

Influence of Mold End Plate Clearance on Volumetric Properties of Gyrotory Compacted Specimens

How SGC mold wear can cause a reduction in compaction effort

Normal wear of a Superpave* Gyrotory Compactor (SGC) specimen mold tends to increase the clearance between the inner wall of the mold and the mold end plates. As this clearance around the end plates increases, there is a reduction in compaction effort, producing specimens with higher air void contents. Normally, mold wear occurs very slowly over time and has a barely perceptible impact on specimen volumetrics. However, this report describes experiments where **purposeful and severe wear** has been applied to molds so as to quantify the impact of such wear on bulk specific gravity. Results of this study are discussed in light of the present specifications for SGC molds.

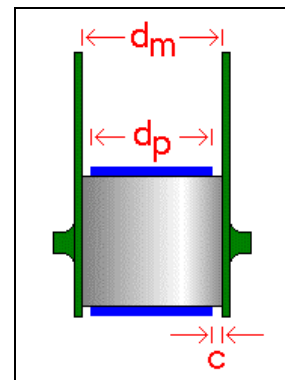
Introduction

Specimen molds for Superpave* Gyrotory Compactors (SGCs) are considered a wear item. With proper care and operation, molds will provide years of service, but due to the abrasive nature of hot mix asphalt, replacement of SGC molds is inevitable. This report provides some technical guidance as to what level of wear is tolerable before negatively affecting compaction results.

The present SGC specification¹ places tight tolerances on the diameters of specimen molds and mold end plates (see Figure I). The inner diameter of the mold (d_M) must be in the narrow range between 149.90 to 150.00 millimeters. The outer diameter of the mold end plates (d_P) must be in the range 149.50 to 149.75 millimeters. This maintains a tight clearance between the end plate and the mold wall. This clearance ($2c$) must fall between 0.15 and 0.50 millimeters.

As an SGC mold wears over time, the end plate clearance tends to grow larger. This can be due to an increase in the inner diameter of the mold (d_M) or a decrease in the outer diameter of the end plates (d_P) or a combination of both. Proper verification of the end plate clearance requires careful measurement of both diameters (d_M and d_P). Furthermore, the mold diameter must be checked at several points along the mold, especially in the portion of the mold where the specimen resides during compaction.

As the clearance increases, the mold end plates enjoy greater freedom of movement (in the horizontal



$$2c = (d_M - d_P)$$

Figure I: SGC End Plate Clearance

plane, both side-to-side and rotational). As the clearance begins to exceed that permitted by the specification ($2c > 0.50$ mm), the bulk specific gravity (G_{mb}) of compacted specimens begins to drop precipitously. In cases where SGC molds are severely worn, this decrease in compaction effort will noticeably affect specimen volumetric properties.

This report describes a set of experiments designed to quantify the impact of SGC mold wear on specimen bulk specific gravity. It should be noted at the outset that many of the molds and end plates used in these experiments were intentionally machined to incorrect dimensions strictly for purposes of this study. The level of (artificial) wear on these molds greatly exceeds that which occurs during normal SGC use. These worn molds were compared to "normal" molds meeting existing specifications.

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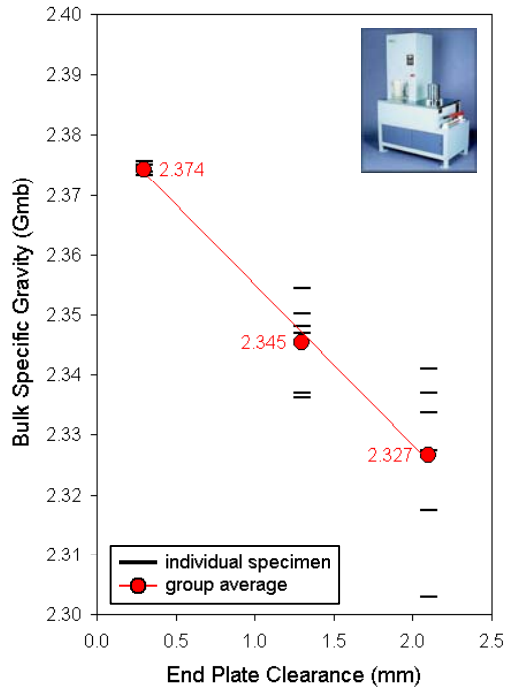


