EFFECT OF SAMPLE GEOMETRY ON BULK RELATIVE DENSITY OF HOT-MIX ASPHALT MIXES

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Abstract

This study emanated from the revision of South African mechanistic-empirical pavement design method. At the CSIR road pavement laboratory, the bulk relative density (BRD) of compacted hot-mix asphalt (HMA) mixes is determined on cores and beams with different number of cut/cored surfaces. Significant variations in voids were observed in the HMA core and beam samples from the same compacted slabs. The objective of this paper is to present the findings of the effect of specimen geometry and cut surfaces on BRD, and the calculated air voids of five South African HMA mixes using the conventional saturated surface dry and the vacuum sealing methods. The BRD results obtained from the two methods showed that the number of cut surfaces significantly affects the BRD of the compacted samples used for this study. However, the BRDs/air voids were comparable regardless of the sample geometry. It is suggested that compacted samples prepared for the determination of HMA properties such as permanent deformation and fatigue life should have the same number of cut surfaces regardless of the sample geometry.

1. INTRODUCTION

The maximum theoretical relative density (MTRD) of loose hot-mix asphalt (HMA) and the bulk relative density (BRD) of the compacted mix are used to determine the air voids of the mixes. The relevant test procedures for determining MTRD and BRD in South Africa are contained in the Technical Methods for Highways (TMH 1): *Standard Methods for Road Construction Materials* (TMH 1 Method C3, 1986). The BRD method is referred to as saturated surface dry (SSD) method. Under the new South African national standard, Method C3 will be replaced by "*SANS 3001-AS10"*,. It was therefore, necessary to use the *SANS 3001-AS10* method in this study. In addition to the SSD method, the BRD of compacted asphalt mix can be determined using the vacuum sealing procedure contained in the American Society of Testing and Materials (ASTM) test method (ASTM D 6752, 2004).

At the CSIR road pavement materials laboratory, BRD of HMA is determined on a cylindrical core and prismatic shaped beam samples. These samples are often cut from the same compacted slab, and their BRDs are determined by using both the SSD and the vacuum sealing methods. The core samples are normally prepared for shear (complex) modulus and repeated load shear permanent deformation tests, whereas the beam samples are prepared for four-point bending beam fatigue testing. Recent studies conducted at the CSIR showed that BRDs obtained from core specimens were always less than the BRDs obtained from the beam specimens although both samples are prepared from the same slab. Thus, high air voids were found in the core specimens when compared to the voids obtained for the beam specimens.

This paper presents an investigation results of BRDs obtained from core and beam samples prepared from five HMA mixes in South Africa. The objective was to determine the effect of specimen geometry (i.e., cylindrical core and prismatic beam samples), and specimen cut surfaces on BRD. The BRD results were used to determine voids in the mixes in order to further investigate the effect of specimen cut surfaces on voids. The results were verified with HMA cores from Marshall briquettes and gyratory compacted samples as well as cores (from the same mixes prepared in the laboratory) extracted from five roads sections in South Africa.

2. MATERIALS AND SAMPLE PREPARATION

2.1. Materials

The five HMA mixes selected for this study were:

- Bitumen-Treated Base (BTB) mix with a 40/50 penetration grade binder.
- Coarse continuously graded mix with A-E2 modified binder.
- Medium continuously graded mix with A-E2 modified binder.
- Medium continuously graded mix with a 60/70 penetration grade binder, and
- Bitumen rubber asphalt semi-open graded mix (BRASO).

All five mixes were designed by Much Asphalt, and prepared in the CSIR pavement materials laboratory in accordance to Technical Methods of Highways (TMH1) Method C2 (TMH1, 1986).

2.2. Sample preparation

2.2.1 Mix preparation

The mechanical mixing and compaction were done in accordance with the recently developed CSIR test protocols for asphalt mixes (Anochie-Boateng et al., 2010). The samples were prepared by using a heated mechanical mixer in which the calculated masses of pre-heated aggregate and binder were placed. Aggregates were blended in accordance with the mix design grading provided by Much Asphalt. The aggregate and bitumen materials were mixed until a uniform mixture was obtained, i.e. all aggregate particles were fully coated with bituminous binder. A pre-heated apparatus were used in order to minimize heat loss during the mixing.

