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AN EVALUATION OF SUPERPAVE GYRATORY COMPACTION OF HOT MIX ASPHALT

Rajib B. Mallick, Shane Buchanan, E.R. Brown, and Mike Huner[1]

ABSTRACT

This study was carried out to evaluate the effect of restricted zone on volumetric properties of mixes consisting of all crushed, and all crushed and partially uncrushed materials. Mix designs were conducted with the Superpave gyratory compactor for two types of aggregate blends: one with all crushed granite and another with crushed granite and 20 percent natural sand. Three gradations for each type of aggregate blend consisted of gradations passing above, through, and below the restricted zone. For a given aggregate blend, gradations below or above the restricted zone provided higher VMA than mixes through the restricted zone. Mixes with crushed aggregate provided higher VMA than mixes with partially crushed aggregate. The mixes with gradations below the restricted zone had the highest voids at $N_{initial}$, whereas the mixes with gradations above the restricted zone had the lowest voids at $N_{initial}$. None of the mixes containing natural sand met all the requirements for volumetric and gyratory properties. The mixtures for all crushed material met all requirements when passing through the restricted zone and below the restricted zone. It is recommended that further work be conducted to evaluate the effect of different types and shapes of aggregates on the volumetric properties of specimens compacted with the Superpave gyratory compactor. According to the current Superpave mix design system, the bulk specific gravity of a compacted specimen at any gyration is back calculated from the bulk specific gravity determined at $N_{maximum}$ and a correction factor determined at $N_{maximum}$. This

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procedure assumes that the correction factor is constant at all gyrations. A part of this study was carried out to compare the correction factors obtained at different gyration levels during compaction of HMA, and to evaluate the change in correction factors with gyration levels. a typical dense mix and a typical Stone Matrix Asphalt (SMA) mix were prepared at optimum asphalt content with traprock aggregates. Specimens were compacted at different gyration levels, and the bulk specific gravity of each of the specimens was determined at each of the gyration levels. Bulk specific gravities at each of the gyration levels were also obtained by back calculation from bulk specific gravity at $N_{maximum}$. The correction factor was found to decrease and become close to constant at higher gyration levels. At lower gyrations, densities were found to be greater than that obtained by back calculation from the density at $N_{maximum}$. The coarse textured mixture had a larger difference between the back calculated and actual air voids. It is recommended that mixes be compacted to N_{design} for determination of design asphalt content.

AN EVALUATION OF SUPERPAVE GYRATORY COMPACTION OF HOT MIX ASPHALT

INTRODUCTION

Background

About 85 percent of hot mix asphalt (HMA) by volume consist of mineral aggregate. One of the most important properties of the aggregate in a HMA mix is the gradation. Normally, a “0.45 power” chart is used to help evaluate the gradation of a blend of aggregates. To help specify a proper aggregate gradation, Superpave (1) has recommended two additional features to the 0.45 power chart: control points and a restricted zone. The control points function as master ranges through which gradations must pass. They are placed on the nominal maximum size, an intermediate size, and the 0.075 size. The restricted zone is placed along the maximum density gradation between the intermediate size and the 0.3 mm size. An example of the 0.45 power chart, the control points, and the restricted zone is shown in Figure 1. Superpave recommends that gradations pass outside the restricted zone in order to provide adequate VMA and to avoid excessive use of rounded sands which leads to reduced rutting resistance (1, 2, 3). This restriction is based on experience with “humped” gradations which are generally caused by excessive amounts of fine sand. Superpave also states that gradations that violate the restricted zone may possess a weak aggregate skeleton that depends too much on asphalt binder stiffness to achieve mixture shear strength.

For the highway community, most of the experience so far with different types of aggregate blends has been with Marshall or Hveem compacted specimens. However, as each state and other highway agencies are gearing up to switch over to the Superpave system, several

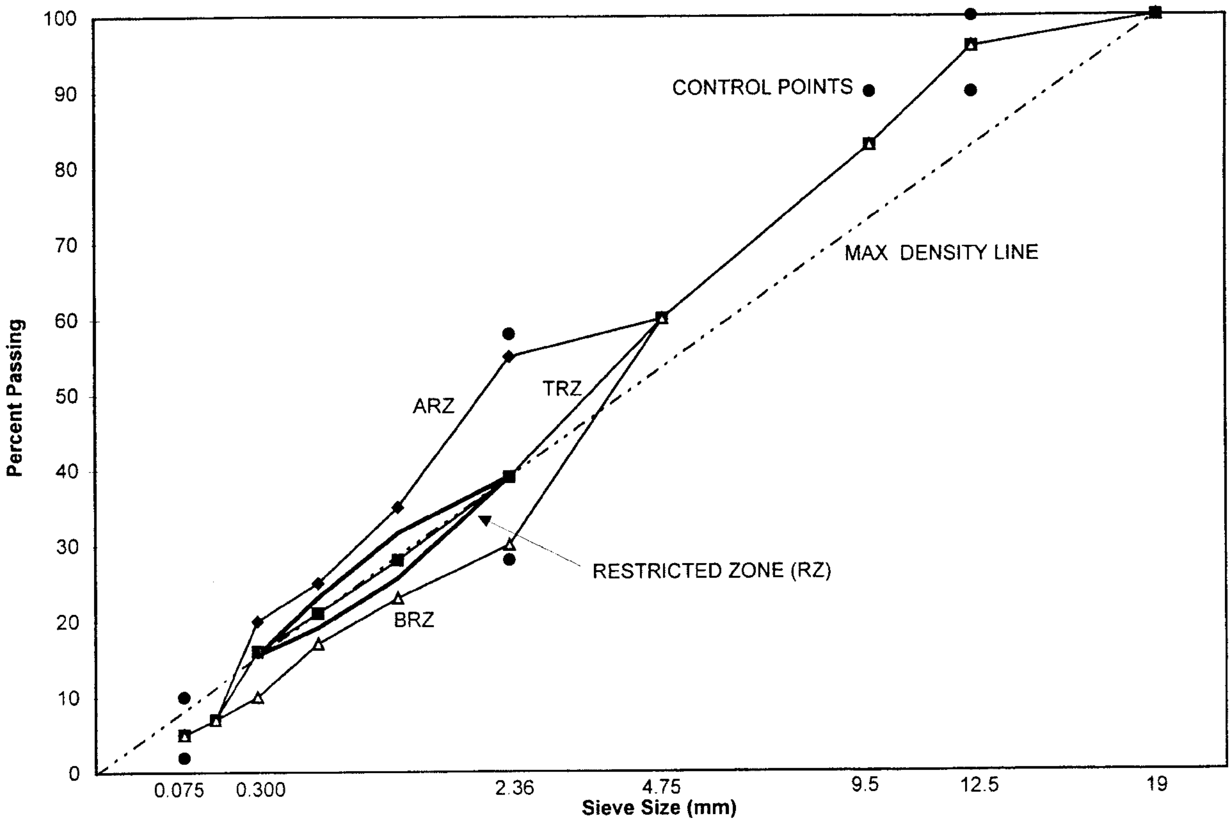

Figure 1. Gradation criteria and project gradations.

questions remain unanswered regarding Superpave gyratory compaction. Of these, one of the most important questions is regarding the restricted zone. There is a need to evaluate the effect of the restricted zone on volumetric properties of specimens compacted with the Superpave gyratory compactor (SGC). More specifically, the following questions need to be answered:

1) How are $N_{initial}$, N_{design} and $N_{maximum}$ values of mixes affected by the restricted zone?

