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Application of density gradient column to flexible pavement materials: Aggregate characteristics and asphalt absorption

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HIGHLIGHTS

- Density gradient column can measure volumetric properties and asphalt absorption.
- Individual aggregate pieces possess different volumetric properties.
- Relations between aggregate properties and asphalt absorption are investigated.
- Asphalt absorption correlates very well with air void volume.
- Density gradient column provides precise results.

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ABSTRACT

Accurate measurements of aggregate volumetric properties are essential to a satisfactory mix design and successful production of pavement. Moreover, determination of aggregate asphalt absorption is required to correctly estimate air voids and optimal binder content. The objective of this research was to apply the density gradient column technique to flexible pavement materials and to investigate aggregate volumetric properties, asphalt absorption and their possible correlation. Results indicated that the density gradient column can accurately measure piece-by-piece volumetric properties and asphalt absorption, and revealed a very good correlation between asphalt absorption and aggregate void volume (as reflected by the aggregate bulk density).

1. Introduction

Accurate measurements of aggregate volumetric properties and absorption are essential to the development of satisfactory mix design and production [1]. A key to the calculation of mixture volumetric properties are aggregate specific gravities, which are numerically equal to densities (for a water density of 1.0 g/cm^3). Aggregate bulk density and apparent density allow conversion between aggregate mass and volume, necessary for calculating mixture volumetric properties such as air void percent, void filled by asphalt (VFA), voids in the mineral aggregate (VMA) and asphalt absorption [2]. Therefore, precise and reliable measurements of aggregate densities are fundamental to the quality of hot mix asphalt or warm mix asphalt pavements.

For several decades, various laboratory tests have been used to evaluate asphalt absorption at different conditions, which is necessary for successful mix designs [3–7]. In paving mixtures, asphalt is absorbed by the porous structure of aggregates. Asphalt absorption is important because incorrect estimates translate into erroneous calculations of air void percent, VFA and VMA, all important parameters used in mixture design to control pavement durability and stability. It has been reported that asphalt absorption is a process controlled by capillary force that depends both on asphalt properties (including asphalt composition, viscosity, and surface tension) and aggregate properties (such as porosity, pore size distribution and surface chemical composition) [8,9]. Particularly, comparison of water absorption and asphalt absorption shows they are correlated [3]. The driving force for asphalt absorption is mainly determined by capillary action and absorption is reported to be a nonlinear function of time [9]. It also has been reported that aggregate tends to selectively absorb some asphalt components over

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others [10]. Recent studies of aggregate volumetric properties and asphalt absorption in asphalt pavement can also be found [11–15].

Although standard testing procedures are available to measure volumetric properties and asphalt absorption in aggregates [16–18], these standard methods have some limitations [19]. The first problem is precision. Measuring aggregate volumetric properties requires achieving a saturated surface dry (SSD) condition of the aggregate, a rather subjective assessment and therefore difficult to reproduce precisely or accurately among investigators. Also, precision is limited by the inherent difficulty of measuring volume accurately and of subtracting two large numbers that differ by a small amount. Second, standard methods are inadequate to understand the fundamentals of asphalt absorption. The standard methods are based on measurements of samples comprised of large numbers of aggregate pieces having variable properties. However, asphalt absorption varies according to the properties of each specific aggregate piece. Reporting average results on large samples veils individual differences between aggregate pieces.

The density gradient column (DGC), often used for determining the densities of small samples of polymers and other materials, is based on the preparation of a stable column of single phase liquid of variable density along its length [20–22]. A specimen introduced into the column settles at the vertical position where it is in hydrostatic equilibrium with the fluid in the column. In the DGC, the density of small specimens can be measured quite precisely. A key feature that improves precision is that density is measured directly rather than mass and volume separately. Although the DGC method has been used for polymer and other materials testing, it has not been applied previously to measurements of aggregate density and asphalt absorption.

A principal objective of this study was to adapt the DGC method to flexible pavement materials in order to more accurately measure aggregate bulk and apparent densities and water and asphalt absorption. Part of achieving improved precision was to eliminate the subjective determination of the saturated surface dry (SSD) condition. In addition, this approach provides a method of measuring aggregate bulk and apparent densities and the ability to compare asphalt absorption directly to water absorption, i.e. to the aggregate void volume. An additional objective was to compare the precision of the DGC method for asphalt absorption to the precision of using the standard methods and practice for measuring asphalt absorption.

2. Materials and methods

2.1. Materials

Six types of pavement aggregates (sandstone, granite, manufactured lightweight, quartzite, limestone, and gravel) and one asphalt binder (PG 64-22) were selected for study. The size of the aggregates ranged from 0.1 cm^3 to 0.5 cm^3. Lithium metatungstate heavy liquid was used to generate a liquid density gradient suitable for pavement aggregate materials, and precision glass beads were used to calibrate the density gradient. Paraffin wax was used as a coating for determining aggregate bulk density.