Figure II: Use of Undersize End Plates (Pine AFGC125X)

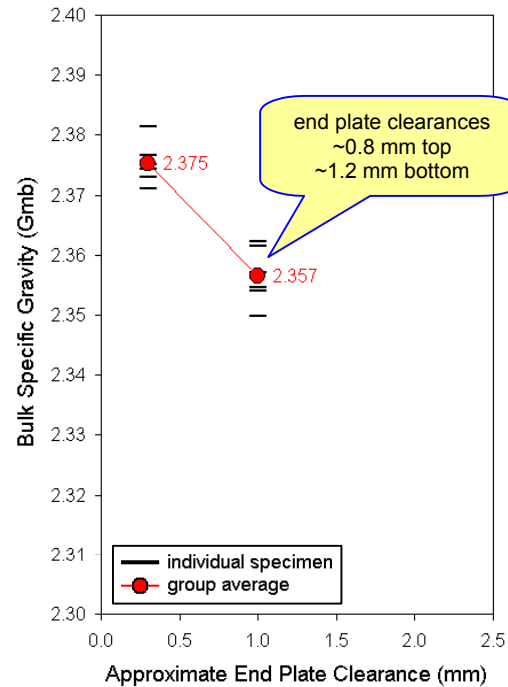


Figure III: Use of Oversize Mold Bore (Pine AFGC125X)

Experimental

HMA Sampling. A single 12.5-mm Superpave mix was used in this study. Mix design details are provided in Appendix A. The mix was obtained at a nearby asphalt plant and transported to the laboratory in 5-gallon metal pails. At a later date (*i.e.*, long after the mix had cooled), several pails were reheated and their combined contents were mixed together on a table. The mix was then split down into multiple pre-weighed samples, each having a mass chosen to produce an SGC specimen with a final height near 115 mm. These sets of “matched” HMA samples were wrapped in paper, cooled and stored until needed for a volumetric comparison trial.

Pine AFGC125X. For the main experiment involving the original Pine AFGC125X compactor, two sets of undersize end plates were manufactured. Each set consisted of a top plate and a bottom plate machined to the same undersize diameter. The two undersize diameters were 147.9 mm and 148.7 mm. A set of “normal” end plates was used as the experimental control. By using each of the three sets of end plates in conjunction with one particular mold, it was possible to produce three different end plate clearances with that very same mold. That is, the clearance ($2c$) was varied by changing the end plate diameter (d_P) while holding the mold diameter (d_M) constant.

In a second experiment involving the Pine AFGC125X compactor, a “normal” mold was compared to an “oversize” mold. Here, the same set of “normal” end plates was used with both molds. Thus, in this second

experiment, the clearance ($2c$) was varied by changing the mold diameter (d_M) while holding the end plate diameter (d_P) constant. The bore of the “oversize” mold was not entirely uniform, so that the end plate clearances were ~0.8 mm on the top and ~1.2 mm on the bottom.

Pine AFG1. For the Pine AFG1 compactor, undersize end plates were fabricated for the bottom of the mold only. The two undersize bottom end plates had diameters of 147.9 mm and 148.7 mm. A “normal” bottom end plate was used as the experimental control. Each of the three bottom end plates was used in conjunction with same mold and mold top, meaning that the bottom end plate clearance was the only variable in the experiment involving the AFG1.

Volumetric Comparisons. Each volumetric comparison trial was conducted as follows: A set of matched samples (typically 18) was reheated to compaction temperature. Samples were removed from the oven and compacted in a sequence. For the comparisons involving undersize end plates, the sequence alternated among the three possible end plate conditions (normal plates vs. one of the two sets of undersize plates). For the comparisons involving an oversize mold, the sequence alternated between the two molds (normal vs. oversize). These careful sequences are thought to distribute any specimen aging effects equally across the various groups of compacted specimens. Specimens were cooled overnight, and their bulk specific gravities (Gmb) were measured the next day as per ASTM D 2726. The average bulk specific gravity was computed for each group of like specimens.

