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Evaluation of bonding between reclaimed asphalt aggregate and bitumen emulsion composites

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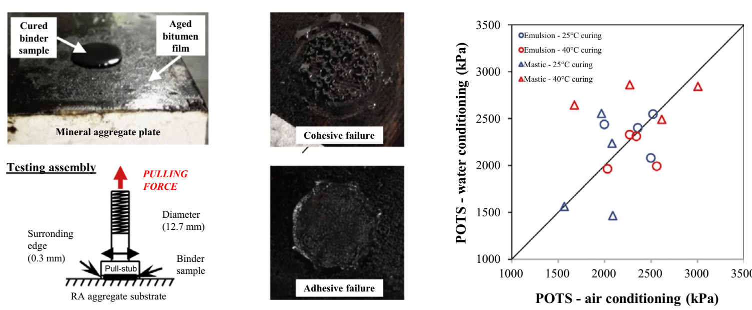
HIGHLIGHTS

- BBS tests on cold bitumen emulsion composites-artificial RA aggregate systems.
- RA aggregate ensures an efficient bond also after water conditioning.
- Cold mastic-RA aggregate systems showed exclusively adhesive failures.
- Curing condition effects on bond strength were more significant for cold mastics.

GRAPHICAL ABSTRACT



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ABSTRACT

The bond strength between bituminous binder and aggregate is fundamental to evaluate the performance and durability of cold bitumen emulsion mixtures (CBEM). The interaction developed at binder-aggregate interface is strongly dependent on the properties of aggregate, residual bitumen and emulsifiers, as well as on the environmental conditions affecting emulsion breaking. When reclaimed asphalt (RA) aggregate is used in the production of CBEM, the adhesion issue becomes more complex because the residual bitumen interacts with the aged bitumen film coating the RA aggregate surface. In this research, the binder bond strength (BBS) test was performed to evaluate the bonding between a bitumen emulsion, a cold mastic prepared using limestone filler and artificial RA substrates produced using two aggregate sources. The moisture sensitivity along with the effect of curing temperature and time on the bond strength development were also evaluated. The results showed good affinity between both cold bitumen emulsion composites and the aged bitumen film coating the RA substrate, also highlighting a reduced moisture sensitivity for most of the tested systems. Moreover, the BBS results allowed to properly discriminate the effect of curing temperature and time on bond strength between the artificial RA aggregate and the cold bitumen emulsion composites.

1. Introduction

Nowadays, the limited availability of natural aggregates, the increasing disposal costs of milled materials along with the growing social and political awareness of environmental issues, strongly address the rehabilitation and construction of asphalt pavements towards the identification of innovative and sustainable technologies. In this context, cold recycling technique surely sounds highly promising for its technical reliability, cost-effectiveness and low environmental impact [1–4]. Specifically, the fact that the use of cold bitumen emulsion recycled mixtures (CBEM) guarantees certain benefits over conventional hot mix asphalt mixtures (HMA) has been accepted for many years [5–8]. Nevertheless, a main issue

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concerns performance and durability of CBEM as compared to conventional HMA.

CBEM properties are strictly related to different factors such as cold technology employed, composition (type and amount of binders, amount of reclaimed asphalt RA) and environmental conditions as well. Among several parameters, the internal cohesion of binder film produced upon emulsion setting, and the adhesion developed at the interface with the virgin or reclaimed aggregate, represents one of the critical aspects related to the failure of mixtures [9–12]. Moreover, the role of adhesion between the binder and aggregate becomes fundamental when considering that the presence of water can accelerate both adhesive and cohesive failures by reducing the compatibility between bitumen and aggregate or causing emulsification of bituminous phase [13–16]. For CBEM, the interaction developed at the binder/aggregate interface is strongly affected by aggregate properties (mineralogy, moisture, roughness, porosity, cleanliness), bitumen emulsion features (composition, polarity) and climatic conditions (temperature, humidity) that affect the curing process [17–19]. In order to promote adhesion, different types of emulsifier are used, and thus a proper bitumen wetting capability is function of aggregate/emulsifier compatibility related to the aggregate mineralogy [17,18,20]. Some aggregates are hydrophilic (i.e. they have a higher affinity for water than bitumen) and in this case full bitumen/aggregate adhesion will not develop until the aggregate surface is completely dry. A proper selection of the emulsifier can mitigate this issue by displacing water from the aggregate surface and creating reaction products that are responsible for the adhesion, as the emulsifier is absorbed by the aggregate [18]. Basically, cationic emulsifiers are preferred for acidic aggregate and anionic ones for basic aggregate.