2) How do the volumetric properties of all crushed and partially uncrushed mixes differ?

This study was carried out to answer these questions.

According to the current Superpave specifications (1), the bulk gravity of a sample is determined in two ways: from the compactor based on geometry of the specimen and from weighing in air and water. Both of these bulk gravities are determined at $N_{maximum}$, and then a correction factor is calculated to convert the bulk specific gravity determined by geometry of the specimen to the actual bulk specific gravity determined by weighing in air and water. The machine measured bulk specific gravity of specimens at all other gyrations are corrected based on this correction factor at $N_{maximum}$. The correction factor, C, is defined as C = (G_{mb}, measured in air and water)/(G_{mb}, based on physical dimensions) at $N_{maximum}$. The purpose of the correction factor is to eliminate the error of machine measured specimens caused by the assumption that each specimen is a smooth sided cylinder. Actually, the measured volume (from weighing in air and water) of the specimen is slightly less than the calculated volume (based on physical dimensions) of the HMA specimen because of surface irregularities. So, the difference between the actual and calculated volume is taken care of by the correction factor.

The above procedure assumes that the correction factor is constant at all gyrations, that is, the correction factor at $N_{maximum}$ (or any gyration level) is the same as the correction factor at, say, N_{design}. Actually, this may not be the case, since surface irregularities change as each sample is compacted. At a gyration level lower than $N_{maximum}$, the surface irregularities will likely be more than at $N_{maximum}$. Hence the difference between the measured and calculated volume at lower gyrations, will be different from that at $N_{maximum}$. Thus, the concept of a constant correction factor may not work in some cases. The problem becomes more complex when one uses mixes with different types of aggregates. Because the surface irregularities depend, to some extent, on aggregate size and shape, the difference between the C at $N_{maximum}$ and C at other gyration levels may be more in some cases, and may be less for other cases.

The variation of C at different gyration levels can cause inconsistency in predicting the volumetrics at N_{design} from compaction curves. The actual volumetrics at N_{design} may be significantly different from that determined from samples compacted to $N_{maximum}$ and corrected to N_{design}. Therefore, a study is required to evaluate the differences in the correction factors at different gyration levels.

This paper is divided into two parts: Part I reports the results of the study carried out to evaluate the effect of restricted zone on volumetric and gyratory properties of HMA samples, and Part II describes the study carried out to evaluate the difference in correction factor at different gyration levels.

PART I: AN EVALUATION OF THE RESTRICTED ZONE FOR AGGREGATES IN HMA

Objective

The objective of this part of the study was to evaluate the effect of gradation and aggregate type on volumetric properties and gyratory properties of specimens compacted with the Superpave gyratory compactor.

Scope

Behavior of HMA mixes are largely affected by aggregate gradation and type of aggregate. This study was carried out to evaluate the effect of aggregate type and gradation on air void properties and gyratory parameters. Three all crushed granite mixes and three mixes containing crushed granite and 20 percent natural sand were prepared. The three mixes with each type of aggregate consisted of three gradations: (1) above restricted zone, (2) through restricted zone, and (3) below restricted zone. Mix designs were conducted with the Superpave gyratory compactor, and air void properties and Superpave design parameters ($N_{initial}$, N_{design}, $N_{maximum}$) were compared for the different mixes.

Test Plan

In total, six different mixes were evaluated. Of these, three mixes consisted of all crushed granite aggregate, and the remaining three consisted of crushed granite and 20 percent natural sand. The three mixes for each type of aggregate blend consisted of three different aggregate gradations: 1) above restricted zone, 2) through restricted zone, and 3) below restricted zone. These gradations can be found in Table 1 and Figure 1. The gradations are different only around the restricted zone. This was done in order to better determine the effect of the restricted zone on volumetric properties. The physical properties of the crushed granite and natural sand aggregates are shown in Table 1. A PG 64-22 asphalt cement was used for all six mixtures evaluated in the study. Mix designs were conducted for each of the mixes with the Superpave gyratory compactor at a 3-10 million ESALs traffic level and a temperature of less than 39°C. This level of traffic and temperature yielded values of $N_{initial}$, N_{design} and $N_{maximum}$ of 8, 96, and 152, respectively. After the mix designs were completed, the volumetric properties of the mixes at optimum asphalt content were compared. The observed design compaction parameters ($N_{initial}$, N_{design} and $N_{maximum}$) for the different mixes were also compared.

Table 1. Gradation Information and Properties of the Crushed Granite and Natural Sand

Sieve Size (mm)	Percent Passing			Superpave Gradation Criteria			
	Mixture[a]			Control Points		Restricted Zone	
	ARZ	TRZ	BRZ	Min	Max	Min	Max
19.0	100	100	100		100.0		
12.5	96	96	96	90.0	100.0		
9.5	83	83	83				
4.75	60	60	60				
2.36	55	39	30	28.0	58.0	39.1	39.1
1.18	35	28	23			25.6	31.6
0.60	25	21	17			19.1	23.1
0.30	20	16	10			15.5	15.5
0.15	7	7	7				
0.075	5.0	5.0	5.0	2.0	10.0		

Aggregate Property	Granite Coarse Aggregate	Granite Fine Aggregate	Natural Sand	Granite/Sand Blend
Bulk Specific Gravity	2.688	2.712	2.618	2.693
Fractured Faces (%)	100	----	----	----
NAA Voids (Method A)	----	49.4	43.0	47.9

[a]ARZ - Above Restricted Zone,
TRZ - Through Restricted Zone
BRZ - Below Restricted Zone

Results and Discussion

The optimum asphalt contents and the mixture properties for the different mixes are shown in Table 2 and Figures 2-5. From observation of Table 2 and Figure 2, it is seen that for both the all crushed and natural sand mixes, the ARZ and BRZ gradations have similar optimum asphalt contents, and the TRZ gradations have the lowest optimum asphalt contents. This is to be expected since the TRZ mix is the gradation closest to the maximum density line and would need less asphalt to fill up the voids. For a particular gradation, the natural sand mixes have lower optimum asphalt contents compared to all crushed mixes. The all crushed mixes also provided a

