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Influence of aggregate mineralogical composition on water resistance of aggregate–bitumen adhesion

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ABSTRACT

The effects of aggregate mineralogical composition on moisture sensitivity of aggregate–bitumen bonds were investigated using four aggregate types (two limestone and two granite) and two bitumen grades (40/60 pen and 70/100 pen). Moisture sensitivity (or water resistance) of the aggregate–bitumen bonds were characterized using retained strength obtained from three different tensile tests (peel, PATTI and pull-off). The results showed significant differences in the amount of moisture absorbed by a given aggregate which suggested strong correlations between aggregate mineral composition and moisture absorption. For most of the aggregate–bitumen bonds, failure surfaces transformed from cohesive to adhesive with conditioning time thereby confirming the strong influence of moisture on aggregate bonds. The three tensile tests used in this study showed similar rankings in terms of moisture sensitivity but the pull-off test was found to be the most sensitive. The effect of bitumen on moisture sensitivity was found to be lower than the effect of aggregates, with the moisture absorption properties of the aggregates depending strongly on certain key minerals including clay, anorthite and calcite. Strong correlations were also found between mineral compositions and moisture sensitivity with clay and anorthite having strong negative influence while calcite showed positive effect on moisture sensitivity. Previous studies have identified various mineral phases like albite, quartz, and k-feldspar, as detrimental in terms of moisture sensitivity. The results appear to support the extension of the existing list of detrimental aggregate minerals to include anorthite and clay while supporting the case of calcite as a moisture resistant mineral.

1. Introduction

Asphalt mixtures are widely used as pavement construction materials. During their service life, asphalt pavements have to sustain harsh traffic loads and environmental conditions and deteriorate with the passage of time. One of the major causes of distress in asphalt pavements can be considered to be moisture damage with about 2.8 billion pounds being spent every year on road maintenance across England and Wales [1]. Moisture damage is an extremely complicated mode of asphalt mixture distress that leads to the loss of stiffness and structure strength of the asphalt pavement layers of a road and eventually the costly failure of the road structure [2]. It has been nearly a century since this distress was first recognised [3] although not all damage is caused directly by moisture, its presence increases the extent and severity of already existing distresses like cracking, potholes and rutting [4]. Existence of moisture in the pavement can result in the loss of cohesion within the bituminous binder itself or the loss of interfacial adhesion between binder and the aggregates [5,6]. The resistance of asphalt mixtures to moisture attack has been related to aggregate mineralogy, surface texture of aggregate, bitumen chemistry and the compatibility between bitumen and aggregate [7,8]. In addition, factors such as permeability of the asphalt mixtures, volumetric properties of binder and the ambient conditions are all important when considering the susceptibility of asphalt mixture [9].

With the view to better understand the performance of the aggregate–bitumen interface when exposed to moisture, this paper presents a combination of three different mechanical tests to quantify the damage that occurs at the aggregate–bitumen interface. The focus of this study was limited to the examination of the aggregate–bitumen tensile strength and fracture energy before and after moisture conditioning in the laboratory. The Pneumatic Adhesion Tensile Testing Instrument (PATTI) Test and pull-off Test were conducted to measure the tensile strength of different

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aggregate–bitumen combinations before and after moisture conditioning. Furthermore, the peel test was applied to quantify the fracture energy of different specimens. The retained tensile strength and fracture energy calculated by dividing the values after moisture conditioning by the values before conditioning were used to characterize the moisture sensitivity. Finally, the correlations between these three mechanical tests were presented.

2. Materials

2.1. Bitumen

Two bituminous binders (B1 and B2) with penetration grades of 40/60 pen and 70/100 pen were selected. The physical properties of the bitumen were characterized using softening point (BS EN 1427) and penetration (BS EN 1426) tests. Based on the tests, the softening points of B1 and B2 were 51.2 °C and 45.2 °C respectively, while the measured penetration of B1 at 25 °C was 46 (0.1 mm) compared with 81 (0.1 mm) for B2.

2.2. Aggregates

Four types of aggregate from different quarries were selected as substrates. They included two limestone aggregates (L1 and L2) and two granite aggregates (G1 and G2). These aggregates are known to behave differently in terms of their mineralogical composition and moisture sensitivity.