When RA is the main component of the aggregate fraction (i.e. cold recycled mixtures), the adhesion issue becomes more complex because the bitumen emulsion interacts with the RA aggregate and not with the mineral aggregate. Taking into account that RA is constituted by aggregate covered with a thin film of aged bitumen, the residual bitumen from emulsion has to develop appropriate bond strength with the coated particles. This aspect raises two key considerations regarding the evaluation of binder/RA aggregate system. First, the adhesion developed at the interface with the RA aggregate is strictly related to the interaction between the residual bitumen and the aged bitumen [21–26], contrarily to the combination bitumen/mineral aggregate where the substrate textural and chemical heterogeneities are significant to yield a good wetting quality (i.e. good adhesion) [9,27]. Second, the presence of the aged binder could affect the mechanism of emulsion breaking differently from the effects due to uncoated mineral aggregate properties (mineralogy and surface characteristics) [18]. A better understanding of the interaction in terms of adhesion and cohesion properties between bitumen and RA aggregate can be achieved by performing a direct quantitative measurement of the bond strength at the interface of the bitumen/RA aggregate system.

Currently, the binder bond strength (BBS) test [28] is successfully performed to measure the bond between hot-applied binder (bitumen and mastic) and a solid substrate. The BBS test is able to discriminate among materials with different chemical and rheological characteristics in terms of moisture sensitivity [13–15,29]. More recently, a BBS procedure for bitumen emulsion applications was also developed [30,31] and introduced in the AASHTO standard. Moreover, an improved procedure to investigate the bond strength of bitumen emulsion residue and cold bituminous mastics on mineral aggregate was satisfactorily used [32].

On this background, the present research study aims at evaluating the use of BBS test as a routine procedure to investigate the bond strength between cold bitumen emulsion composites (bitumen emulsion residue or cold mastic) and RA. A full factorial experiment and a statistical analysis were performed to evaluate the effects of the curing conditions (temperature and time) and moisture susceptibility of the systems on the bond strength. Moreover, in order to account for the bitumen coating on the RA, BBS tests were also performed on virgin aggregate substrates.

2. Experimental program

2.1. Materials

The cold bitumen emulsion composites considered in this research were a residual bitumen obtained from emulsion by water evaporation and a cold mastic prepared by mixing bitumen emulsion, filler and deionised water.

Bitumen emulsion was an overstabilized cationic type, designated C60B10 in accordance with EN 13808 (Table 1). Such bitumen emulsion is specifically formulated for cold in-place recycling, indeed the class 10 of breaking behaviour indicates its slow setting feature and high mixing stability with cement.

A natural filler (finely ground limestone) was used to produce the cold mastic. Its main physical properties were measured in terms of particle dimension (D_{90} = 0.018 mm, D_{50} = 0.0053 mm), Blaine surface area (0.51 m^2/kg) [33] and Rigden voids (31.1%) [34]. The cold mastic was prepared adopting a volumetric ratio of 0.3 between the filler and the residual bitumen according to the procedure described in [32].

Two types of aggregate, commonly used in road construction were selected to produce suitable substrates: limestone and basalt (Fig. 1a).

A SBS polymer modified bitumen (SBS content = 3.8% by bitumen mass, penetration @25 °C = 52 × 0.1 mm, softening point = 70.8 °C, dynamic viscosity @135 °C = 1.24 Pa·s) was used to coat the aggregate surface for the preparation of the artificial RA substrate. Such bitumen was selected because RA coming from most of the Italian Motorways is composed of a similar binder.

2.2. Preparation of artificial RA substrate

A specific treatment was adopted to reproduce the surface of RA aggregates [35], the main steps of the protocol are summarized in the following. First, aggregate plates (Fig. 1b) are heated at 135 °C, while a sample of SBS polymer modified bitumen is heated at 160 °C, in order to obtain a fluid consistency. Then, a uniform thin film of hot bitumen is distributed by means of a brush on the surface of the hot aggregate (Fig. 1c). The amount of bitumen used to coat the aggregate ranged between 0.2 and 0.3 g, depending on the aggregate surface porosity and its tendency to absorb bitumen. This amount of bitumen was found suitable to produce a film thickness of approximately 9.5 μm on the aggregate plates, which is believed to simulate adequately the bitumen thickness coating RA aggregates [35–38]. Afterwards, the coated aggregate plates were aged in a forced-draft oven at 135 ± 3 °C for 4 h and then at

Table 1
Properties of the bitumen emulsion.

Property	Test standard	Nominal value
Emulsion		
Binder content	EN 1428	60%
Viscosity at 40 °C-efflux time	EN 12846-1	40 s
Adhesivity: water immersion test	EN 13614	95%
Breaking behaviour: mineral filler method	EN 13075–1	190
Mixing stability with cement	EN 12848	<2%
Residual bitumen		
Penetration at 25 °C	EN 1426	70 mm/10
Softening point	EN 1427	50 °C