Table 2. Mix Design Results

Mixture[a]	Mixture Design Properties : $N_{initial}$ (8), N_{design} (96), and N_{max} (152)							
	Optimum AC content (%)	VTM (%)	VMA (%)	VMA Criteria Met? 14% Min	VFA (%)	VFA Criteria Met? 65-75%	% G_{mm} $N_{initial}$ < 89%?	% G_{mm} N_{max} < 98%?
ARZ, CR	5.1	4.0	15.2	YES	73.7	YES	NO	YES
TRZ, CR	4.7	4.0	14.4	YES	72.2	YES	YES	YES
BRZ, CR	4.9	4.0	14.9	YES	73.2	YES	YES	YES
ARZ, NS	4.6	4.0	14.0	YES	71.4	YES	NO	YES
TRZ, NS	4.1	4.0	13.0	NO	69.2	YES	NO	YES
BRZ, NS	4.5	4.0	13.9	NO	71.0	YES	YES	YES

[a] ARZ, CR - Above Restricted Zone, 100 Percent Crushed Aggregate
TRZ, CR - Through Restricted Zone, 100 Percent Crushed Aggregate
BRZ, CR - Below Restricted Zone, 100 Percent Crushed Aggregate
ARZ, NS - Above Restricted Zone, 20 Percent Natural Sand
TRZ, NS - Through Restricted Zone, 20 Percent Natural Sand
BRZ, NS - Below Restricted Zone, 20 Percent Natural Sand

higher optimum asphalt content than the mixes containing natural sand. It is observed in Table 2 and Figure 3 that at optimum asphalt content, all of the mixes except (TRZ, NS) and (BRZ, NS) meet the VMA criteria of at least 14 percent. The (BRZ, NS) mix barely fails the VMA criteria (VMA = 13.9). However, all of the mixes evaluated meet the VFA requirements for a 12.5 mm nominal maximum size mixture. From Figure 3, it is noted that the TRZ mix for the all crushed gradation (TRZ, CR) satisfies the VMA and VFA requirements. The TRZ mix for the natural sand gradation (TRZ, NS) however, fails to meet the VMA criteria (VMA = 13.0). Figure 4 shows the $N_{initial}$ (corresponding to density of 89 percent of TMD) and Figure 5 shows the $N_{maximum}$ (corresponding to density of 98 percent of TMD) values for the different mixes. For both the all crushed and natural sand mixes, the ARZ gradation has the lowest $N_{initial}$, the BRZ gradation has

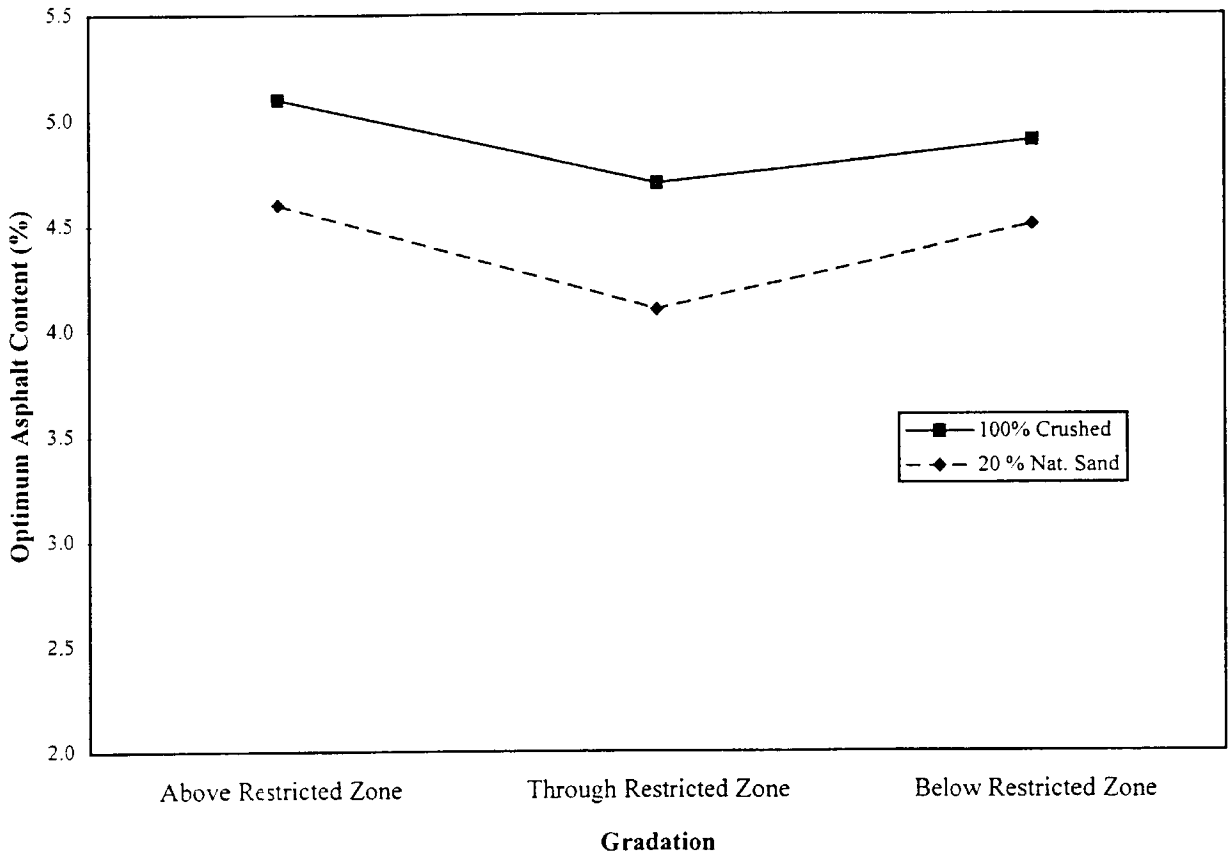

Figure 2. Optimum asphalt contents versus gradation.

the highest $N_{initial}$, and the TRZ gradation had values in between. The natural sand mixes for each gradation had lower $N_{initial}$ values compared to the all crushed mixes. If the $N_{initial}$ criteria ($N_{initial}$ = 8, density <89%) for 3-10 million ESALs is considered, only three mixes meet the specification; the all crushed TRZ and BRZ and the natural sand BRZ gradations.

