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The influence of the mineral filler on the adhesion between aggregates and bitumen

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ABSTRACT

The loss of adhesion is a major mechanism of physical distress in hot-mix asphalt (HMA) because it could reduce the durability of HMA. In this study, active and passive adhesions between the aggregates and the bitumen that are part of HMA were analysed. As part of the analysis, the Boiling Water Test and measurements of the mixing times were conducted. Four aggregates (hornfels, feldspatic schist, gabbro and dolomitic calcite) and five fillers (from natural aggregate, from natural aggregate + 1% hydrated lime, commercial limestone, grey Portland cement and fly ash) were used to generalise the conclusions. The experimental results indicated that the use of filler, particularly the grey Portland cement, improves the passive adhesion. The results also indicated that the use of natural filler results in the worst active adhesion. The statistical analysis confirmed the observed results and indicated that active and passive adhesions are not related.

1. Introduction

Hot-mix asphalt (HMA) is a construction and building material that is widely used at a global level [1] for flexible pavements in the road industry. Nevertheless, this material presents a serious drawback: HMA may fail due to poor water resistance. Indeed, water is the major cause of failure in HMA [2] because the presence of water could lead to a loss in the structural strength and durability of the HMA [3].

HMA is composed of aggregates of various sizes that must be completely coated by the binder, that is, the bitumen. When HMA is in service, water can interact both in the liquid state and as vapour [4] or even in the solid state. Thus, water can damage HMA in several ways, such as the freezing of entrapped water [5], the loss of adhesion between the aggregate–binder interface and a lack of cohesion of the mastic [6]. These two later mechanisms are the two primary driving mechanisms of moisture damage [5]. Among them, the loss of adhesion is a major mechanism of physical distress in bituminous mixtures [7]; however, this damage mechanism usually does not work alone and typically coexists with the lack of cohesion [8,9].

Note that in the road pavement industry, two types of adhesion can be distinguished: active and passive adhesions [10]. Active adhesion is the ability of the binder to completely coat the aggregate during the mixing operation in the HMA manufacture plant, while passive adhesion is the ability of the binder to remain on the aggregate surface without the risk of displacement due to the action of water and traffic during the service life of the asphalt [11].

On the one hand, a poor aggregate coating by the binder, that is, an inadequate active adhesion during the HMA manufacturing process, could lead to the creation of pathways through which water could penetrate. On the other hand, the loss of passive adhesion as a consequence of the action of water and traffic during the service life of the HMA could accelerate the creation of several pavement distresses, such as ravelling, cracking, bleeding, potholes, or premature rutting (Fig. 1) and could also increase its extent and severity [2,3,8,12,13]. These pavement distresses result in a loss of comfort and road safety, as well as a reduction in the strength and durability of the pavement [14].

A great variety of products is available to improve the moisture damage resistance of the mixtures. These products include the use of mineral fillers (mineral powders with physical size passing the 0.063 mm sieve) which have a decisive influence on the adhesion between the aggregate and the binder for two reasons [15]. The first reason is that the mineral filler fill the voids in the bituminous mixtures, thereby preventing water entry. The second reason is that several mineral fillers exhibit a better chemical affinity with the bitumen than with the aggregate. In this regard, some authors indicate that the use of Portland cement as filler leads to an improvement in the water resistance of the mixture [8,16]. Other authors stated that using fly ash as mineral filler also improves the water resistance of HMA [5,16]. Nevertheless, hydrated lime is the most used

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anti-stripping agent, generally in percentages of 1–2% by dry weight of the aggregate [3,5,16,17].

In this regard, the aim of this study is to analyse the influence of mineral filler on both active and passive adhesions between the aggregates and the bitumen, with the ultimate objective of improving the water sensitivity and therefore, the performance and the durability of HMA against the action of water; thereby improving road service quality and traffic safety and reducing the costs of operating and maintaining the pavement of highways In addition, an analysis is performed regarding whether there is any relationship between the active and passive adhesions. To compare and generalise the findings, this investigation was conducted with aggregates of four different mineralogical compositions. To perform the analysis of the aggregates and bitumen passive adhesion, the Texas Boiling Water Test was selected, due to its short measurement time and simplicity [18]. To perform the analysis of the aggregate and bitumen active adhesion, the mixing times were measured.

2. Materials

2.1. Aggregates

Four types of aggregates typically used in Spain in road construction were selected to perform this work: hornfels, feldspatic schist, gabbro and dolomitic calcite. Because the analysis of the adhesion between the aggregate and the binder requires knowledge of the siliceous or limestone nature of the aggregates, an analysis of the chemical composition and crystalline phases of the asphalt were conducted.