2.2.2 Slab compacted samples

The slabs for the HMA mixes were produced using Transport Research Laboratory (TRL) slab compactor available at the CSIR, and in accordance with the CSIR in-house test protocol. The mass of the loose asphalt samples were calculated using the maximum theoretical density (MTRD), the volume of the slab mould, and the voids required in the mix. A detailed procedure of slab compaction at the CSIR is contained in the CSIR test protocols (Anochie-Boateng et al., 2010). From the compacted slabs, rectangular prismatic beam samples of dimensions 400 x 65 x 50 mm and cylindrical core samples of size 150 mm diameter x 50 mm high were cut for the investigation.

The current practice at the CSIR is to cut five surfaces of the beam samples, leaving one surface uncut for testing, whereas core samples are tested with both top and bottom surfaces uncut. Figure 1 shows core and beam samples of all five asphalt mixes with two surfaces uncut, and Figure 2 shows samples with only one uncut surface. Each HMA sample is represented by one specimen in these figures. A total of 20 beams and 20 cores were prepared from the five mixes.

SSD and vacuum sealing tests were conducted on all the samples to compare the results of the air voids obtained from the two methods. Details of the tests and the test results are presented in the subsequent subsections in this paper.

(a) Core specimens – top and bottom uncut

(b) Beam specimens – top and bottom uncut

Figure 1. Core and beam specimens with two faces uncut

(a Core specimens – only bottom uncut

(b) Beam specimens – only bottom uncut

Figure 1. Core and beam specimens with only one face uncut

2.2.3 Marshall briquetts samples

The Marshall briquettes were prepared to verify the effects of cut/uncut surfaces on the BRDs of the five asphalt mixes. THM 1 method C2 for preparing the Marshall briquettes was followed (TMH1, 1986). Figure 3a shows briquettes of partially cut (top and bottom cut) and a fully uncut samples of the five mixes. Three replicates of each mix were used for the investigation.

(a) Marshall briquettes – top and bottom cut

(b) Marshall specimens – all surfaces uncut

Figure 2. Marshall compacted briquettes

2.2.4 Gyratory compacted samples

Gyratory compacted sample were produced for verification purposes. Details of gyratory compaction test method for preparing and determining the density of HMA samples by means of the Superpave gyratory compactor is provided in the American Association of State Highway and Transportation Officials (AASHTO) test method T312 (AASHTO, 2009). The samples were compacted to a diameter of 150 mm and a height of 170 mm. The BRD tests were conducted on the fully uncut and fully cut gyratory samples (Figure 4) to compare the BRDs and air voids of the five HMA mixes. A 100 mm diameter by 150 mm high fully cut gyratory samples (all surfaces are cut) were obtained by coring and cutting from the 150 mm diameter x 170 mm compacted samples. The fully cut samples are used to conduct dynamic (complex) modulus tests samples proposed for the South Africa pavement design method project.

(a) Fully uncut gyratory specimens

(b) Fully cut gyratory core specimens

Figure 3. Gyratory compacted samples

2.2.5 Roadway core aspahlt samples

Six cores for each of the five asphalt mixes were extracted from the road sections on which the mixes were placed. The various mixes have been placed between three to six months. The road sections and their respective asphalt mixes are:

- N3, between Heidelberg Weg and Geldenhuys interchange (BTB 40/50);
- N3 between Geldenhuys and Buccleuch interchange (Coarse A-E2);
- R21 between Benoni and Olifantsfontein interchanges (Medium A-E2);
- N1 between Golden Highway and 14th Avenue interchange (Medium 60/70); and
- N1 between Diepkloof and Uncle Charlies interchange (BRASO).

3. LABORATORY TESTING

The bulk relative density (BRD) tests were conducted on the laboratory prepared cores and beams (from the same slabs), gyratory compacted cores, Marshall briquettes, and the roadway cores. Brief outlines of the test procedures for the BRD and voids determination are presented in the following subsections.

3.1. Maximum theoretical relative density (MTRD)

The maximum theoretic relative density (MTRD) of loose HMA mix and the BRD of the compacted mix are used to determine voids. The MTRD of the five HMA mixes were determined in accordance with the relevant procedures in TMH1 Method C4 (TMH1, 1986). The MTRD tests were conducted using three replicate specimens of each mix. The average MTRD values were used in the computation of the voids.

