1 January 2003

Committee D04 on Road and Paving Materials
Subcommittee D04.21 on Specific Gravity and Density of Bituminous Mixtures

Research Report RR #D04-1020

Inter-Laboratory Study to Establish Precision Statements for ASTM D6752, Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Automatic Vacuum Sealing Method

Technical Contact:
Mr. Brian Prowell,
Auburn, AL 36830
USA
334-844-6228
Prowebd@eng.auburn.edu

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

BULK SPECIFIC GRAVITY ROUND-ROBIN USING THE CORELOK VACUUM SEALING DEVICE

L. Allen Cooley, Jr., Brian D. Prowell, Mohd Rosli Hainin and M. Shane Buchanan
National Center for Asphalt Technology

INTRODUCTION

A major concern of the hot mix asphalt (HMA) industry is the proper measurement of the bulk specific gravity (G_{mb}) for compacted HMA samples. This issue has become a bigger problem with the increased use of coarse gradations. G_{mb} measurements are the basis for volumetric calculations used during HMA mix design, field control, and construction acceptance. During mix design, volumetric properties such as air voids, voids in mineral aggregates, voids filled with asphalt, and percent maximum density at a certain number of gyrations are used to evaluate the acceptability of mixes. All of these properties are based upon G_{mb}.

In most states, acceptance of constructed pavements is based upon percent compaction (density based upon G_{mb} and theoretical maximum specific gravity). Whether nuclear gages or cores are used as the basis of acceptance, G_{mb} measurements are equally important. When nuclear gages are utilized, each gage has to first be calibrated to the G_{mb} of cores. If the G_{mb} measurements of the cores are inaccurate in this calibration step, then the gage will provide inaccurate data. Additionally, pay factors for construction, whether reductions or bonuses, are generally applied to percent compaction. Thus, errors in G_{mb} measurements can potentially affect both the agency and producer.

Bulk Specific Gravity By The Saturated-Surface Dry Method

For many years, the measurement of G_{mb} has been accomplished by the water displacement concept, using saturated-surface dry (SSD) samples. This consists of first weighing a dry sample in air, then obtaining a submerged mass after the sample has been placed in a water bath for a specified time interval. Upon removal from the water bath, the SSD mass is determined after patting the sample dry using a damp towel. Procedures for this test method are outlined in AASHTO T166 and ASTM D2726.

The SSD method has proved adequate for conventionally designed mixes that utilize fine-graded aggregates. Historically, mixes have been designed to have gradations passing close to or above the maximum density line (fine-graded). However, since the adoption of the Superpave mix design system and the increased use of stone matrix asphalt (SMA), mixes are being designed with coarse-graded aggregate resulting in erroneous G_{mb} measurements. Many of the HMA mixes that were designed with the Superpave mix design system have been coarse-graded (gradation passing below the restricted zone and maximum density line). SMA mixes utilize a gap-graded gradation that is also coarse-graded.

The problem in measuring the G_{mb} of coarse-graded Superpave and SMA mixes using the SSD method comes from the internal air void structure within these mix types. These types of mixes tend to have larger internal air voids than the conventional mixes, though the volume of air voids is the same. Figure 1 illustrates this point. Mixes with the coarser gradations have a much higher percentage of large aggregate particles. At a certain overall air void volume, which is mix specific, the large internal air voids of the coarse mixes can become interconnected. During G_{mb} testing with the SSD method, water can quickly infiltrate into the sample. However, after removing the sample from the water bath to obtain the saturated-surface dry condition the water can also drain from the sample quickly. This draining of the water from the sample is what causes the errors with the water displacement method.