Results

Pine AFGC125X. For the Pine AFGC125X, compaction using undersized pairs of end plates (same undersized diameter on top and bottom) was compared with compaction using normal end plates. As the end plate clearance increased, specimen compaction dropped dramatically (see Figure II). The relationship between the average bulk specific gravity (Gmb) and the end plate clearance (2c) was quite linear. For each additional millimeter of clearance, the average bulk specific gravity dropped by about 27 kg/m^3 (0.027 Gmb units). Another observable trend in this experiment was larger scatter in the individual specimen densities as the end plate clearance increased.

In a similar experiment involving an “oversize” Pine AFGC125X mold, compaction of specimens was again significantly influenced by additional end plate clearance (see Figure III). Compared to the “normal” mold, this particular “oversize” mold had $\sim 0.7 \text{ mm}$ additional end plate clearance. Specimens compacted with the oversize mold had bulk specific gravities that were lower, on average, by 18 kg/m^3 (0.018 Gmb units).

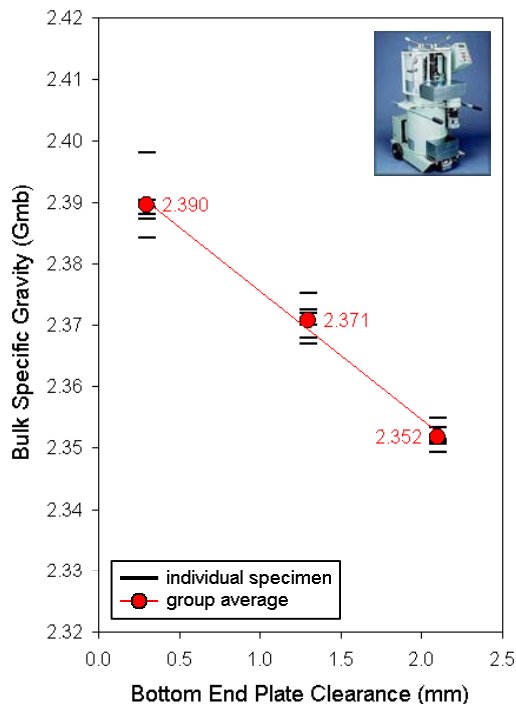


Figure IV: Use of Undersize End Plates (Pine AFG1)

In both of the AFGC125X experiments, the additional clearance had nearly the same influence on bulk specific gravity (*i.e.*, similar slopes in Figures II and III). This suggests that it is not the absolute measure of end plate or mold bore diameter that matters, but rather the net clearance between the two.

Pine AFG1. For the Pine AFG1, the influence of end plate clearance was studied by varying the outer diameter of the bottom mold plate. The same mold and mold top were used throughout the experiment, so the upper end plate clearance remained unchanged in this comparison. Over the same range of end plate clearances used in the AFGC125X experiment (0.3 to 2.1 mm), the AFG1 produced a similar dramatic decrease in bulk specific gravity (see Figure IV). The relationship between the average bulk specific gravity (Gmb) and the bottom plate clearance was again linear, with each additional millimeter of bottom plate clearance causing a drop in the bulk specific gravity of 21 kg/m^3 (0.021 Gmb units).

SGC Mold Specifications

The relationship between compaction (*i.e.*, bulk specific gravity) and end plate clearance can be used to assess the validity of the present specification for SGC molds. The tolerance on end plate clearance is already tight, spanning a mere 0.35 mm (from 0.15 to 0.50 mm), and the sensitivity of compaction to end plate clearance is $\sim 25 \text{ kg/m}^3$ per millimeter of clearance (for the particular mix and SGCs studied here). Thus, over the narrow range of allowed clearances, the predicted variation in bulk specific gravity is just less than 10 kg/m^3 (0.010 Gmb units). Given that 10 kg/m^3 is the generally accepted level of discrepancy between two SGCs (in careful, same day, single operator, side-by-side comparisons²), then it would appear that the present tolerance for end plate clearance is entirely justified.