3.2. Relative bulk density (BRD)

3.2.1 Saturated surface dry (SSD) method

As mentioned earlier, the new South African National Standards will replace TMH1 method C3 for the determination of BRD of compacted asphalts with SANS 3001-AS10 (2010) test procedure. SANS 3001-AS10 was used in this study to determine the BRD of all the mixes. A comparison of voids calculation of the two test methods indicated that if water absorption of the asphalt samples is less that 0.85%, then, the SANS 3001-AS10 method is similar to the TMH1 method C3. All five HMA mixes used for this study had water absorption of less than 0.85%.

3.2.2 Vacuum sealing method

In addition to the SSD method, BRD of the compacted HMA samples were also determined using the vacuum sealing method with CoreLok device (Figure 5). The standard test method for the determination of BRD of HMA mixes using vacuum sealing is ASTM D 6752 (2004). The test involves vacuum sealing the HMA samples in plastic bags. The inaccuracies of the conventional SSD method in determining densities of porous samples or samples with interconnected voids (in essence where water absorption exceeds 2%) are avoided by using the vacuum sealing method. Thus, for coarse-graded HMA mixes, the vacuum sealing method is preferred to the SSD method for greater precision and accuracy (Crouch et al., 2002; Williams et al., 2007).

Figure 4. CoreLok device at CSIR Lab and vacuum sealed sample

4. DISCUSSION OF TEST RESULTS

4.1. BRD results of the five HMA mixes

It is well known that the air voids in HMA mixes are directly linked to performance. Therefore, accurate measurement of BRD is essential for obtaining reliable voids content of the HMA mixes. Tables 1 through 4 present the average BRD results obtained from the various samples prepared for the five asphalt mixes studied (refer to sample preparation). The BRDs determined by the SSD and the vacuum sealing methods validate each other for the effect of sample geometry and cut surfaces of all five mixes. It can be seen from the tables that the differences between the BRDs of the SSD and vacuum sealing methods diminishes to zero for the fully cut samples of all five mixes.

Table 1: BRD results for slab cores

Mix	Top and bottom uncut			Bottom uncut		
	Vacuum	SSD	Difference	Vacuum	SSD	Difference
BTB 40/50	2.476	2.507	0.031	2.507	2.519	0.012
Coarse A-E2	2.576	2.596	0.02	2.605	2.607	0.002
Medium A-E2	2.452	2.485	0.033	2.479	2.496	0.017
Medium 60/70	2.468	2.495	0.027	2.499	2.508	0.009
BRASO	2.248	2.284	0.036	2.237	2.264	0.027

Table 2: BRD results for slab beams

Mix	Top and bottom uncut			Bottom uncut		
	Vacuum	SSD	Difference	Vacuum	SSD	Difference
BTB 40/50	2.471	2.500	0.029	2.503	2.514	0.011
Coarse A-E2	2.603	2.617	0.014	2.634	2.630	-0.004
Medium A-E2	2.473	2.504	0.031	2.503	2.508	0.005
Medium 60/70	2.484	2.499	0.015	2.511	2.511	0
BRASO	2.228	2.266	0.038	2.261	2.272	0.011

Table 3: BRD results for the Marshall briquettes samples

Mix	Fully uncut			Top and bottom cut		
	Vacuum	SSD	Difference	Vacuum	SSD	Difference
BTB 40/50	2.420	2.480	0.06	2.494	2.526	0.032
Coarse A-E2	2.553	2.610	0.057	2.581	2.625	0.044
Medium A-E2	2.458	2.514	0.056	2.483	2.517	0.034
Medium 60/70	2.310	2.369	0.059	2.409	2.435	0.026
BRASO	2.163	2.270	0.107	2.202	2.281	0.079

Table 4: BRD results for gyratory core samples

Mix	Fully uncut			Fully cut		
	Vacuum	SSD	Difference	Vacuum	SSD	Difference
BTB 40/50	2.466	2.492	0.026	2.508	2.508	0
Coarse A-E2	2.553	2.582	0.029	2.604	2.606	0.002
Medium A-E2	2.472	2.498	0.026	2.534	2.536	0.002
Medium 60/70	2.442	2.460	0.018	2.498	2.477	-0.021
BRASO	2.237	2.278	0.041	2.283	2.283	0

