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Development of an estimative model for the optimal tack coat dosage based on aggregate gradation of hot mix asphalt pavements

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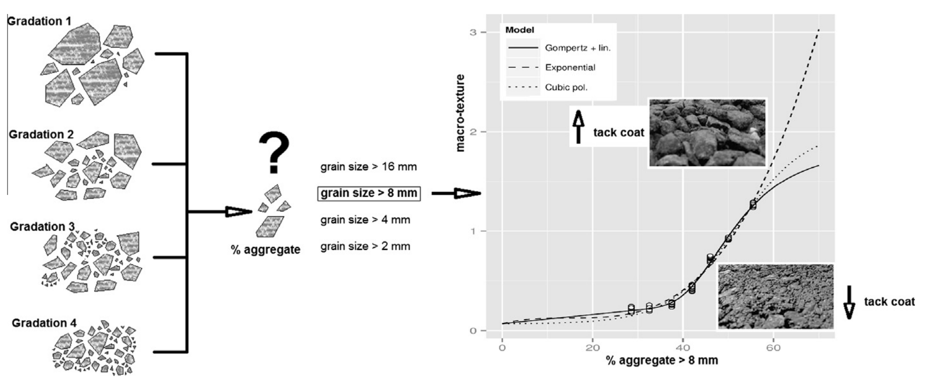
HIGHLIGHTS

- Aggregate larger than 8 mm is directly related to macro-texture.
- The Gompertz model represents the higher increase of macro-texture on AC22 mixes.
- Shear strength is influenced more by aggregate gradation than tack coat dosage.
- Absorption of *on site* test decreases when % of aggregates larger than 8 mm increases.

GRAPHICAL ABSTRACT



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ABSTRACT

In this work the performance of tack coats on asphalt pavement layers is analysed. Adjustment models based on experimental measurements were implemented, relating surface layer macro-texture and aggregate content larger than 8 mm. The best fits were obtained with a Gompertz model, which follows the expected physical macro-texture changes outside the test range. Shear strength was analysed, through prediction curves of each evaluated tack coat dosage, with an optimum tack coat performance for aggregate contents larger than 8 mm between 45% and 50%, and no relevant influence of the tack coat dosage used.

1. Introduction

Deteriorations appear frequently on flexible pavements due to slippage of their layers, especially in areas of acceleration or deceleration, crosses or curves. In these areas, the critical stress level is located at the interface of the upper layers (base/binder and surface layers), whereby the level of bonding between them directly affects the performance and serviceability of the pavement. This bond is ensured by extending asphalt emulsions, as tack coats. The use of such coats as a bond improvement method has been supported by several authors [1–3], who showed that its use significantly increases the lifetime of a flexible pavement,

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avoiding premature failures due to slippages, or fatigue failures in areas of high intensity loads generated in the horizontal direction. Mohammad et al. [4] conclude that the importance of such coats increases for thinner pavement layers, especially in the upper layers.

Studies related to implementing tack coats have focused on understanding the main parameters inherent to emulsion characteristics, which have a direct influence on the bond degree achieved by the coat. These parameters include the type of emulsion used, dosage applied, binder-aggregate adhesion in the interface or setting time of the emulsion [4–12]. Some authors have further evaluated the importance of surface conditions on pavements, such as the degree of surface dust particles or the level of surface texture, which highly influences the final bond degree between layers, in some cases more than the characteristics of the emulsion [2,8,11,13]. Raposeiras et al. [8] indicate that the surface macro-texture of the layer influences slippage resistance between pavement layers bonded by a tack coat. This knowledge is fundamental when selecting an adequate emulsion dosage for the coat.

A procedure for estimating the strength range generated by the tack coat prior to its application, based on the results of the surface characteristics is yet to be implemented, allowing the selection of the optimal emulsion dosage. A model using experimental data from shear strength tests was adjusted, which allows us to estimate the optimal magnitude of slip resistance on layer interfaces before the tack coat is applied. This is analysed according to the aggregate gradation of the asphalt layer to which the tack coat is applied, which is directly related to the macro-texture degree of the asphalt layer [8].

2. Background

2.1. Influential factors on the bond between layers

It is well known that bonding between layers depends on several factors [1,5,14,15]. One of the most studied factors is the applied binder dosage. In terms of residual binder dosage, Collop et al. [14] obtained that the best results are achieved with low dosages, in contrast to what was observed by Recasens et al. [7] and Raposeiras et al. [8], who obtained the least effective dosages below 300 g/m^2 of residual binder and the best results from 300 to 450 g/m^2.