Figure 5 shows that BRZ gradations for both all crushed and natural sand mixes have substantially lower $N_{maximum}$ values compared to the ARZ and TRZ gradations. The plot of percent of TMD versus log number of gyrations has been shown to be approximately a straight line. Since the plot is a straight line it is expected that mixes with the lowest percentage of TMD at $N_{initial}$ will

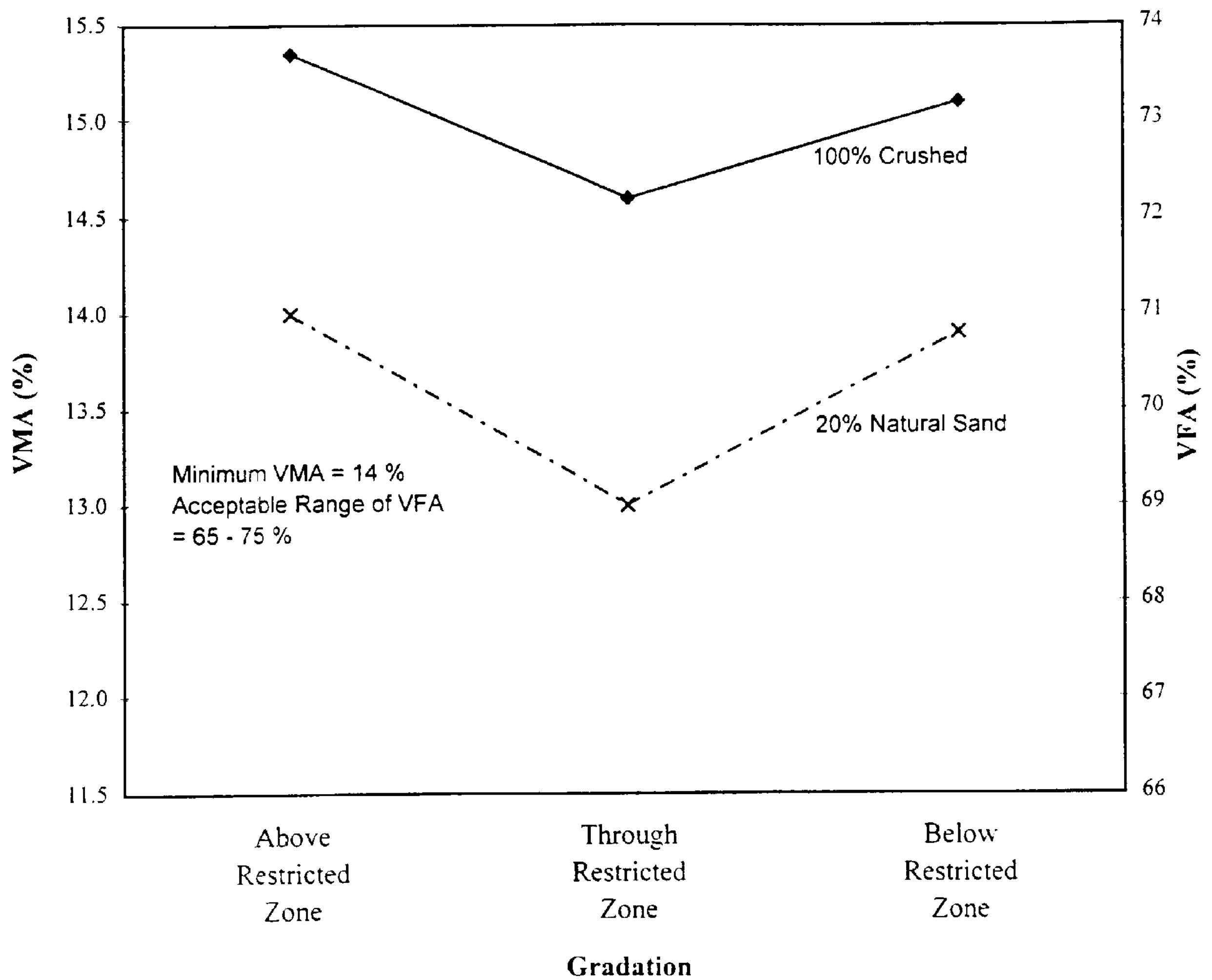

Figure 3. Voids in mineral aggregate and voids filled with asphalt versus gradation.

have the highest percentage of TMD at $N_{maximum}$. A comparison of $N_{maximum}$ for the various mixtures show that as expected, the natural sand mixes have a higher percentage of TMD at $N_{maximum}$. However, all of the mixes meet the $N_{maximum}$ (= 152, density <98%) criteria for 3-10 million ESALs design traffic (Table 2).

To summarize the observations, Table 2 shows the mixes that meet and do not meet Superpave criteria. In both types of mixes (the all crushed and the natural sand), the ARZ blend