4.2. Air voids of cores from lab compacted slab

Figure 6 shows a plot of air voids of cores obtained from slabs. The voids from samples uncut at the top and bottom, and the samples uncut at the bottom only are presented in the figure. The results are presented for BRDs obtained from the SSD and the vacuum sealing methods. It can be seen that the voids of the samples with both top and bottom faces uncut are higher than the voids obtained for the samples with only one face uncut (i.e., bottom). These results indicate that voids diminished when more surfaces of compacted HMA mixes are cut. The trend is the same for all mixes tested, and also for the two test methods. The number of cut surfaces of cores from compacted slabs, therefore could have significant impact on the HMA samples used for shear dynamic (complex) modulus and repeated load shear permanent deformation tests.

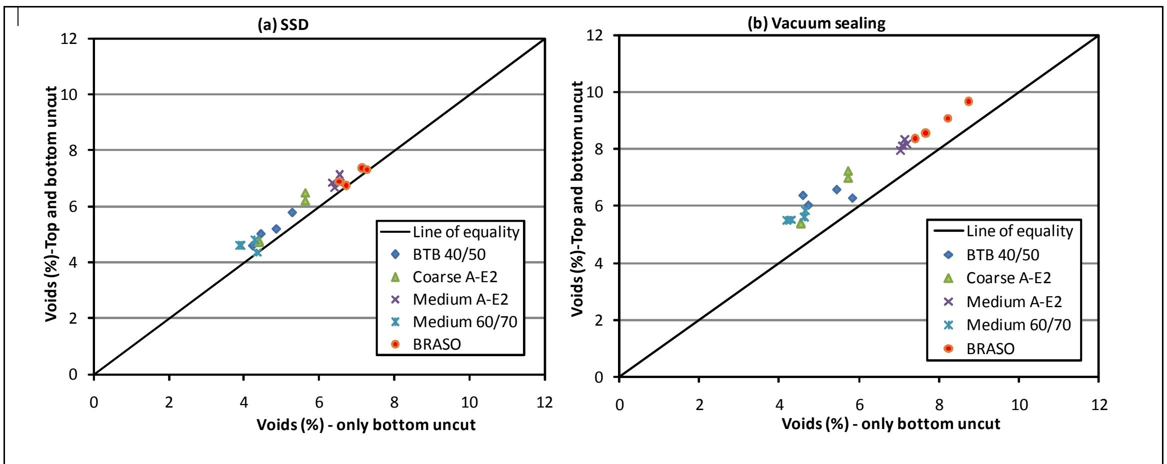

Figure 5. Air voids of cores from lab compacted slab

4.3. Air voids of beams from lab compacted slab

Figure 7 shows a plot of air voids of beams obtained from the slabs. The voids were obtained from samples that were uncut at the top and bottom, and samples that were uncut at the bottom only. Results are compared for BRDs obtained from the SSD and the vacuum sealing methods. Similar to the cores cut from the slabs (Figure 6), the voids obtained from the beam samples with both top and bottom faces uncut are higher than the voids form the samples with only one face uncut (i.e., bottom). It is noted that two specimens of the coarse A-E2 mix did not follow the same trend, which could be treated as an outlier if statistical analyses were performed on the test results. A similar assertion could be made in terms of the impact of the voids from uncut and cut surfaces on beam fatigue test results.

