging by means of the Pressure Aging Vessel equipment, in accordance with European Standards EN 12607-1 and EN 14769. Bitumen H was selected to simulate the binder included in the RA because the corresponding level of polymer modification is the most common for Italian motorways. It is worth noting that the choice to use a laboratory aged bitumen rather than a bitumen directly extracted from milled material does not limit the general validity of this study as each extracted bitumen would have its own characteristics and could be considered in any case not exhaustive of the all possible conditions, analogously to the laboratory aged one. Moreover, the laboratory aged bitumen is always reproducible for further investigation or comparative purpose.

The three virgin modified bitumens (S, M, H) were blended with various percentages of the artificial reclaimed bitumen (R) through a low shear mixer operating at 60 rpm, for a processing time of 15 min and a processing temperature lower than 165 °C. The blending procedure parameters were selected in order to prevent bitumens from severe processing conditions and to minimize additional aging effects.

All the bituminous blends studied are summarized and codified in Table 2.

4. Experimental program and test procedures

The laboratory investigation was divided into two main steps: the first phase focused on the chemical analysis carried out using Fourier Transform Infrared Spectroscopy (FT-IR) whereas the second was centred on the rheological characterization of the blends. In order to have an overview as complete as possible of the mechanical behaviour of the selected materials, the "classical" rheological characterization introduced by the Strategic Highway Research Program (SHRP) was carried out. Moreover, the results were compared with those obtained with more advanced and innovative tests and analyses (e.g. healing capability) performed on the same blends in a previous study [10]. The test program is summarized in Table 3. Details of each test are provided in the following paragraphs together with the corresponding experimental procedures.

4.1. Chemical characterization

Rheological testing methods and analyses developed to investigate the mechanical performance of bitumen, are not always sufficient to completely characterize the intrinsic behaviour of bituminous materials. For this reason a supplementary chemical analysis is needed in order to relate the performance of the material to its chemical structure. In particular, this becomes even more important when modified bitumens are analyzed, as it is necessary to study both the effects of oxidation on polymer integrity and the relationship between the polymer and the binder components. To that end, Fourier Transform Infrared Spectroscopy (FT-IR) can be helpful in order to better evaluate the influence of aging on bituminous material properties [11].

Spectroscopy uses electromagnetic waves within a wide, continuous range of frequencies to study the interactions of matter with electromagnetic radiation. Fundamental vibrations, mainly the stretching and bending of chemical bonds, as well as some rotational motions in molecules, can be detected within the interval of wavelengths from 3 μm to 50 μm, which is the Middle Infrared Region (MIR), extending from wavenumbers 4000 to 400 cm^{-1}. In MIR spectroscopy, signal interferences are generated by the interferometer at each wavelength within a selected interval of IR frequencies (or wavenumbers). The intensity of the signal passing through the probing sample is measured at each specific wavelength (or frequency, or wavenumber) by a detector resulting in an interferogram which is immediately transformed into an IR spectrum by the Fourier transform mathematical function. Therefore, in the absence of absorbing molecules, almost 100% IR light is transmitted to the detector (e.g. background sample); on the contrary, the intensity of IR light transmitted through the sample to the detector is reduced when the molecules enter a resonant state with specific frequencies of IR light [12].

In this study, FT-IR spectroscopy has been applied to assess the amount of polymer in the bitumen after the aging process. The intensity band ratio between SBS (699 and 966 cm^{-1}) and bitumen (1377 cm^{-1}) reference peaks allows the calibration curve (peak heights ratio vs SBS percentage) to be obtained, and hence the polymer percentage for each bituminous blend to be calculated [13–16].

4.2. Rheological characterization

Since bitumen can be considered a thermo-dependent visco-elastic material, it is necessary to carry out several tests under different loading and temperature conditions. Thus, the experimental program involved different test methods.

Table 1
Basic characteristics of the virgin bitumens used in this study.

Bitumen type	Code	SBS polymer content by weight %	Penetration @ 25 °C 0.1 mm	Ring and ball softening point °C	Ductility @ 25 °C cm	Dynamic viscosity @ 135 °C Pa s	Residue after RTFOT – mass loss %
Base	B	0	68	45.4	82	0.22	0.07
Soft	S	1.8	59	66.8	97	0.81	0.08
Medium	M	2.8	52	68.6	>100	1.02	0.13
Hard	H	3.8	54	70.8	>100	1.24	0.05