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# Bond strength of whitetoppings and bonded overlays constructed with self-compacting high-performance concrete

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## HIGHLIGHTS

- Direct pouring of SCHPC provides bond strengths comparable to the other treatments.
- Cohesive failure is obtained in asphalt substrates without interfacial treatment.
- No correlation exists between roughness level, pure tension and shear strengths.

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## ABSTRACT

A bonded concrete overlay consists of a concrete layer poured over a deteriorated pavement. Its mechanical performance depends on the quality of the bond between the lower and the uppermost layers. This paper reports an extensive experimental program to evaluate bond strength between Conventional Concrete (CC) and Asphalt Concrete (AC) substrates and Self-Compacting High-Performance Concrete (SCHPC) overlays. In all, 8 interface treatments are tested under Direct Tension, pure shear "LCB", and compressive Slant Shear tests. The results show that direct pouring of the SCHPC overlay over CC and AC substrates produces similar or higher strengths than the other treatments analyzed.



## 1. Introduction

Over recent years, highway agencies have invested immense effort in successful maintenance strategies for their road networks, despite tighter budgets, increased traffic volumes and loads, and the critical focus that has emerged on pavement sustainability and conservation [1]. In many pavement conservation activities, resurfacing with a bonded concrete overlay may represent a more cost-effective, rapidly constructed, and sustainable solution than full reconstruction [2].

When placing the concrete layer over an asphaltic (whitetopping) or a Portland cement concrete (overlay) pavement, the bond strength between substrate and the upper layer plays a crucial role in the mechanical behaviour of the composite pavement. Thinner overlays are possible, as the bond ensures a monolithic response under stress [3]. Additionally, the inherent self-compacting behaviour of Self-Compacting High-Performance Concretes (SCHPC) can further reduce resurfacing thicknesses and increase bonding strength [4]. SCHPC overlays may therefore be placed on pavements with height limitations such as tunnels, underpasses, and urban streets where levels are restricted by sidewalks, drains, manhole covers, etc. Furthermore, the use of SCHPC can also reduce the long-term economic cost of pavement maintenance [5].

Table 1 summarizes some of the works reporting laboratory tests that characterize the bonding strength between substrate layers of both Asphalt Cement (AC) and Conventional Concrete (CC) made of Portland cement and concrete top layers at different compressive strengths ($f_{ck}$). These experimental programs comprise tests for assessing bond strengths under pure tension, pure shear and combinations of normal and shear stresses. Note that there are no experimental programs that differentiate between those types of substrate. Furthermore, in the case of AC substrates, the authors have found no investigations on whitetopping bond characterizations with $f_{ck} > 60$ Mpa, nor experimental programs that combine tests to assess pure tension, pure shear and combined normal-shear stresses.

The absence of experimental studies with both AC and CC substrates make it difficult to ascertain whether a particular

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**Table 1**
Summary of studies reporting laboratory tests that characterize bonding strengths between AC and CC substrates and concrete overlays.

| Reference | Substrate Material | | Uppermost Concrete Layer | | Tests | | |
|---|---|---|---|---|---|---|---|
| | AC | CC | $f_{ck} \leq 60$ MPa | $f_{ck} > 60$ MPa | Pure tension | Pure shear | Combined stresses |
| [6,7] | | • | • | | • | | |
| [8] | | • | • | | | • | |
| [4] | | • | • | | | | • |
| [9] | | • | • | | • | | • |
| [10] | | • | • | | • | • | • |
| [11] | | • | • | • | • | | |
| [12] | | • | | • | | | • |
| [13] | | • | | • | • | | • |
| [14,15] | | • | | • | • | • | • |
| [16] | • | | • | | | • | |
| [17,18] | • | | • | | | | • |
| [19] | • | | • | | • | | |
| This Study | • | • | | • | • | • | • |

concrete mix can achieve sufficient bonding strength with these two materials; a situation that may occur in real-life situations, where resurfacing maintenance is planned for a road with both types of pavements. There is moreover a lack of knowledge on the bonding strength of SCHPC poured over AC layers, because no previous experimental tests exist on the matter.

The main objective of this work is to characterize and compare the bond strength obtained under different stress configurations with diverse interfacial treatments in whitetoppings and overlays constructed with SCHPC. To do so, an extensive experimental program is reported in this paper conducted with the two types of substrate materials (CC and AC), SCHPC overlays and 8 interface treatments (4 for CC and 4 for AC substrates). The specimens were tested under "pure" tensile and "pure" shear stresses and combined compression-shear stresses with Direct Tensile (DT), guillotine "Laboratorio de Caminos de Barcelona" (LCB) and compressive Slant Shear (SS) tests, respectively.