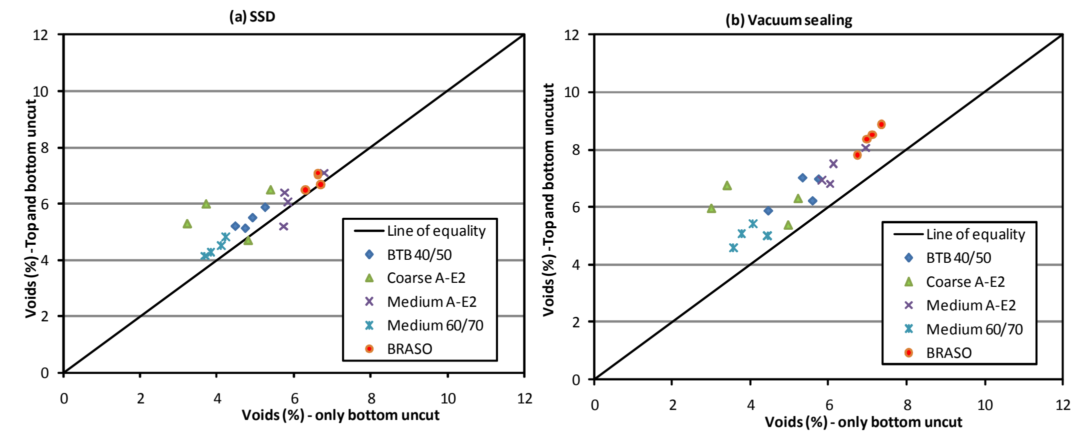

Figure 6. Air voids of beams from lab compacted slab

4.4. Voids in slab cores and beams of same number of cut/uncut surfaces

Figures 8a-d compares the voids obtained from the cores with the voids obtained from the beams of the five mixes studied. The results obtained from both SSD and the vacuum sealing methods are presented for the mixes. There are relatively good comparisons of the results in terms of data scatter around the line of equality, implying that the cores and beams from the same slab with the same number of cut surfaces could reasonably provide comparative voids, especially when the top and bottom surfaces of the samples are left uncut.

