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Tribological characterization of bituminous binders with Warm Mix Asphalt additives

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HIGHLIGHTS

- A novel tribological characterization for bituminous binders is proposed.
- A detailed procedure to perform tribological tests on bituminous binders is described.
- Tribological tests allow to better understand the workability of bituminous mixtures.
- A direct correlation between viscosity and minimum friction is provided.
- Waxes act on viscosity, chemical additives mainly modify the lubricating properties.

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ABSTRACT

Warm Mix Asphalt (WMA) technologies allow reducing production, laying and compaction temperatures of bituminous mixtures, leading to relevant environmental and technical benefits. According to recent studies, some WMA additives lead to this temperature reduction by potentially improving the lubricating properties (i.e. the tribological behaviour) of the bituminous binder. In this study, the effect of a chemical and a wax additive on the tribological behaviour of two base bituminous binders was investigated, by considering different percentages of additive. All the binders were preliminarily characterized with Fourier Transform Infrared Spectroscopy (FTIR) and viscosity analysis. After optimizing the test procedure, tribological tests were carried out with a ball-on-three-plates fixture at 85 °C and 120 °C. A statistical analysis was also performed on the tribological results to evaluate the statistical significance of the differences between the binders. Results showed that the additives might alter the oxidative state of the binder, the chemical additive is able to modify the tribological behaviour of the binder, the wax additive acts solely on the viscosity and the effect of the additive depends on the chemical composition of the base binder. Moreover, a correlation between the minimum friction and the viscosity was found.

1. Introduction

Warm Mix Asphalt (WMA) refers to bituminous mixtures that are produced and placed at temperatures 20–55 °C lower than typical Hot Mix Asphalt (HMA) [1]. The goal of WMA is to produce mixtures with similar strength, durability and performance characteristics as HMA using substantially reduced production temperatures [2]. Over the last few decades, WMA technologies have undergone strong development thanks to this temperature reduction, which allows important environmental benefits: lower emissions, lower fuel and energy consumption and reduced exposure of workers to asphalt fumes [2,3]. Besides the environmental benefits, this development has been possible also because various technical benefits derive from reduced temperature [2–4], such as reduction of binder ageing, longer haul distance, improved compaction during cold weather paving (by night, in winter), reduced time of pavement cooling (thus allowing faster opening to traffic), and use of higher Reclaimed Asphalt Pavement (RAP) percentage in the mixtures [5,6]. Moreover, WMA technology also provides some practical advantages: less inconvenience to public near production and work sites (as fumes and odours are reduced) and easier permitting plant sites close to urban areas, because of reduced emissions, dust and noise [4]. Finally, some potential economic benefits derive from the reduction in energy costs (thanks to lower energy consumption) and less wear on asphalt plant (due to reduced temperature) [4].

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All existing WMA technologies can be grouped into three main categories [3]: foaming processes [7,8], wax (or organic) additives [9] and chemical additives [10]. It has been demonstrated that these technologies work effectively in the field [5,6], but the mechanisms that allow mixture densification at reduced temperatures are not completely known to date. In fact, it has been noted that the reduced binder viscosity provided by WMA additives is not sufficient to completely explain the reduction of the production and compaction temperatures of the final mixture in the field [9,11,12]. On the contrary, in some cases, the addition of the WMA additive has even caused an increase in the viscosity of the binder [13]. Furthermore, in some studies concerning the workability of both WMA and HMA mixtures [2,12,14], it has been found that the mixture compactability does not improve linearly as the temperature increases, but it gets worse above a certain level of temperature. It has been hypothesized that this phenomenon is likely related to the friction mechanisms at the contact zone between the aggregates, with a correlation to the thickness and the lubricating characteristics of the binder film around the aggregates.

Therefore, in recent studies [11,13,15–17], the improvement of the lubricating properties of the bituminous binder has been proposed as a possible mechanism involved in the densification of bituminous mixtures, as an alternative or in addition to viscosity reduction.

Friction, lubrication and wear of contact surfaces in relative motion are studied by the science of tribology [18]. Specifically, the lubricating behaviour of a material placed between two solids in relative motion is usually described by the Stribeck curve (Fig. 1a), that shows the evolution of the coefficient of friction as a function of the sliding speed. The variation in the coefficient of friction is due to the changes in the thickness of the lubricating film (Fig. 1b).