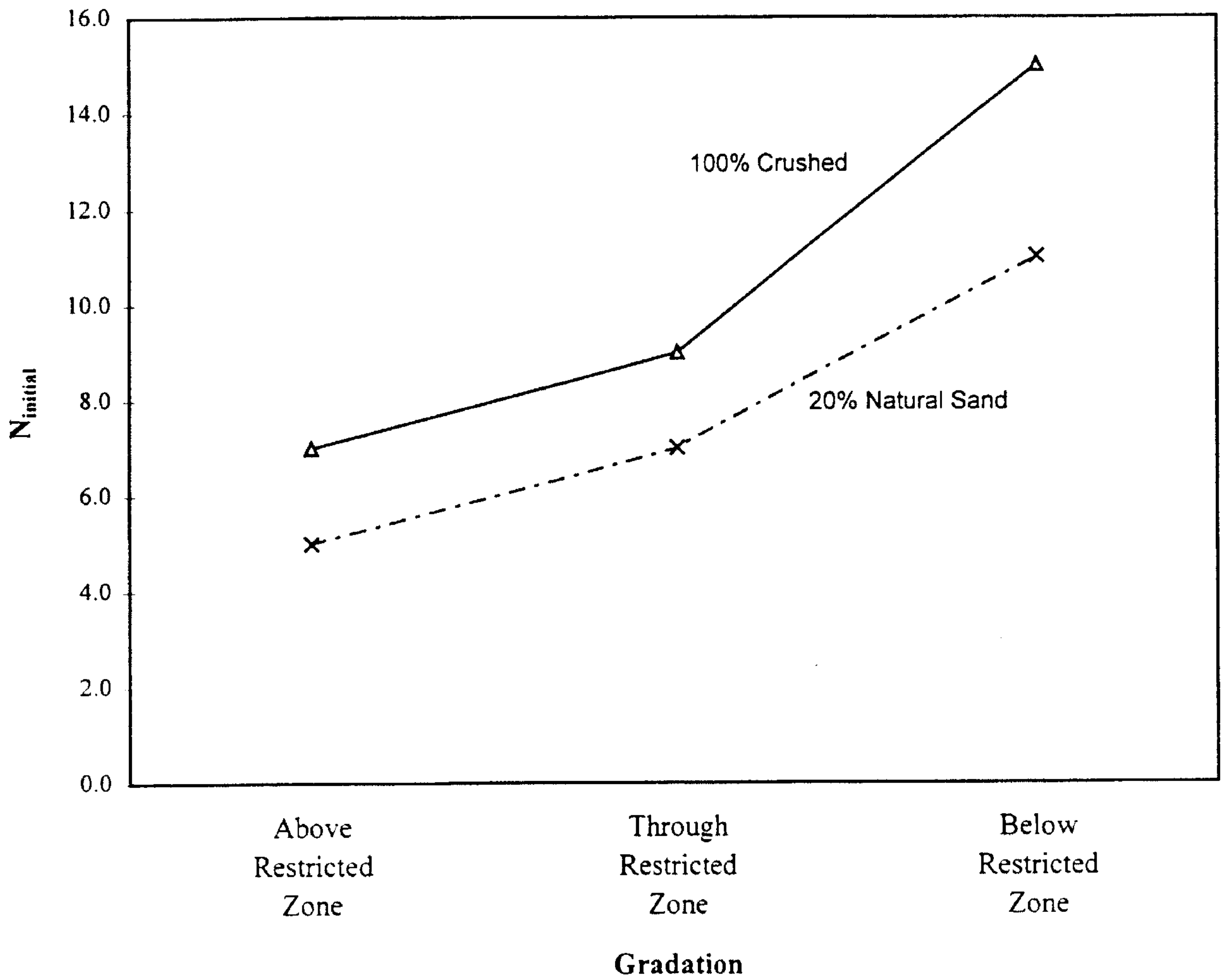

Figure 4. $N_{initial}$ versus gadation.

fails to meet the $N_{initial}$ criteria. It is observed that in spite of passing through the restricted zone, the all crushed TRZ aggregate blend meets all of the Superpave mix design requirements and may be expected to perform adequately (4). The BRZ all crushed blend meets all of the criteria for $N_{initial}$, $N_{maximum}$ and volumetrics. The natural sand BRZ blend barely fails the VMA criteria. This indicates that inclusion of natural sand can lead to potential problems in meeting gyratory properties and volumetrics. Obviously this will depend on the quality of the natural sand and the

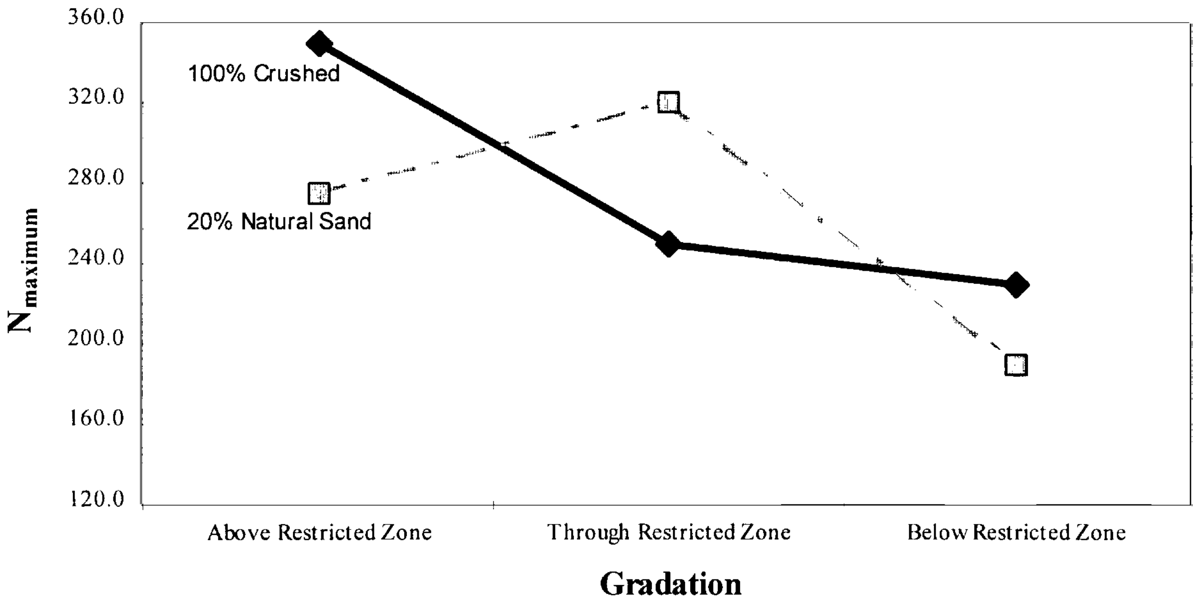

Figure 5. $N_{maximum}$ versus gradation.

amount used in the mixture. The all crushed TRZ blend appears to have better properties than BRZ or ARZ blends for the mixes with 20 percent natural sand.

PART II: AN EVALUATION OF CORRECTION FACTOR

Objective

The objective of this part of the study was to compare the correction factors obtained at different gyration levels during compaction of HMA, and to evaluate the change in correction factor, if any, with gyration levels.

Scope

The two traprock aggregate gradations selected for this study consisted of a typical SMA (to represent a coarse textural mix) and a typical dense mix gradation (to represent a fine textural mix). A PG 64-22 asphalt cement was used with both gradations. Gyration levels and optimum asphalt contents were determined from previous experience with these two gradations. Mixes were prepared and specimens compacted with the Superpave gyratory compactor at different gyration levels. Theoretical maximum density was determined for the mixes, and the bulk specific gravity of each of the specimens was determined at each of the gyration levels evaluated. Correction factors obtained at different gyration levels were plotted against gyration levels. Based on the correction at $N_{maximum}$, gyrations versus density plots were prepared for the two mixes. Gyrations versus compaction plots derived from measured bulk specific gravities were also plotted.

Test Plan

The test plan consisted of the following steps:

Step 1

Sixteen batches were made with traprock aggregate for SMA and dense graded mixtures. The gradations are shown in Table 3. Hence, a total of 32 batches were prepared. Based on previous experience with this aggregate type and gradation, sixteen specimens of the dense mix were compacted at 4.9 percent asphalt content; two specimens were compacted at each of the following gyration levels: 27, 46, 66, 85, 97, 109, 120, and 132.

Table 3. Gradation Of Aggregate

Sieve Size(mm)	Stone Matrix Asphalt Gradation	Dense Mixture Gradation
19.0	100	100
12.5	90	97
9.5	54	83
4.75	24	56
2.36	20	39
1.18	18	28
0.60	14	19
0.30	13	13
0.15	11	7
0.075	10.0	4.0

Similarly, based on previous experience, sixteen specimens were compacted using the SMA aggregate gradation at 5.1 percent asphalt content; two specimens were compacted at each of the following gyration levels: 40, 71, 101, 132, 153, 174, 194, and 215. Higher gyration levels were used because of the rougher surface texture. Theoretical maximum densities for each of the two mixes were determined from two mix samples.

Step 2

Based on the estimated bulk specific gravity (from specimen height), and measured bulk specific gravity, correction factors were determined at each of the eight different gyration levels for the two types of mixes (dense graded and SMA). The correction factors were then plotted against gyration levels to evaluate any change.

Step 3

Based on the correction factor determined at $N_{maximum}$, the measured bulk specific gravities at other gyration levels were corrected. The corrected density at each of the gyration levels were then determined. Gyration versus density data was then plotted for the two mixes.