But the present SGC mold specification is worded in terms of diameters rather than in terms of end plate clearance. The inner diameter of the mold (d_M) must fall in the range between 149.90 to 150.00 mm , and the outer diameter of the mold end plates (d_P) must fall in the range 149.50 to 149.75 mm . While the present wording assures that end plate clearance remains below 0.5 mm , the precise wording may actually be unnecessarily stringent. SGC molds that might be perfectly useful could easily be excluded by the present wording of the specification.

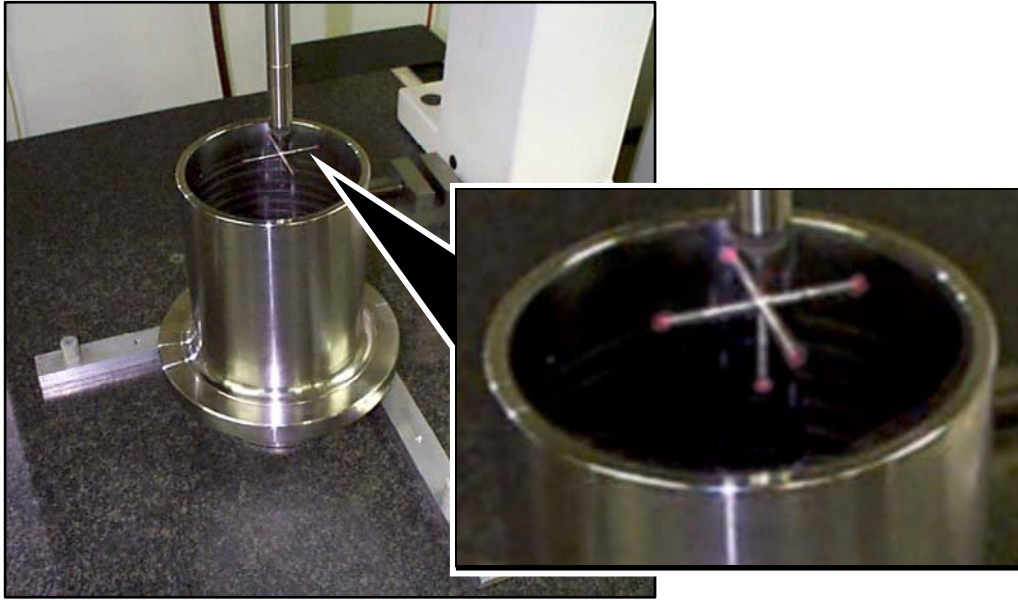


Figure V: Factory Certification Using a Coordinate Measurement Machine

Consider, for example, the following two molds:

| MOLD "A" | MOLD "B" |
|---------------------------|---------------------------|
| $d_p = 149.54 \text{ mm}$ | $d_p = 149.70 \text{ mm}$ |
| $d_M = 149.95 \text{ mm}$ | $d_M = 150.10 \text{ mm}$ |
| clearance = 0.41 mm | clearance = 0.40 mm |

Both molds have nearly identical end plate clearances, and specimens compacted in each mold would likely be indistinguishable from one another in terms of bulk specific gravity. However, mold "B" fails to meet the existing specifications, and would have to be discarded.

To avoid needless replacement of useful SGC molds, an alternate wording for the SGC mold specification might place greater emphasis on the end plate



Figure VI: IMPROPER Mold Measurement Technique

clearance. For example, an inner mold diameter (d_M) range might be relaxed to allow for inevitable wear (*i.e.*, 149.9 to 150.3 mm), but at the same time the requirement for end plate diameter would be rewritten in terms of keeping the end plate clearance below 0.5 mm. Reconstructing the specification in this manner could double or triple the useful lifetime of a mold with minimal impact on mix design.

SGC Mold Verification

The dimensions of newly manufactured SGC molds are subjected to careful scrutiny using a **Coordinate Measurement Machine** (CMM) like that shown in Figure V. Such a device can evaluate critical mold and end plate dimensions at the micrometer level ($\pm 0.0015 \text{ mm}$) and can also determine the "roundness" of the mold bore and end plates. The CMM probe can also reach down inside the mold to measure the inner diameter at the actual location where specimen compaction occurs. This is a very important aspect of any mold diameter verification—*the mold diameter must be checked in the region of the mold where the end plates are located during compaction*. Simply checking the diameter at the top or bottom ends of the mold is not sufficient.