Chen et al. [5] and Deysarkar [6] studied the emulsion setting time and found that shear strength decreases when the surface layer is extended prior to emulsion breaking. However, Tashman et al. [11] point out that this effect has minimal influence on the magnitude of strength. As for the type of emulsion, Mohammad et al. [9] and Zamora-Barraza et al. [12] concluded that this factor influences tack coat performance since higher strength values are obtained with modified and trackless emulsions than those produced by conventional emulsions. Many of the authors mentioned above indicate that there must be external factors more influence on the final strength other than the type and dosage of binder.

This has led to the study of the role of layer surface condition where the coat is applied. Raab & Partl [2,16] evaluated the effect of surface pollutants, such as water or dust, concluding that the presence of these agents significantly decreases shear strength, with a more pronounced effect in low emulsion dosages.

Another important factor is the surface finish, which was evaluated by Tashman et al. [11], who observed greatest sample strength with milled surfaces, where the tack coat has a minimal influence. Raposeiras et al. [8] evaluated the role of the surface layer macro-texture to where the coat was applied. This parameter is defined as the degree of surface deviations present in the longitudinal direction range of 0.5–50 mm and peak amplitude of 0.2–10 mm, in relation to a flat surface [17]. The influence of this variable was estimated, observing that the greatest shear strength results are generated for high macro-texture values, while the lowest ones are observed for lower macro-texture values and also sawn surfaces. This study also shows that there is not an optimum tack coat dosage value valid for all types of asphalt mixes, but that this depends directly on the layer macro-texture.

2.2. Assessment and prediction of the macro-texture of asphalt mixes

Currently there are two types of procedures to assess macro-texture of an asphalt mix layer. The first one is the volumetric method or sand patch test (ASTM E965-06 [18] and UNE-EN 13036-1:2010 [19]), in which glass spheres, with specified sizes between 0.18 mm and 0.25 mm, or sand, with particles between 0.16 mm and 0.32 mm or between 0.16 mm and 0.08 mm, are used as a means to determine surface voids through Mean Texture Depth (*MTD*). On the other hand, methods based on longitudinal profiles use instruments with laser technology to measure the Mean Profile Depth (*MPD*), as specified by the ASTM E1845-09 [20] standard, which is then linearly transformed to values that are equivalent to the Mean Texture Depth (*MTD*).

In order to predict macro-texture levels of an asphalt pavement, Stroup et al. [21] developed a mathematical model based on characteristics of the aggregate mix. The adjusted values were obtained from measurements of samples from 20 different US roads with Superpave, SMA (Stone Mastic Asphalt) and OGFC (Open Graded Friction Courses) mixes. The model used consists of a linear combination of four variables defined from the aggregate gradation to determine the Estimated Texture Depth (*ETD*) [22]:

$$ETD = 0.0198 \cdot MS - 0.004984 \cdot P4.75 + 0.1038 \cdot C_c - 0.004861 \cdot C_u \quad (1)$$

where *MS* corresponds to the maximum nominal diameter of the aggregate, in mm; *P4.75* corresponds to the percentage of aggregate passing through a 4.75 mm sieve, in %; C_c corresponds to the coefficient of curvature; and C_u correspond to the coefficient of uniformity.

The coefficients C_c and C_u are defined as:

$$C_c = (D_{30})^2/(D_{10} \cdot D_{60}) \quad (2)$$

$$C_c = D_{60}/D_{10} \quad (3)$$

where D_{10} corresponds to the sieve size associated to 10% passing, in mm; D_{30} corresponds to the sieve size associated to 30% passing, in mm; and D_{60} corresponds to the sieve size associated to 60% passing, in mm.

From the analysis of the model's variables (1) it is observed that the maximum aggregate size *MS* is the indicator with the largest influence on macro-texture values estimated by the model. However, for this to be truly representative, the percentage of *MS* from the total aggregate mass must be considered, that is the probability of this aggregate to be present on the surface. The percentage of aggregate passing through the 4.75 mm sieve is a measure to quantify aggregates of smaller diameter filling surface voids generated by higher aggregates and to a certain degree reducing surface macro-texture. This effect is also dependent on the compaction level of the mixture. Curvature and uniformity coefficients are indicators of the aggregates' distribution degree, and they are used in the model to represent variability in the observed textures of SMA and OGFC mixes, with a non-uniform distribution of their gradation.

The model showed a relatively low correlation level, with a coefficient of determination $R^2 = 0.65$, which may be attributed to the fact that their influence would not be represented by a linear