Step 4

Based on the bulk specific gravity measured from the specimens at different gyration levels, gyration versus density data was plotted for the two mixes. This plot was compared to the plot obtained in step 3 to evaluate how close the predicted values were to the actual density values.

TEST RESULTS AND ANALYSIS

Correction factors for dense and SMA mixes are shown in Table 4. Plots of correction factors versus gyration levels for the SMA and dense graded mixes are shown in Figure 6. For both gradations, the value of C is higher at lower gyrations, and the value decreases with an increase in gyration levels. This confirms the idea that the difference between the assumed and actual specimen volume is greater at lower gyrations than at higher gyrations. The spread in the values of C is much greater in the case of the SMA gradation mix than in the case of the dense graded mix. This is due to the presence of a greater amount of coarse aggregate and rougher surface texture in the SMA mix. The presence of a greater amount of coarse aggregates resulted in a more uneven surface, compared to the dense graded mix. The uneven surface causes the difference between the machine measured and actual specimen volumes. In the case of the dense

Table 4. Density Results for Dense and SMA Mixtures

Mix	Gyrations (N)	Average					Error in Calculation of Air Voids (B-A)[a]
		Estimated Specific Gravity G_{mb} (Est.)	Measured Specific Gravity G_{mb} (Meas.)	Correction Factor	Estimated Density (Back-Calculated From N_{max}) (A)	Actual Density (Samples Compacted up to N gyrations (B)	
Dense	27	2.450	2.523	1.030	92.0	92.6	0.6
	46	2.492	2.560	1.027	94.0	94.0	0.0
	66	2.538	2.602	1.025	95.2	95.6	0.4
	85	2.555	2.612	1.022	96.1	95.9	-0.2
	97	2.562	2.621	1.023	96.6	96.2	-0.4
	109	2.581	2.643	1.024	97.0	97.0	0.0
	120	2.587	2.644	1.022	97.1	97.0	-0.1
	132	2.596	2.654	1.022	97.4	97.4	0.0
SMA	40	2.348	2.506	1.067	91.2	92.7	1.5
	71	2.412	2.560	1.061	93.7	94.6	0.9
	101	2.446	2.578	1.054	94.9	95.4	0.5
	132	2.487	2.604	1.047	95.7	96.3	0.6
	153	2.484	2.600	1.047	96.1	96.1	0.0
	174	2.487	2.610	1.049	96.5	96.5	0.0
	194	2.484	2.606	1.049	96.8	96.4	-0.4
	215	2.520	2.626	1.042	97.1	97.1	0.0

[a] Positive error means that estimated air voids (on the basis of correction factor at $N_{maximum}$) is more than actual air voids.

graded mix, the aggregate matrix (containing a relatively lower percentage of coarse aggregate and hence a smoother surface texture) had less surface texture and as a result the difference between the machine measured and actual volume specimens does not vary over a wide range. It was observed that the rate of change in the correction factor value decreases with an increase in gyration level.

Table 4 shows the density of compacted dense mix at different gyration levels for the dense graded mix. Figure 7 shows the gyration versus density plots for dense graded mix. There are two plots in the figure. One was derived from the actual bulk specific gravities (determined by weighing in air and water), and the other plot was prepared after correcting the estimated bulk specific gravities with correction factor obtained at $N_{maximum}$ (corrected plot). Of the eight actual

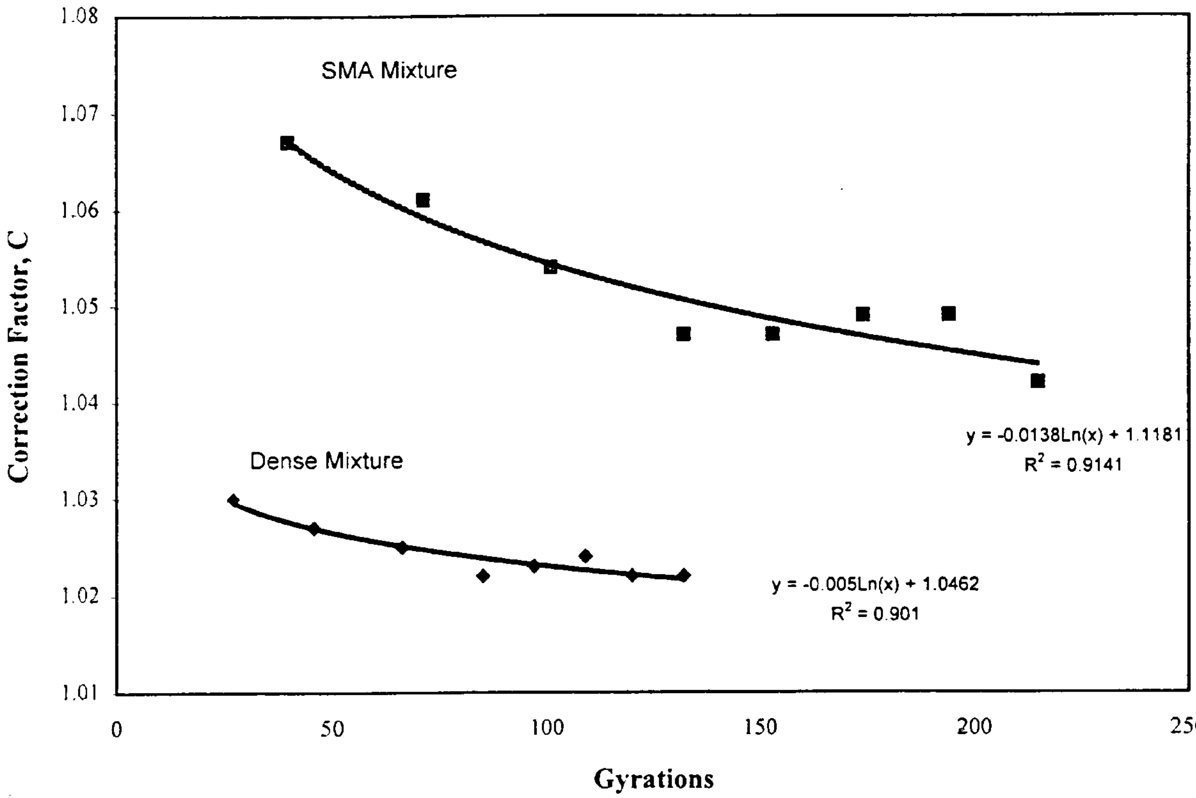

Figure 6. Correction factor versus gyration level.

measured data points for the dense mix, the first and the third points (at 27, and 66 gyrations) fall approximately 0.5 percent above the corrected plot. This will result in voids calculation being in error by 0.5 percent. The next two data points (97 and 109 gyrations) fall slightly below the corrected plot. The final three data points fall more or less on top of the corrected plot. Table 4 also shows the error in calculation of air voids.

