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# Laboratory evaluation of the effect of low-temperature application of warm-mix asphalts on interface shear strength

E. Pasquini [a,*], G. Giacomello [b], M. Pasetto [b], F. Canestrari [a]

[a] Department of Civil and Building Engineering and Architecture, Polytechnic University of Marche, Via Brecce Bianche, 60131 Ancona, Italy
[b] Department of Civil, Architectural and Environmental Engineering, University of Padua, Via Marzolo 9, 35131 Padua, Italy

## HIGHLIGHTS

- Low application temperatures of the upper layer may lead to weak interface bonding.
- Using a polymer modified binder in the upper layer reduces the risk of debonding.
- The use of the warm modifier does not clearly affect the interface shear strength.

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## ABSTRACT

A potential drawback, not yet investigated, of low application temperatures of asphalt mixes could be a reduced interface shear strength. Such low temperatures could be due to improper construction as well as to the use of warm mix asphalt (WMA) technology. In this sense, this paper illustrates an experimental laboratory research aimed at characterizing interface shear properties of double-layered asphalt systems. The upper layer of the specimens (WMA or hot mix asphalt control mix) was mixed and compacted at different temperatures in order to simulate different application conditions. A plain bitumen and a polymer modified binder were used for the asphalt mixes whereas an organic (wax) additive was selected as warm modifier. Experimental data were also compared with the stress field of a typical flexible pavement calculated through a layered elastic theory (LET) model. The research study mainly showed that interface shear strength sensibly decreases for low application temperatures of the upper layer (below 140 °C) regardless of bitumen type and presence of the warm additive. However, the use of polymer modified bitumen as binder for the upper layer asphalt concrete leads to noticeably higher interface shear strength at any test temperature reducing the risk of delamination.



## 1. Introduction

A potential drawback, not yet investigated, of low application and compaction temperatures of asphalt mixes could be a reduced interface shear strength. This fact potentially leads to de-bonding failure of interfaces close to the road surface (where the shear stresses transmitted by vehicles remain still high) causing both structural and functional damage to the pavement. In fact, a multi-layered pavement system is composed of several layers whose interfaces should be able to transfer shear stresses. In case of interlayer de-bonding, this stress transfer is not possible and the multi-layered structure does not act as a composite system any more. This occurrence seriously affects pavement characteristics and could lead to premature failure even though durability and mechanical performance of the single layers are appropriate [1]. Low application temperatures can occur due to an improper construction or to a proper use of warm mix asphalt (WMA) technology. In this sense, it is worth noting that WMA technology has recently gained increasing interest due to the fact that environmental considerations about the preservation and protection of natural and working environments have become of strategic importance.

In fact, hot mix asphalt (HMA) production requires high temperatures (>150 °C) that lead to considerable energy consumption and emission of pollutants whereas WMA is a modified asphalt concrete, obtained by using organic (wax), chemical or foaming additives, which can be produced, applied and compacted at lower temperatures (100–140 °C) than HMA. In particular, the most common commercial organic products available are Fischer–Tropsch

* Corresponding author. Tel.: +39 071 220 4507; fax: +39 071 220 4510.
*E-mail addresses:* e.pasquini@univpm.it (E. Pasquini), giovanni.giacomello@unipd.it (G. Giacomello), marco.pasetto@unipd.it (M. Pasetto), f.canestrari@univpm.it (F. Canestrari).

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(F–T) synthesis waxes that, thanks to their melting/crystallizing properties, are solid at ambient temperature and melt at higher temperatures producing a low viscosity liquid.

The F–T process is used to convert synthesis gas containing hydrogen and carbon monoxide to hydrocarbon products that are mostly liquid at ambient temperature, such as alcohols, diesel fuel, kerosene, and waxes. The F–T wax is in the carbon chain length ranging from C40 to C120, with a melting point of approximately 100 °C. Thus, it can be considered a fluidifying agent suitable for WMA applications since it reduces the viscosity of the bitumen above its melting point, allowing lower mixing and compaction temperatures than traditional HMA, without affecting bitumen consistency at pavement service temperatures [2–5].

The use of WMA can lead to environmental benefits (reduced energy consumption, gas and fume emissions) as well as to operational advantages such as longer hauling distances and extended construction periods [2–5].

Clearly, the basic WMA challenge is the production of a pavement mixture characterized by at least the same performance of traditional HMA, thus able to assure acceptable in-service mechanical performance and durability. In this sense, it is worth noting that the mechanical properties of WMA mixes can vary in a large range mainly depending on the amount of additive and the type of WMA technology used [3].