X-ray fluorescence (XRF) spectroscopy (Bruker S4 Pioneer Fluorescence Spectrometer) was used to determine the bulk composition in the weight of the aggregates. As presented in Table 1, the composition of hornfels, feldspatic schist and gabbro is mainly siliceous. Consequently, these aggregates have a high potential to exhibit poor moisture damage performance. On the contrary, dolomitic calcite aggregates are mainly a limestone aggregate, and thus, adequate water resistance is expected.

The crystallography was evaluated using the X-ray diffraction (XRD) method (Siemens D5000 X-ray diffractometer). Fig. 2 shows the results of the X-ray diffraction test. Note that hornfels and feldspatic schist mainly present quartz in their mineralogical composition. Because quartz usually has a poor adhesion with the binder [19], it is expected that the adhesion with the bitumen is not adequate. The gabbro mainly exhibits chlorite–serpentine in its mineralogical composition. Chlorites are present in non-polar active sites, which are generally found on hydrophobic surfaces [20]. Nevertheless, taking into account that quartz also appears in the mineralogical composition of the gabbro and that non-polar active sites appear to a lesser degree in the chlorites than in other minerals [21], it is not expected to exhibit good adhesion with the binder. Crystallography results confirm the XRF results in the case of dolomitic calcite. This aggregate is mainly composed of dolomite, thus a good adhesion with the bitumen is expected [19].

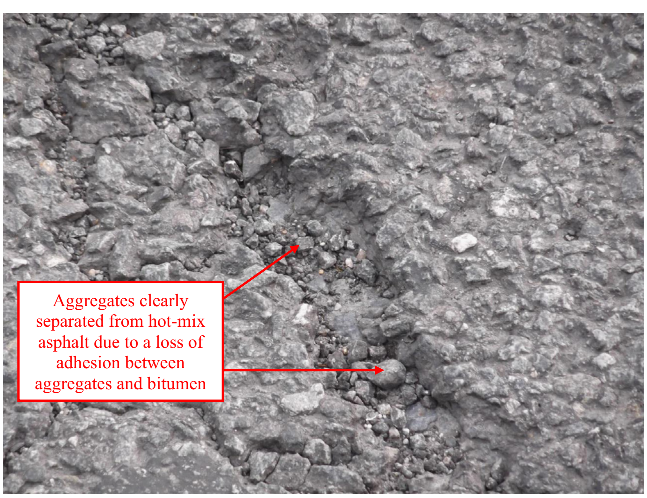

Fig. 1. Hot-mix asphalt that has suffered from stripping, as a consequence of a loss of adhesion between the aggregates and the binder due to the action of water.

2.2. Binder

A penetration grade bitumen B50/70 was used as the binder. The bitumen came from Venezuela and is typically used in the hot-mix asphalt industry in Spain. The bitumen penetration grade was obtained following the Spanish standard NLT-124/84 [22]. In this test, the amount of penetration produced in a sample of bitumen at 25 °C by a calibrated needle, which is charged with 100 g and is allowed to act for 5 s, is measured. As expected, the penetration grade obtained for B50/70 (5.2 mm) was between 5.0 mm and 7.0 mm.

2.3. Filler

In this study, in addition to filler from natural aggregate, four mineral fillers were chosen among the most used to improve the adhesion between the aggregates and the bitumen. These four fillers were filler from natural aggregate + 1% hydrated lime CL-90S (minimum content of CaO + MgO 90%); commercial limestone ($SiO_2 < 0.08\%$ and $CaO > 63.77\%$); grey Portland cement CEM II/B-M (V-L) 32.5N; and fly ash (SiO_2 content between 33.1% and 63.5% and CaO content between 1.85% and 11.5%).

Since the grain size of the filler can influence the aggregate–bitumen adhesion, Fig. 3 includes the grain size distribution of the fillers used in the present investigation, obtained by means of laser diffraction (light scattering) using a Saturn Digisizer II equipment. As can be seen, the commercial fillers (fly ash, commercial limestone, Portland cement and hydrated lime) have finer size distribution than the filler from natural aggregates (hornfels, feldspatic schist, gabbro and dolomitic calcite).

Table 1
Bulk composition in weight of the aggregates according to the X-ray fluorescence results.

Aggregate	SiO_2 (%)	CaO (%)	AL_2O_3 (%)	K_2O (%)	CO_2 (%)	MgO (%)	Fe_2O_3 (%)	TiO_2 (%)	Na_2O (%)	SO_3 (%)	P_2O_5 (%)	SrO (%)
Hornfels	62.3	0.3	19.0	4.3	2.5	1.6	7.4	0.9	1.3	0.6	0.1	0.01
Feldspatic schist	72.1	0.5	12.4	2.5	1.8	1.6	3.9	0.5	3.6	0.7	0.2	0.01
Gabbro	49.2	9.6	17.5	0.6	2.4	8.0	9.0	0.7	2.4	0.1	0.1	0.03
Dolomitic calcite	16.1	32.3	0.8	0.2	36.7	12.6	0.9	–	–	0.2	–	0.03