Table 4 shows the density data obtained on the basis of correction factor at $N_{maximum}$ and measured bulk specific gravities for the SMA mix. Figure 8 shows the gyration versus density plot. All of the first four actual data points (40, 71, 101, and 153 gyrations) were observed to fall above the corrected plot. This means that the actual measured density at these four gyration levels

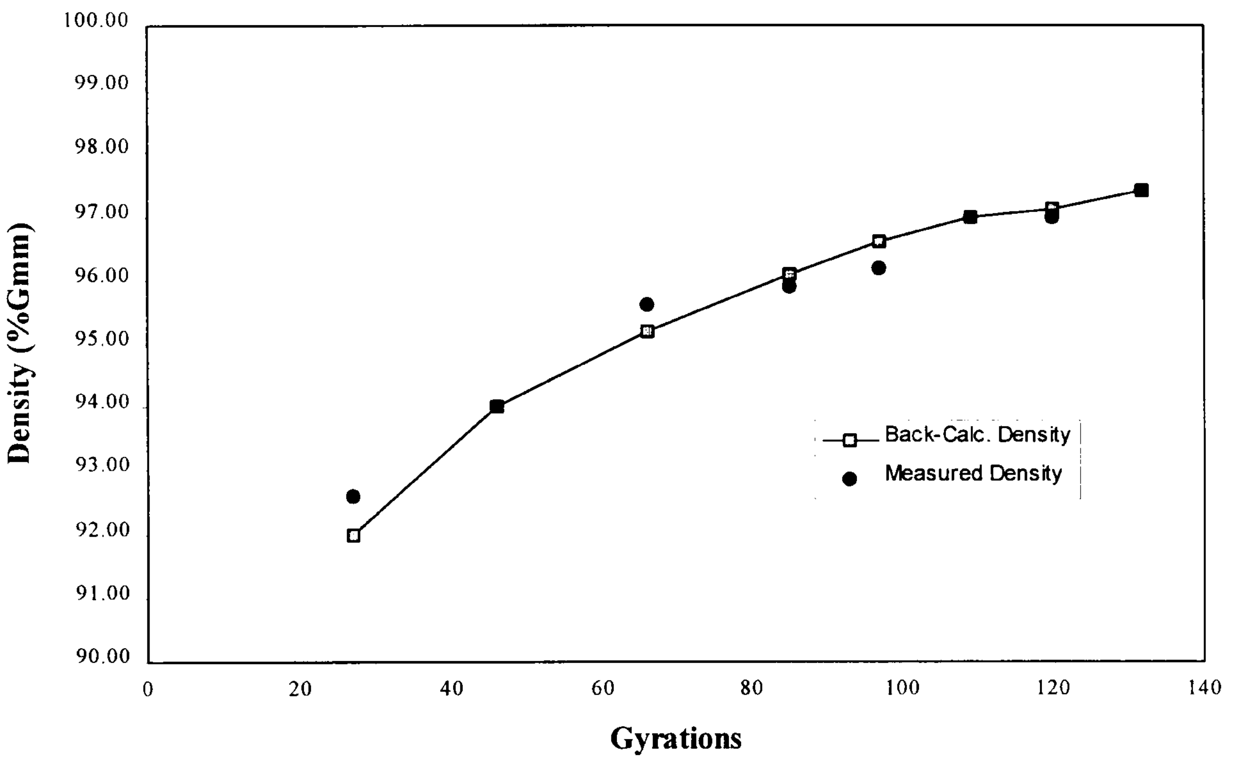

Figure 7. Density versus gyration level for the dense mixture.

was greater than those predicted by the corrected plot. The difference between the data points and the corrected plot ordinates ranged from 1.5 to 0.5 percent. As observed in Table 4, errors in calculated air voids are significantly higher at lower gyrations (the maximum error is 1.5 percent). The percentage of error in air voids (back calculated versus actual) at different gyrations is shown in Figure 9. The error decreases with an increase in gyrations. However, at lower gyration levels the error is significant (the maximum error is 0.6 percent). Figures 7 and 8 show that for both dense and SMA mixes, the gyration versus density plots derived from correction factor at $N_{maximum}$ seem to underestimate the density at lower gyrations. For some mixes this difference is significant and for other mixes this difference is likely not significant. A method to determine air voids is

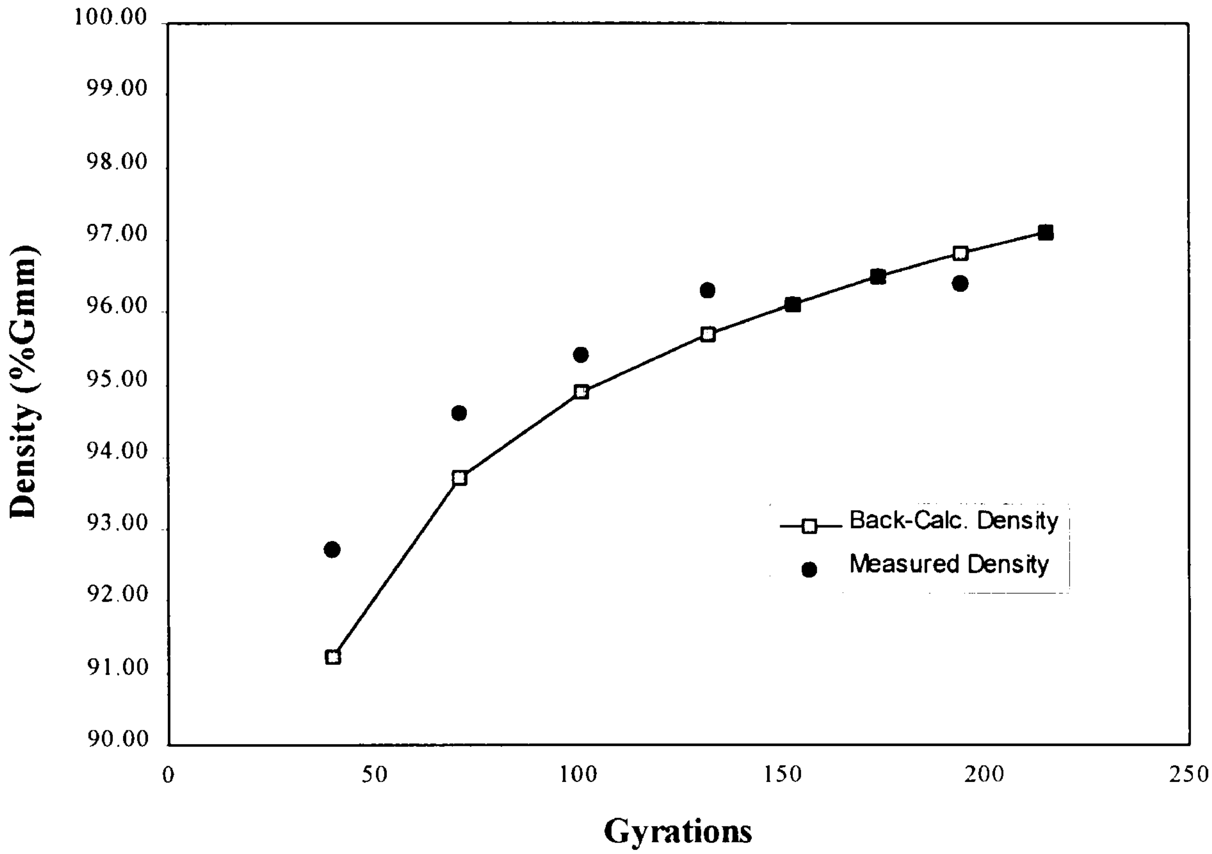

Figure 8. Density versus gyration level for the SMA mixture.

needed that works correctly for all mixtures.