While the CMM offers the most accurate method for traceable verification of SGC mold dimensions, use of a simple pair of **dial calipers** is perhaps the least appropriate and least accurate way to verify mold dimensions (see Figure VI). The range of mold diameters permitted by the SGC specification (149.90 to 150.00 mm) spans a mere 0.10 mm; but a typical



Figure VII: Use of a Three-Point Micrometer to Probe SGC Mold Bore
(photographs courtesy of the Florida Department of Transportation)

pair of dial calipers is accurate to only ± 0.025 mm. Clearly, a measurement tool with an uncertainty approaching 25% of the quantity being measured is not the right tool for the job.

Dial calipers are also lacking in their ability to verify the diameter along the entire length of the mold bore. A meaningful and relevant verification of the inner diameter must examine the region of the mold where the specimen is actually compacted, especially the area where the end plates tend to wear against the mold wall. All too often, molds are “verified” at the wrong location within the mold (as in Figure VI). Measurements made at either end of the mold are typically nowhere near the critical wear surfaces within the mold.

Field verification of SGC mold bores should be performed using either a **three-point micrometer** (Figure VII) or a **dial bore gauge** (Figure VIII). A dial bore gauge is an excellent hand tool for measuring the inner mold diameter at any location within the mold (see Figure IX). The three-point micrometer has the added advantage of self-centering within the bore of the mold. The accuracy of both of these devices is typically ± 0.0025 mm.

A **5" to 6" micrometer** (Figure VIII inset) is useful for field verification of end plate diameters. This kind of micrometer is typically accurate to within ± 0.0025 mm, and it can be used for field calibration of the dial bore gauge as well.



Figure VIII: Dial Bore Gauge and 5" to 6" Micrometer (inset)



Figure IX: Use of Dial Bore Gauge to Probe SGC Mold Bore

Conclusion

Given the potential for SGC mold wear to influence the volumetric properties of compacted specimens, it is clear that routine verification of SGC mold dimensions is required. Such verification should be carried out using the proper measurement tools. The key mold dimension is the clearance between the end plates and the mold wall, and this clearance should not exceed 0.5 mm. While the present SGC mold specification (when enforced) does indeed assure that the end plate clearance remains below 0.5 mm, a revised wording of this specification might place greater emphasis on this key parameter.

Reprints

Reprints of this report are available upon request from Pine Instrument Company, 101 Industrial Drive, Grove City, PA 16127 (www.pineinst.com)

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References

1. *Standard Method for Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the SHRP Gyratory Compactor*. Standard T312, 2001. American Association of State Highway and Transportation Officials, Washington, D.C. Note that this standard replaces the previous provisional standard AASHTO TP 4.
2. *Standard Practice for Evaluation of Superpave Gyratory Compactors*. Standard PP35. American Association of State Highway and Transportation Officials, Washington, D.C. Results for all compactors evaluated to date may be downloaded from this web page:

www.utexas.edu/research/superpave/articles

Appendix A: Mix Design

| Aggregate | Type | crushed limestone |
|-----------------|------|---------------------|
| Sieve Size (mm) | | Percent Passing (%) |
| 50.0 | | 100 |
| 37.5 | | 100 |
| 25.0 | | 100 |
| 19.0 | | 100 |
| 12.5 | | 96 |
| 9.5 | | 87 |
| 4.75 | | 49 |
| 2.36 | | 32 |
| 1.18 | | 23 |
| 0.600 | | 16 |
| 0.300 | | 10 |
| 0.150 | | 7 |
| 0.075 | | 4.4 |

Binder

| | |
|---------|----------|
| Grade | PG 64-22 |
| Content | 5.3% |

Mix

| | |
|---------------------|-------|
| N_{DES}^{\dagger} | 75 |
| Gmm * | 2.464 |

* Maximum theoretical density is based on information provided by supplier. It may differ slightly for the twice reheated specimens used in this study.

† Although N_{des} for this mix is 75 gyrations, this particular sample of plant produced mix was only compacted to 55 gyrations because the air void content was closer to 4.0% at 55 gyrations.