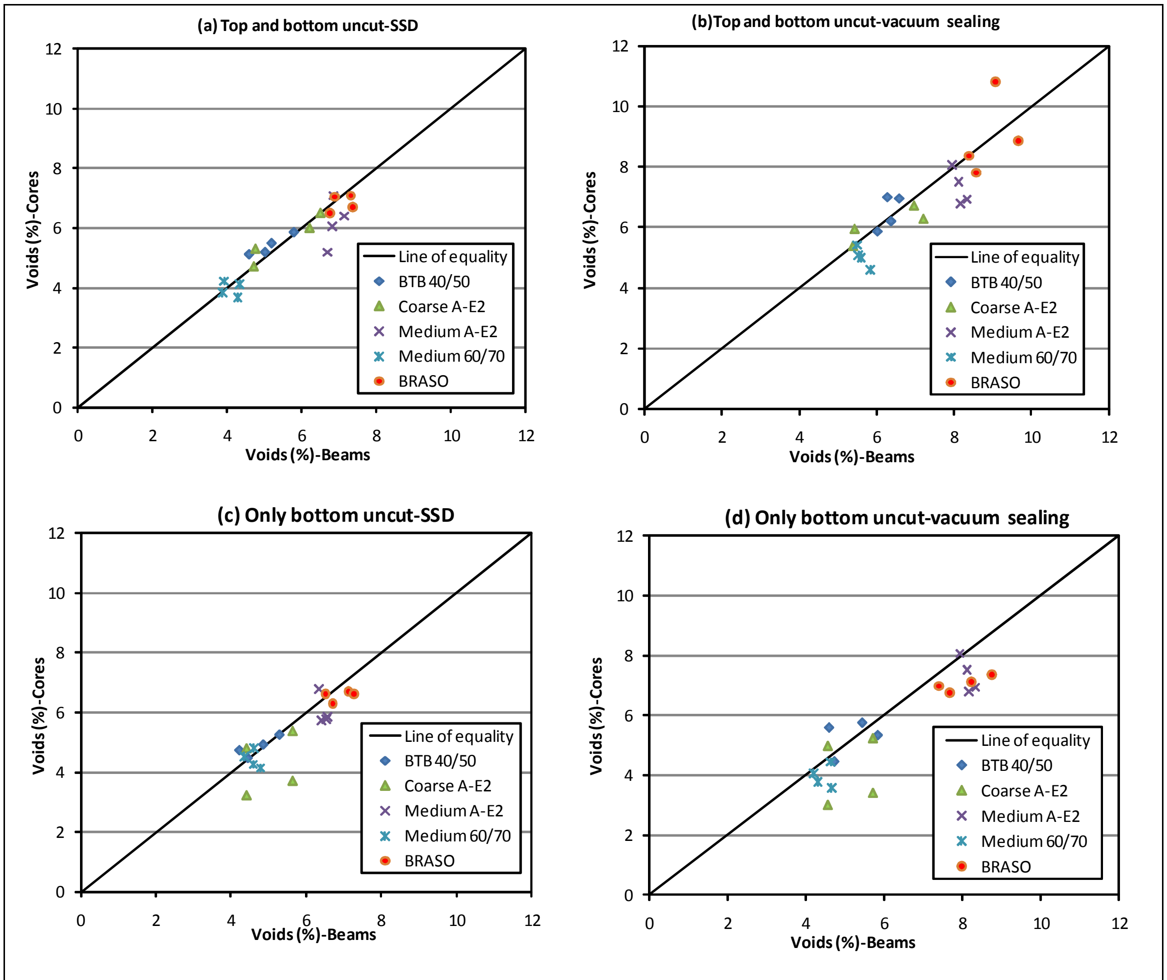

Figure 7. Air voids of slab cores versus beams from compacted slab

4.5. Air voids of the Marshall briquette samples

Figure 9 shows a plot of the voids content from the Marshall briquettes with fully uncut surfaces against the voids of partially cut (top and bottom) for the five mixes. The results obtained from the SSD and the vacuum sealing methods are presented for the mixes. As expected the voids of the fully uncut specimens are higher than those top and the bottom cut.

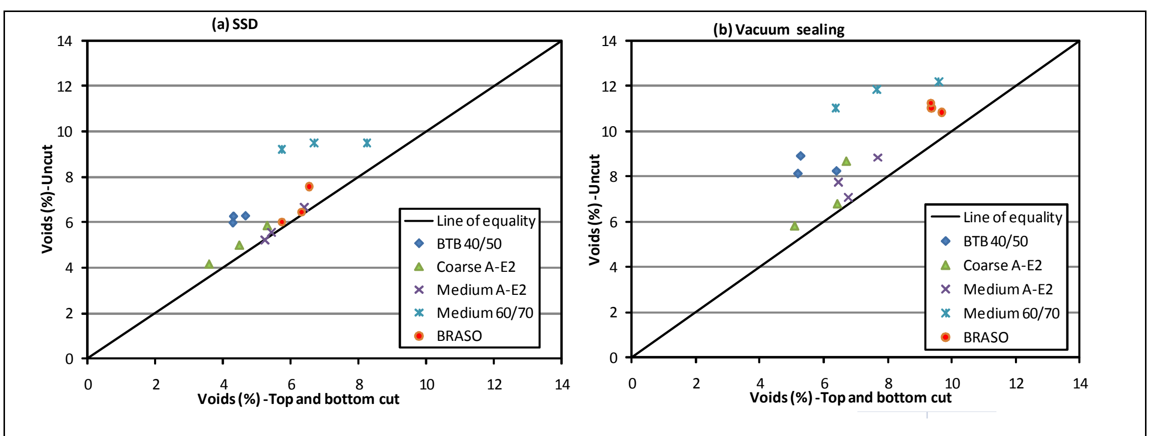

Figure 8. Air voids content of the Marshall briquettes

4.6. Air voids of gyratory compacted samples

Figure 10 shows a plot of voids obtained from the gyratory compacted fully uncut against the voids of fully cut samples. The results from the SSD and the vacuum sealing methods showed that the voids of the fully uncut specimens are higher than those of fully cut. This was expected, and it also indicates that the number of cut surfaces have significant impact on the BRDs of HMA samples used for dynamic modulus testing.