RECOMMENDED PROCEDURE

This limited study shows that the method of back calculating corrected density on the basis of correction factor at $N_{maximum}$ will lead to erroneous air voids results for mixtures having a rough surface texture. It is suggested that in the mix design process, trial samples be compacted to N_{design} with different asphalt contents. This will result in accurate volumetrics at N_{design}, the most important point. The optimum asphalt content is then determined as the asphalt content that

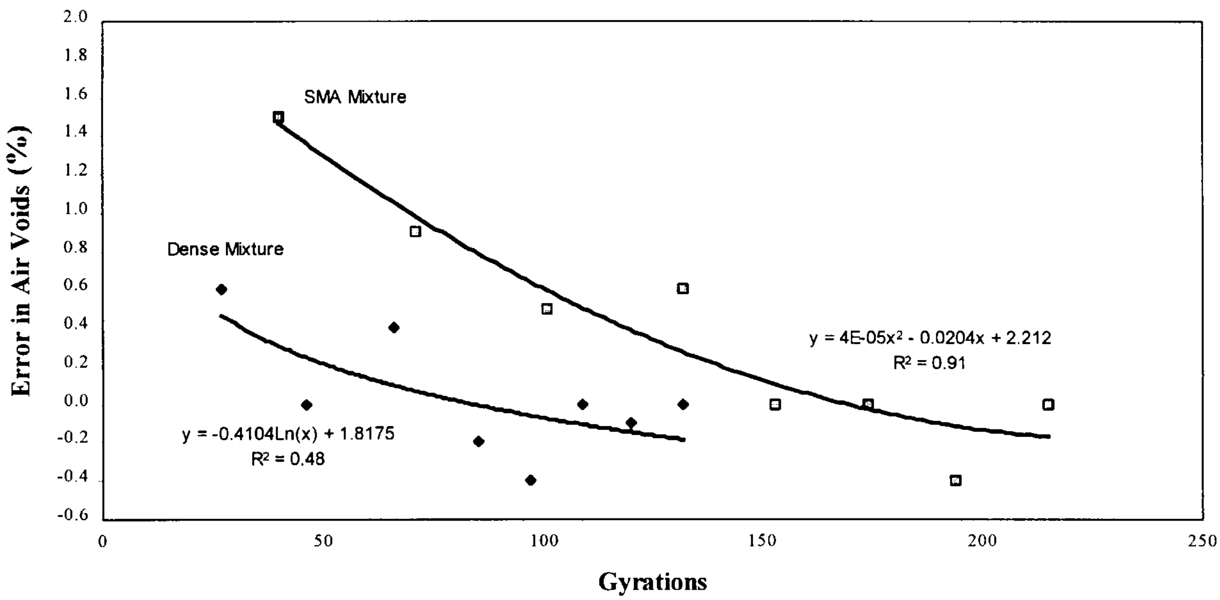

Figure 9. Error in air voids calculation versus gyration level.

provides 4 percent air voids. To check air voids at $N_{maximum}$ after the mix design, samples can be compacted up to $N_{maximum}$ and the air voids evaluated to determine if the criteria for $N_{maximum}$ is met. Also, the air voids at $N_{initial}$ can be calculated on the basis of the correction factor determined at N_{design}. In this way, the effect of the significant difference between the correction factors at lower gyration levels and $N_{maximum}$ can be minimized, and the estimated air voids at $N_{initial}$ will be closer to the actual air voids.

CONCLUSIONS

This limited study was carried out to evaluate the effect of different types of aggregate and aggregate blends on volumetric properties of specimens compacted with the Superpave gyratory compactor and to evaluate the correction factor at different gyration levels. The following conclusions are made:

1. For a given aggregate, gradations below or above the restricted zone provided higher VMA than mixes through the restricted zone.
2. Mixes with crushed aggregate provided higher VMA than mixes with partially crushed aggregate.
3. The mixes with gradations below the restricted zone had the highest voids at $N_{initial}$, whereas the mixes with gradations above the restricted zone had the lowest voids at $N_{initial}$.
4. For all crushed mixes, the mixes with gradations above the restricted zone had the highest voids at $N_{maximum}$ whereas the mixes with gradations below the restricted zone had the lowest voids at $N_{maximum}$.
5. None of the mixes containing natural sand met all the requirements for volumetric and gyratory properties. The mixtures for all crushed material met all requirements when passing through the restricted zone and below restricted zone.
6. Gradations through the restricted zone had the lowest optimum asphalt content and lowest VMA (compared to gradations above and below the restricted zone).
7. For this study the all crushed material through the restricted zone had better volumetric properties than the mix with 20 percent natural sand below the restricted zone.
8. The correction factor used to correct specific gravities of specimens compacted with the Superpave gyratory compactor is not constant at different gyration levels for all mixtures. For the dense graded and SMA mixes studied, the correction factor was found to decrease and become close to constant at higher gyration levels. The coarser textured mixture had a larger difference between the back calculated and the actual air void levels.

9. At lower gyrations, densities of specimens for the two mixes were found to be greater than the densities predicted by the gyration versus compaction plot obtained on the basis of correction factor at $N_{maximum}$. The difference between the actual and predicted densities were greater for the coarser gradation (SMA mix) than for the finer gradation (dense graded mix).

It is recommended that further work be conducted to evaluate the effect of different types and shapes (crushed, uncrushed) of aggregates on the volumetric properties of specimens compacted with the Superpave gyratory compactor. Aggregates with a range of breakdown potential should be studied. Regarding the restricted zone, it appears that some mixtures that pass through the zone have very good $N_{initial}$, $N_{maximum}$. and volumetric properties.

To avoid erroneous air voids results, it is suggested that mixes be compacted to N_{design} for determination of design asphalt content. Air voids at $N_{initial}$ can be checked on the basis of a correction factor obtained at N_{design}. After the mix design is completed, mixes can be compacted up to $N_{maximum}$ to determine if $N_{maximum}$ requirements are met.

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