2.2. Density gradient column apparatus and methodology

The density gradient method is based on the direct measurement of particle density in a column of fluid that has a linear density gradient. The gradient is generated by continuously blending two completely miscible make-up fluids of different densities and feeding them slowly to the bottom of the column. For asphalt binder measurements the two make-up fluids were water and a brine solution of appropriate density. For aggregate measurements, the two make-up fluids were water and a heavy liquid (lithium metatungstate, density 2.95 g/cm^3). The heavy liquid was regenerated by evaporating the water.

The DGC method is direct and efficient because it does not require measuring particle volume, a difficult measurement to do precisely. Instead, the accuracy of the method depends upon an accurate calibration of the density variation with position in the column. Two sets of glass beads, traceable to NIST weights and measures, were used for calibrations; one set (for asphalt density determinations) provides density calibrations at 23 °C from 0.94 to 1.10 g/cm^3 ±0.0002 g/cm^3 and the other set (for aggregate density determinations) provides density calibrations from 2.0 to 2.8 g/cm^3 ±0.0005 g/cm^3. The thermal expansion coefficient of the beads was given to be 0.000037 g/cm^3/°C. An example calibration of a column prepared for aggregate measurements is presented in the Results and Discussion section, below. The measurement requires generating a linear density fluid in an appropriate graduate cylinder containing the calibration beads. The beads, each of different density, settle at the point in the column equal to their density. Particles of asphalt or aggregate are dropped into a column of appropriate density range and also settle according to their density. The position of each asphalt bead or aggregate particle was read with a cathetometer of 0.001 cm precision. Asphalt or aggregate densities were determined by linear interpolation of the vertical calibration.

Fig. 1 shows a schematic of the DGC; aggregate particles of varying states were dropped into the DGC to measure their density. These states included wax coated, water saturated, and asphalt treated, and are described below.

2.3. Asphalt absorption calculation

The DGC methodology requires immersing the aggregate with asphalt binder at 121 °C for 15 s on a hot plate followed by curing the coated aggregate at 143 °C for 2 h in the oven, to approximate TxDOT specifications on laboratory preparation of asphalt mixture [23]. The mass of asphalt absorbed by aggregate $m_{abs\text{-}b}$ is determined by subtracting the aggregate mass from the mass of aggregate plus absorbed and coated asphalt and then correcting for the mass of asphalt coating:

$$m_{abs-b} = f(m_{ab}, m_a, \rho_b, \rho_{ab}, \rho_{av}) = m_{ab} - m_a - \frac{m_{ab}\rho_b}{\rho_{ab}} + \frac{m_a\rho_b}{\rho_{av}} \quad (1)$$

where m_{ab} is the mass of aggregate coated with asphalt (including both absorbed asphalt and excess asphalt coating), m_a is the mass of aggregate (including air voids of negligible mass), ρ_b is the asphalt density, ρ_{ab} is density of asphalt-treated aggregate (including both absorbed asphalt and excess asphalt coating), ρ_{av} is bulk density of the aggregate, i.e., the density of the aggregate including its air voids. The masses were measured using a precision balance, and densities were measured using the DGC. While the first four properties can be measured directly, ρ_{av} is measured using the wax-coating method described below.

2.4. Bulk density determination

The bulk density of a single aggregate particle is the density (mass/volume) of the aggregate including its accessible air voids volume. The bulk density of a sample of many aggregate particles is the density (mass/volume) including all of the particle accessible internal air voids but excluding the void spaces in the interstices between particles. Thus, the bulk density of an aggregate sample of many particles is an average bulk density of those particles. In the standard method, a saturated surface dry (SSD) condition is necessary to determine aggregate bulk density. Under this SSD condition, the pores of aggregate particles are filled with water and no excess water is on the particle surfaces (i.e., in the spaces between particles). The SSD condition is experimentally achieved by removing this excess water from the aggregate by absorbing surface moisture with towels (for large aggregate) or allowing finer aggregate to dry to "the appropriate state". This method is subjective to an

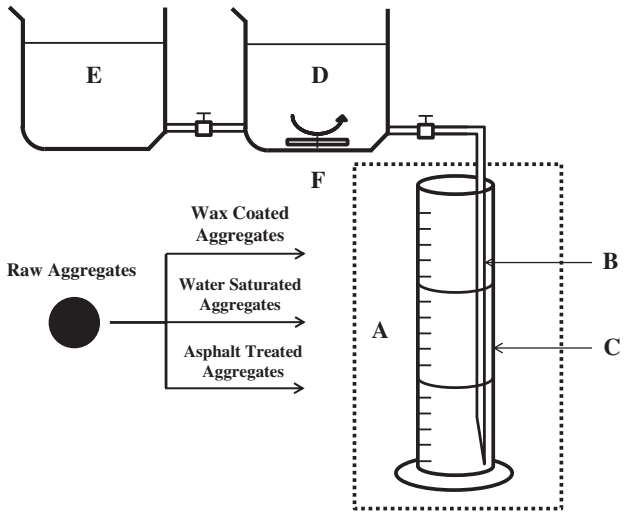

Fig. 1. Schematic diagram for the density gradient column. (A: density gradient column area; B: capillary tube; C: column; D: low density liquid; E: high density liquid; F: magnetic stirring bar).