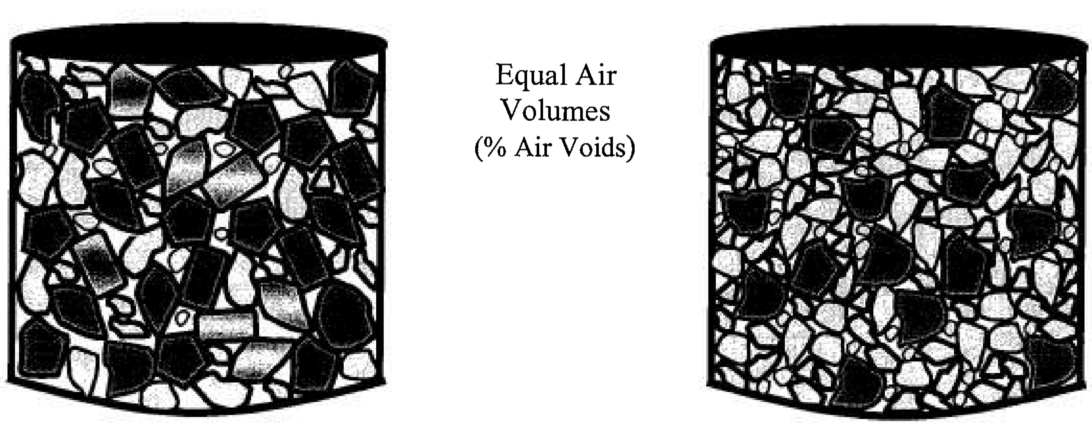

Figure 1: Differences in Internal Void Structure for Coarse- and Fine-Graded Mixes.

To understand the cause of potential errors, one must first understand the principles of the water displacement method. The philosophy of the SSD method is based upon Archimedes' Principle. Archimedes' Principle states that a material immersed in fluid is buoyed up by a force equal to the mass of the displaced fluid. Take for instance the material submerged in water illustrated within Figure 2. The surface of the material that is in contact with water can be divided into two halves: the upper surface

(face BCE) and lower surface (face BDE). Submerged in this manner, there are three forces acting on the material: 1) the weight of the material in a dry condition acting along BDE (W_M); 2) the force of the water within ABCEF on the material (F_{D2}); and 3) the force of the buoyant resistance acting upward (F_{U1}) which is equal to the weight of the water within ABDEF.

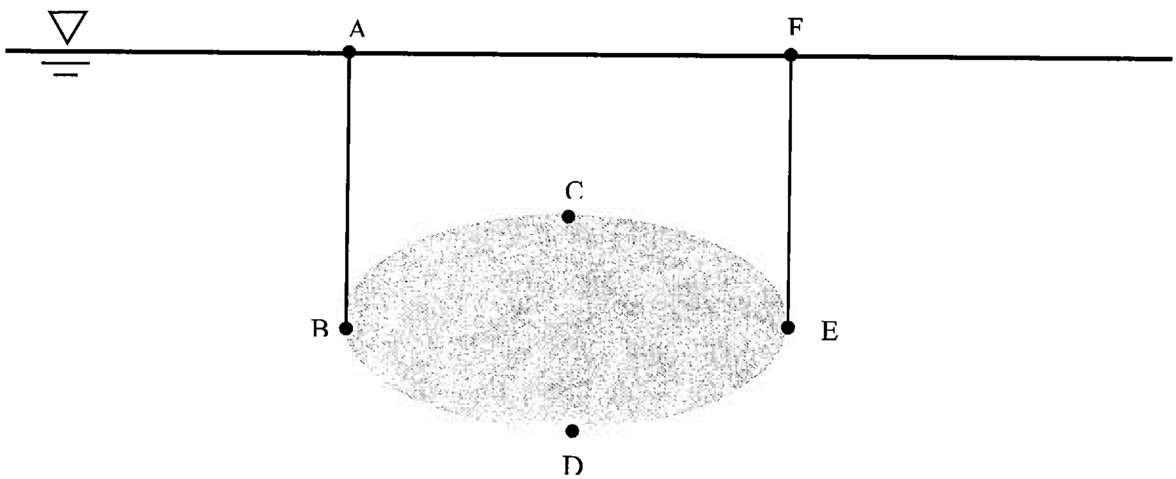

Figure 2. Hydrostatic Forces on a Submerged Material

Using these known forces acting on the material, a series of relationships can be identified:

$$\text{Total force acting downward} = F_D = W_M + F_{D2} \qquad (1)$$

$$\text{Total net force} = F_N = W_M + F_{D2} - F_{U1} \qquad (2)$$

The net force acting downward on the block (F_N) can be determined by measuring the weight of the block when it is submerged in water (W_{MW}). Therefore, the weight of the material submerged in water is equal to the right hand side of Equation 2. Further, the difference in the weight of the two water columns (F_{D2} and F_{U1}) is equal to the fluid that is displaced when the material is submerged in water (W_W). Hence:

$$W_{MW} = W_M - W_W \tag{3}$$

Now, using the properties shown in Equations 1 through 3 and the definition of density and specific gravity, the equation for the water displacement method can be derived. The definition of density and specific gravity are as follows:

$$\gamma_M = M_M / V_M \tag{4}$$

$$G_s = \gamma_M / \gamma_W \tag{5}$$

Where:

γ = the density of an object (γ_M for material and γ_W for water);

M_M = the mass of a material; and

V_M = the volume of the material.

G_s = specific gravity of a material

Since the volume of the material is equal to the volume of the water displaced by the material, substituting Equation 4 into Equation 5 yields the following:

$$G_s = M_M / M_W \tag{6}$$

The mass of a material is equal to the weight of that material divided by the acceleration caused by gravity; therefore, Equations 3 and 6 can be used to derive the equation used for determining the specific gravity of a material using the water displacement method:

$$Gs = M_M / (M_M - M_{MW}) \tag{7}$$

Equation 7 is the method of determining the specific gravity of a material using Archimedes' Principle. However, within the context of HMA materials this equation defines the apparent specific gravity and not the bulk specific gravity. A brief discussion of the differences between the apparent and bulk specific gravities of compacted HMA is provided.

Figure 3 illustrates volumes and air voids that are associated with compacted HMA. Each of the diagrams within Figure 3 are divided into halves with each half representing the volumes and air voids of mixes with coarse and fine gradations. The dark black line in Figure 3a shows the volume that is associated with the specific gravity measurements using the dimensional procedure. Dimensions (height and diameter) of the sample are used to calculate the volume of the sample. Figure 3a illustrates the effect of using this volume in determining the air void content of HMA. The volume includes any surface irregularities on the outside of the sample and thus overestimates the internal air void content. Of the three cases illustrated in Figure 3, the gyratory volume is the highest, resulting in the lowest measured density.

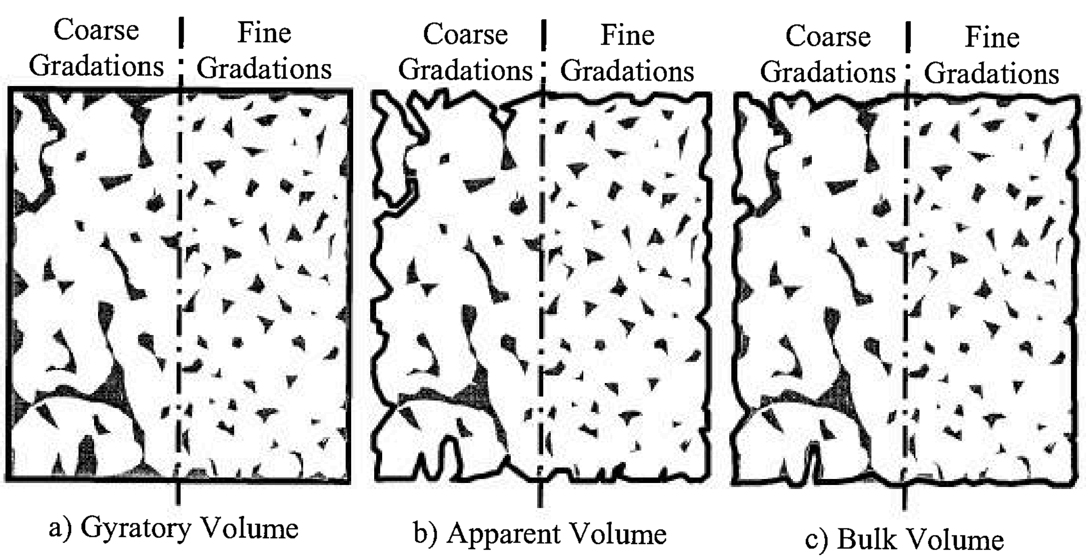

Figure 3. Volumes Associated with Compacted HMA