The Stribeck curve can be divided into four regions, that correspond to four different lubrication regimes [15–17,19,20]:

- the boundary regime (1), in which friction is mainly caused by the interaction of the asperities of the two solids;
- the mixed regime (2), where a reduction of friction occurs, because the direct contact between the solids is reduced by the hydrodynamic pressure of the lubricant;
- the elasto-hydrodynamic regime (3), in which the surfaces of the solids are no longer in contact and therefore the minimum friction, which is related only to the lubricant properties, is reached;
- the hydrodynamic regime (4), where friction increases because of the increase in the viscous drag of the lubricant.

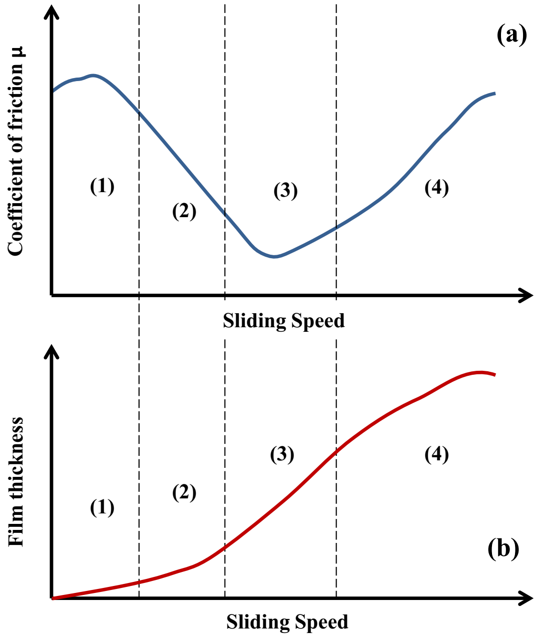

Fig. 1. (a) Stribeck curve: coefficient of friction as a function of the sliding speed; (b) film thickness as a function of the sliding speed.

It is worth noting that the lubricating behaviour of a material is not only a function of the sliding speed but also of its viscosity, of the nature (type and wear) of the two solids in contact and of the applied normal load [17]. For thermo-dependent materials, such as bitumen, also the temperature has to be taken into account, as viscosity strongly depends on the temperature. Moreover, the viscoelastic properties of the bitumen imply that at high sliding speeds (or low temperatures) it tends to behave as an elastic solid, thus probably varying, in the hydrodynamic regime (4), from the fluid behaviour typically shown by common lubricants.

In order to investigate the possible benefits provided by WMA additives on the lubricating characteristics of bituminous binders, tribological tests have been recently introduced in the field of road materials. However, different studies consider different testing geometries, procedures and parameters, and the effect of WMA additives on the behaviour of bituminous binders is still a subject of debate [17]. The test geometries that have been used so far are ball-on-three-plates [15–17,19], four-ball [11,13,17] and Asphalt Boundary Lubrication Test [17], and the testing parameters to be selected are sliding speed, temperature, normal load and substrate type.

The objective of this study is the evaluation of the possible effect of WMA additives on the tribological behaviour of bituminous binders. To this end, two types of additives (one chemical and one wax) and two base binders (characterized by the same penetration grade but different chemical nature) were considered. Tribological tests on the binders were conducted with a ball-on-three-plates apparatus. The test procedure was optimized based on a previous literature review [17] concerning the tribological behaviour of lubricants in general. The binders were preliminarily characterized by chemical and rheological analysis, through the Fourier Transform Infrared Spectroscopy (FTIR) and viscosity tests, respectively.

2. Materials

Two unmodified bituminous binders of different sources were studied as base binders, coded as “A” and “B”. Both binders were characterized by a penetration grade of 70/100 and their main properties are shown in Table 1.

Two WMA additives were used during the experimental investigation: one chemical, coded as “CA”, and one wax, coded as “WA”. Table 2 summarizes the main characteristics of the two tested additives.

Table 1
Main properties of the base binders.

Properties	Standard	A	B
Penetration at 25 °C [0.1 mm]	EN 1426 [21]	84	73
Softening point R&B [°C]	EN 1427 [22]	45.4	46.6
Dynamic viscosity at 60 °C [Pa·s]	EN 12596 [23]	187	160
Viscosity at 135 °C [mPa·s]	EN 12595 [24]	345	351
Fraass breaking point [°C]	EN 12593 [25]	−16	−15
Penetration after RTFOT at 163 °C [0.1 mm]	EN 1426 [21]	54	44
Softening point R&B after RTFOT at 163 °C [°C]	EN 1427 [22]	51.1	50.8