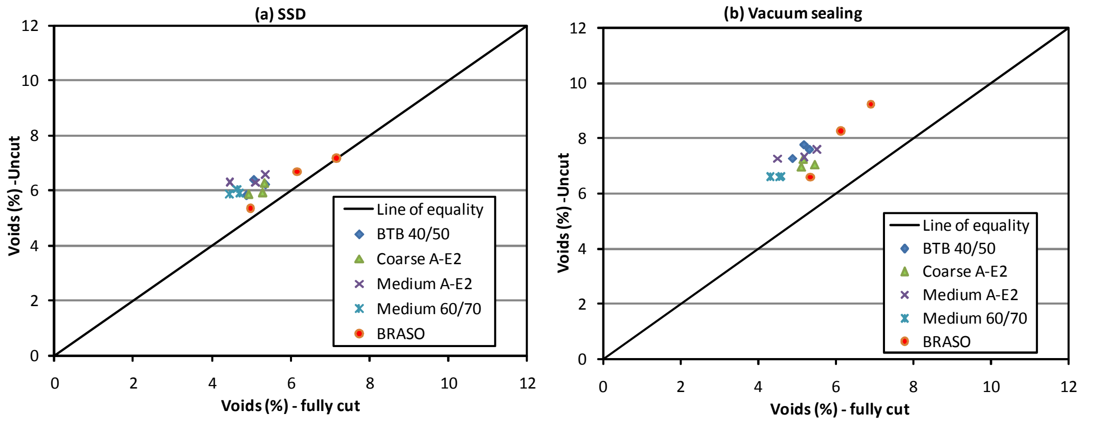

Figure 9. Air voids of gyratory compacted specimens

4.7. Comparison of air voids of roadway cores

Figure 11 shows a plot of the entire dataset of the air voids of the roadway cores. Both SSD and vacuum sealing methods were used to determine the BRDs for the determination of the voids. Overall, the results represent 30 roadway core samples for the five asphalt mixes investigated. The voids range from 4 to 9.9 %. Generally, good correlation exists between the air voids determined by using the two methods with an exception of the coarse A-E2 and BRASO mixes (BRDs from the SSD method were slightly higher than the BRDs from the vacuum sealing method).

This trend was also observed by Williams and his co-researchers who concluded that the SSD and the vacuum sealing methods provide significantly different BRD measurements for coarse-graded HMA mixes when compared to medium to fine-graded mixes (Williams et al., 2007). It should be mentioned that this paper does not focus on the comparison of the two methods. A detail statistical analysis would be required in order to make any valid comparison of the SSD and the vacuum sealed methods.

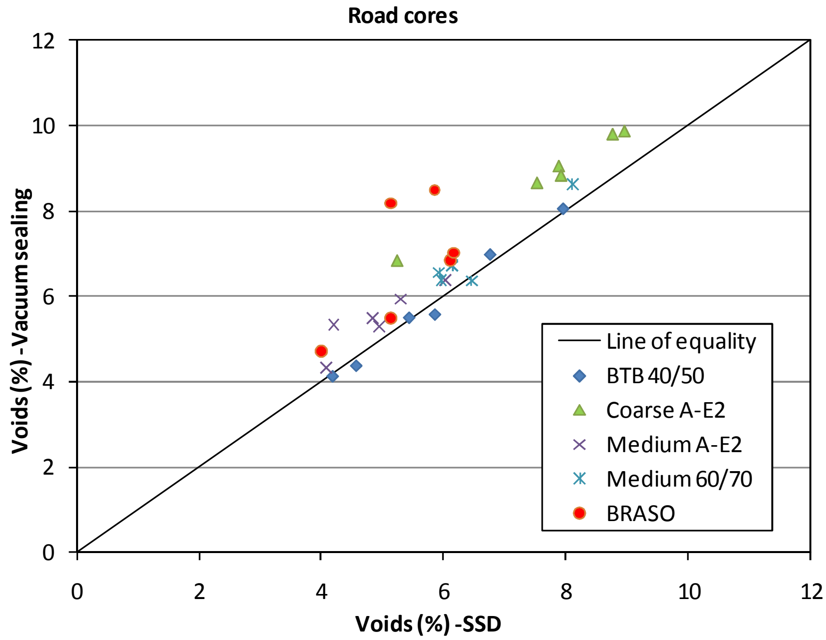

Figure 10. SSD versus Vacuum sealing for all roadway cores

5. CONCLUSIONS

This paper investigated the effect of number of sample cut surfaces and sample geometry on the bulk specific density (BRD) of five HMA mixes in South Africa. The conventional saturated surface dry (SSD) and the vacuum sealing methods were used for the determination of BRDs of the samples. The samples were prepared from three different laboratory compaction methods (slab, gyratory and Marshall), and a roadway coring. Based on the discussions provided in this paper the following conclusions can be made:

- There is a significant variation in the air voids obtained from the core and the beam samples when the number of cut surfaces is not the same.
- Sample preparation methods for the determination of BRDs of compacted HMA mixes for permanent deformation and fatigue cracking tests to be modified to have the same number of cut surfaces.
- The conventional SSD and the vacuum sealing methods for the determination of BRDs of compacted HMA samples should be fully investigated exclusively for coarse, medium and fine-graded asphalt mixes.

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