Generally, besides uncertainties regarding long-term WMA performance, the most documented drawbacks related to the reduction of mixing and compaction temperatures are greater moisture susceptibility, higher rutting potential, reduced cracking resistance as well as coating and bonding problems depending on the adopted warm-mix asphalt technology, i.e. organic, chemical or foaming additives [3–5]. In this sense, F–T organic waxes should be able to offset the rutting problem since at in-service temperatures they solidify (crystallize) providing enhanced stiffness and permanent deformation resistance. However, at mid-range and low service temperatures, waxes may increase fatigue and thermal cracking susceptibility [3–14].

As anticipated, a further possible drawback of using WMA could be a reduced interface shear strength. In this sense, possible reduction of interface shear strength due to low mixing and compaction temperatures could make the environmental and economic advantages provided by WMA fruitless.

## 2. Research objective and description

Despite the huge literature concerning shear strength of asphalt interfaces, the influence of application and compaction temperatures has received no attention yet. In particular, since low application temperatures can occur due to improper construction or proper use of WMA technology, the main goal of this experimental laboratory study is the evaluation of interface shear properties of double-layered asphalt systems whose upper layer (HMA or WMA) was mixed and compacted at different temperatures simulating different application conditions. This objective was accomplished by performing Ancona Shear Testing Research and Analysis (ASTRA) tests on double-layered specimens according to the experimental plan schematized in Fig. 1.

In particular, the upper layer of the tested double-layered systems consisted of a dense graded asphalt mixture prepared with limestone aggregates and plain (P) or SBS polymer modified (M) binder. A commercial organic additive (F–T synthesis wax) was selected as warm modifier, obtaining four different mixes prepared with both binders (P and M) including or not the synthetic wax. For each mixture, four double-layered slabs were prepared in the laboratory varying the mixing and compaction temperatures of the upper layer from 100 °C to 160 °C, for a total of 16 slabs, each one representing a different interface configuration. It is worth specifying that HMA was mixed and compacted also at low temperatures (100 °C and 120 °C) in order to simulate wrong application procedures whereas WMA was applied also at high temperatures (140 °C and 160 °C) for comparison purposes.

Hereafter, each system is coded as "XYnnn" depending on the characteristics of the upper layer where "X" = H (hot mix asphalt) or W (warm mix asphalt), "Y" = P (plain bitumen) or M (modified bitumen) and "nnn" = 100, 120, 140 or 160 depending on the application temperature (in °C) of the upper layer. For example, WP100 means an upper layer realized with an asphalt mixture containing the warm additive (W), prepared with plain bitumen (P) and applied at 100 °C.

From each slab, eight cylindrical specimens were cored to be tested at 20 °C with the ASTRA equipment carrying out a total of 128 interface shear tests by applying three different normal stress levels (3 replicates at 0.0 and 0.2 MPa and 2 replicates at 0.4 MPa). Experimental data were also compared with the stress field of a typical flexible pavement calculated through a layered elastic theory (LET) model.

### 3. Materials and methods

*3.1. Materials*

Dense graded asphalt mixtures prepared in the laboratory were used for the upper layer of the tested double-layered systems.

A plain bitumen, classified as 70/100 according to EN 12591, and a SBS polymer modified binder, classified as PMB 25/55-75 according to EN 14023, were selected as the base binders for this study.

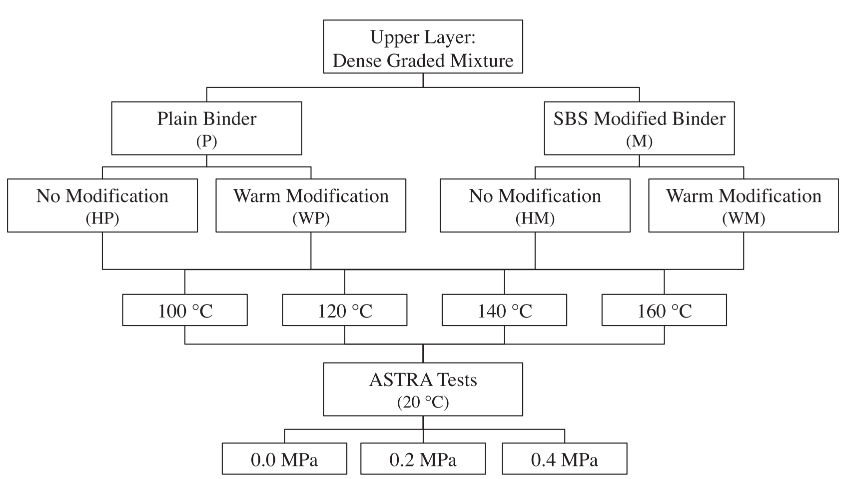


**Fig. 1.** Experimental plan.