## 2. Review of experimental bond-strength tests

The interfaces between pavement layers are constantly exposed both to normal ($\sigma$) and to shear stresses ($\tau$). The debonding of an interface may occur due to three different stress situations: pure tension, pure shear and mixed situations with a combination of shear and compressive or tensile stresses [17,20,21]. Different tests are found in the literature to study these cases of debonding under static loads.

Table 2 summarizes the type of tests according to the type of stresses produced along the interface (pure tension, pure shear and mixed mode). Based on a previous work by Espeche & León [11], the table includes three additional tests for mixed mode failure.

Pure tension stresses may be generated directly (a, b) or indirectly (c, d), depending on whether the load direction is parallel or normal to the stresses, respectively. Pure shear strength may be evaluated by inducing torsion (e) or shear stresses (f, g, h, I, j, k, l). As Espeche & León [11] mentioned, "pure shear" is a theoretical situation that these tests are a long way from reproducing, because they induce a bending moment.

The mixed mode is a combination of normal and shear stresses. Espeche & León [11] mentioned combined compression and shear tests (m, n), although tests to induce shear and tensile stresses (o) in concrete-to-concrete specimens are also found in literature [22]. Bending tests (p, q) have recently been used for bonding characterization between cement-based layers [23–25] and between asphalt and Portland cement concretes [17,18,26].

## 3. Experimental program

Fig. 1 shows the 2 variables considered in this experimental study: the substrate material (Conventional Concrete (CC) And Asphalt Concrete (AC)) and the treatment applied to the interface between substrates and overlays. 4 treatments were studied for each of the substrate materials. A "XYY" code is used to identify the 8 cases, where "X" refers to the substrate (C for Conventional Concrete and A for Asphalt Concrete) and "YY" refers to the interface treatment.

The appearances of all treatments are gathered in Fig. 2a–g. For CC specimens the treatments were: (i) no preparation of the surface (CNP) where chemical bonding is obtained by pouring the fresh upper layer of Self-Compacting High-Performance Concrete (SCHPC) onto the smooth interface (Fig. 2a); (ii) spreading a cement paste over the smooth surface (CCP) (Fig. 2b); (iii) bush-hammering the interface (CBH) for increased roughness (Fig. 2c); and, (iv) bush-hammering and subsequent extension of a cement paste (CBC) (Fig. 2b and c).

The AC treatments were: (v) no preparation of the surface (ANP) with the SCHPC poured over the leveled but porous surface (Fig. 2d); (vi) bush-hammering the interface (ABH) (Fig. 2e); (vii) extending a bituminous emulsion (ABE) that fills the pores (Fig. 2f); and, (viii) spreading a bituminous emulsion and then placing gravel over the bitumen (AEG) to provide a new rough surface with no partial removal of material (Fig. 2g).

The characterization of the mechanical strength of the interfaces was performed with three types of tests. A "pure" tension condition was evaluated through Direct Tension tests (DT). The "Laboratorio de Caminos de Barcelona" (LCB) test [27,28] was used to assess the "pure" shear strength. Finally, a combined situation of shear and compressive stresses was studied with compressive Slant Shear tests (SS). Results were compared between them to determine qualitatively the best interfacial treatments.

In total, 72 specimens with CC substrates were tested, amounting to 6 specimens for each type of surface treatment and test. The number of specimens tested with AC substrates amounted to 56. This number is the sum of 12 specimens (6 for DT and 6 for LCB tests) for each 4 treatments and 8 specimens for SS tests (4 ANP, 3 ABH and 1 ABE). The lack of SS specimens resulted from the difficulty of compacting the AC substrates with a shear surface and might indicate that this test is not especially suitable for AC substrate specimens.

### 3.1. Materials

A semi-dense Asphalt Concrete (AC) for wearing courses was employed (see Table 3), designated as AC 16 SURF according to UNE-EN 13108–1:2008 [29]. It contained 50/70 bitumen (according to UNE-EN 12591:2009 [30]) and its Marshall density was 2.330 kg/m$^3$. The density of 48 Φ100 x 100 mm cylindrical substrates was measured, obtaining an average Marshall density value of 94.1% with a variation coefficient of 3.28%. Although 97% of the Marshall reference is commonly required for road constructions, the density achieved in the present work is considered acceptable.

The materials and mixture proportions of CC and SCHPC are shown in Table 4. The Conventional Concrete (CC) was designed taking as a reference the mix of the wearing layer of a real bi-layer concrete pavement constructed in northeastern Spain [31]. Limestone aggregates with the same minimum and maximum sizes described in [31] were used and the proportion between components was maintained.

The SCHPC mixture was designed, considering common recommendations such as high cement content, small size of coarse aggregate and low water-cement ratio (apparent water/cement ratio = 0.16). Additionally, treated limestone micro-filler was included to improve workability, the packing of the granular skeleton and the cementitious matrix.