3. Experimental procedures

3.1. Mineral Liberation Analyser (MLA) test

The mineralogical compositions of aggregates are believed to have a profound influence on moisture damage susceptibility of asphalt mixtures. The mineralogy of the different aggregates was studied using a Mineral Liberation Analyser (MLA) in order to understand the effect of their morphology on moisture damage resistance of aggregate–bitumen bonds. The experimental procedures used for the MLA included the following. Aggregates were first washed in deionised water and then dried in an oven at 40 °C for 24 h. The oven-dried aggregates were then cast in resin moulds with 25 mm diameter and 20 mm height, followed by polishing of the surface using a rotary polishing machine. Finally, carbon coating was applied to form an electrically conductive surface. An FEI Quanta 600 Scanning Electron Microscopy (SEM) with MLA capability was used for the mineral analysis. During testing, the SEM collects back-scattered electron (BSE) images and energy dispersive X-ray data for a series of frames step by step across the specimen surface. Measurement of the backscattered electron intensities allows for the segmentation of mineral phases within each particle section, while energy dispersive X-ray (EDX) analysis of a given phase allows for phase identification [10]. For each aggregate type, one replicate sample was tested.

3.2. Aggregates moisture absorption

Another important parameter that influences moisture-induced damage in asphalt mixtures is the rate and amount of water absorption of the aggregates. This approach of considering the moisture absorption properties of the aggregate is in contrast to most previous studies that only consider conditioning time when evaluating moisture damage. The current approach recognises the differences in moisture absorption characteristics of different aggregates. To perform the moisture absorption experiments, rectangular aggregate beams with dimensions of 100 mm × 20 mm × 10 mm were first cut from boulders. Then the aggregate beams were cleaned using deionised water and dried in an oven at 40 °C for 24 h to remove all the moisture. The weight of each beam in the dry condition was measured using a balance with the precision of 0.1 μg. All aggregates were moisture conditioned by placing them in baths containing deionised water at 20 °C and weighing them periodically until steady stable conditions were reached. The results from three replicate specimens were used to calculate the mass uptake of aggregates as a percentage of the dry aggregate weight (Eq. (1))

$$\text{Mass uptake } (\%) = M_t = \frac{w_t - w_0}{w_0} * 100 \tag{1}$$

where M_t is the moisture uptake at time t, w_0 is the initial mass of the aggregate in dry condition, w_t is the mass of aggregate after time t.

3.3. Peel test

The peel test (as described in ASTM D6862-11) is used to characterize the adhesive bonds and is widely used in aerospace, automotive and electronics applications [11–13]. Horgnies et al. undertook a peel test to peel bitumen from aggregate surface by using polyethylene terephthalate (PET) as a membrane [14]. Blackman et al. undertook a similar peel test but used an aluminum peel arm rather than a PET membrane [15]. The test is considered to be a reliable method to measure the peel strength (fracture energy) if suitable corrections for plastic work could be performed.

The set-up for the peel test used in this study is shown in Fig. 1. The aggregate substrates with dimensions of 200 mm × 20 mm × 10 mm were prepared as previously described. They were then bonded to aluminum (Alu 1050A) peel arm using bitumen as the adhesive layer. The thickness of the bitumen adhesive layer was controlled by placing five wire spacers on the

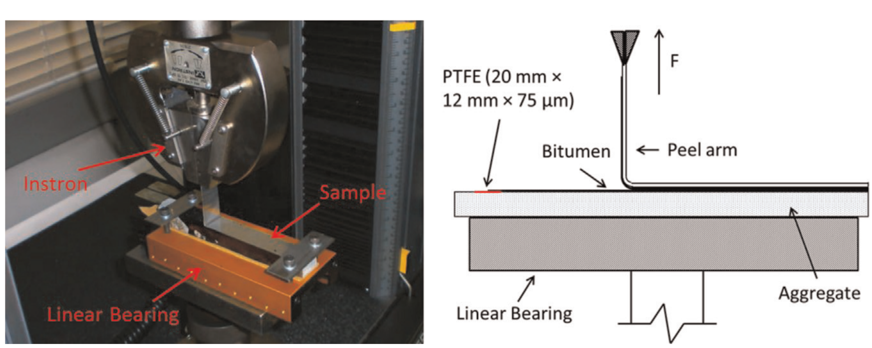

Fig. 1. Details of peel test equipment.