Comparison of in-situ and lab-measured void contents for a bituminous pavement of a carriageway

Lewis Kabwe KIZYALLA[1] and Stephen EKOLU

Department of Civil Engineering, University of Johannesburg, South Africa

Abstract. In situ air voids are a function of mix design (aggregate type and gradation, and bitumen content), manufacture and the level of compaction achieved during construction and subsequent traffic [1-2]. During the improvement of N12-19 highway construction project between Snake road interchange and Kingsway interchange in Johannesburg, South Africa, the quality control (QC) of a bitumen treated base layer was done according to Committee of Land Transport Officials (COLTO) specifications where compliance is a statistical judgment of three parameters namely, the relative compaction, binder content (lab binder) and voids in the mix (lab air voids).

The focus of this paper is to analyse only one of the three parameters namely, voids content obtained from the laboratory and from in-situ field measurements. It was found that for a given random sample, there is a considerable difference between in-situ void and lab void for the same material. Therefore, it becomes interesting to statistically evaluate the random sample results of in-situ air voids in order to decide on its compliance with quality control requirements. The study concluded that QC evaluation based on lab void results might be accepted but use of in-situ air voids values may lead to rejection decision, for the same bituminous mixtures.

Keywords: Marshall compaction, core density, air voids

Introduction and background

There has been some concern that the voids in the mix aggregate (VMA) attained in the field can be somewhat different than the laboratory measured VMA for a given mix. The proportion of air voids in a compacted asphalt mix is a critical performance characteristic [3]. The bitumen random sample (BTB166) examined herein displays differences between in-situ voids and lab voids but the routine statistical judgment is usually done with lab voids. In the past, many researches have been done to find the relationship between lab voids and in-situ voids, yet there is still not proper relationship between the two parameters to date [4]. Through this paper, the statistical judgment is done with in-situ air voids as well as in-situ voids are directly linked to the pavement designed life. The outcome of the two judgments

[1]Corresponding author : jlsacrekiz@yahoo.fr

are compared to finally decide on the compliance of the BTB166 random sample. Marshall mix design testing methodology often called “Full Marshall” was employed as it widely used over the other more fundamental methods and is the most widely used mix design method in South Africa [5].

It is important to point out the fact that a Hot Mix Asphalt mixture produced in laboratory may have all the desired mix properties but the same mix may perform poorly under subjected traffic loading if the mix is not compacted to the proper level of density on the roadway [1]. The performance of bituminous layer after construction is influenced by volumetric properties resulting from mixing and compacting at high temperature. Compaction provides adequate lubrication for aggregates to stick each other, therefore high quality [6].

Compaction is the process by which the volume of an asphalt mixture is reduced, leading to an increase of the mixture in interlock among aggregate particles [7]. Compaction increases the service life of a bituminous pavement in many ways. It reduces rutting, increases mix stability and enable the pavement to carry traffic for longest period. Compaction is achieved by forcing the aggregate in the mix into close contact with each other. Consequently, the air voids content in the mix is reduced [8]. Excessive air voids content is undesirable as it may cause a pavement premature failure [9]. With air voids reduced, the pavement will have three important properties of:

(a) Cohesion: With fewer voids, the pavement is also more cohesive. Cohesion is the ability of the bituminous materials to hold together. Asphalt and filler are blended into a binder that holds the aggregate in place.

(b) Impermeability: This refers to the resistance of a pavement to the passage of air and penetration of water. Properly compacted bituminous material is dense enough to prevent connecting voids that would allow moisture to penetrate through the compacted material. The resulting pavement is durable and impermeable.

(c) Stability: Stability refers to the resistance of a pavement against internal movement. Even under high traffic loads, a properly compacted roadway will be stable. Stability depends on the internal friction between aggregate particles. Compaction, forces the aggregate into close contact with each other, interlocking the mixture together and improving its internal friction.

The aim of this paper is to calculate and compare in-situ voids content with laboratory voids values (referred to as ‘lab voids’), apply statistical evaluation of data from lab voids and from in-situ void measurements. The two sets of results are then examined on the basis of QC decision that may be reached using lab void results vis-a-vis in-situ measurements.

1. Literature review

The two most common asphalt mixture design methods, namely Marshall and Superpave, use air void content (AVC) as the main controlling element that determines binder content. The design AVC represents the ultimate level desired in situ as a result of compaction efforts [10]. AVC is commonly considered by the pavement engineering community to be the single most important factor that affects mixture behaviour and pavement performance. In the typical Marshall testing method, the design AVC ranges between 3 and 5%. In the Superpave methodology, the design AVC is fixed at 4%. A study by Khatri et al [8] re-evaluated this target value for the Superpave system. The study concluded that a design AVC in the range of 3 to 5% is adequate for all Superpave mixture types, for all aggregate gradations, and for all binder grades.

With high air void content, the asphalt becomes permeable to water and air, which causes reduced service life. With a very low air void content, the asphalt becomes rutted and deforms under traffic. Thus, for the mix to perform as expected, the contractor must be able to compact the mix to the desired level of density or air-void content [11].

1.1 Influence of air voids on asphalt performance

Asphalt consists of four main materials: bitumen, aggregate, fillers (fine particles) and air. Asphalt without sufficient air entrapped in the layer will deform under traffic and result in a rutted and rough surface. Field (in-situ) air voids represent the amount of entrapped air in an asphalt layer that has been placed on-site [12].

1.2 Variability in the determination of Void Mineral Aggregate (VMA)

The overall precision of the VMA calculation depends on the precision of many parameters of the compacted mixture. All laboratory tests performed on similar materials will have some variability due to inherent random testing errors. Other causes of variability are sampling procedures, operator experience, equipment, etc. [11].

1.3 Effect of variability on VMA

To calculate VMA, it is necessary to determine the Bulk Relative Density (BRD) and Theoretical Maximum Relative Density (TMRD) of the compacted mixture. The greater the variability among these two properties, the greater the variability of the VMA. Yildrim et al [7] stated that the variability of measured TMRD of the aggregate and compacted specimens can significantly affect the variability of VMA, regardless of whether the same asphalt content is used.

1.4 Influence of air voids on compliance

The Committee of Land Transport Officials (COLTO) considers air voids to be one of the major factors influencing the compliance based on a statistical analysis called “Judgment plan B” [13]. In this judgment, the variability of the values of tests is calculated and applied where acceptance limits for sample means are determined. Despite acceptance of those properties judged by this statistical method, the materials or work submitted will be rejected when other properties which aren’t controlled statistically fail to comply with the requirements of the specifications, or where there are other causes of rejection.

2. Results presentation

2.1 Results

Samples were prepared according to Marshall Mix design method to determine all the engineering mix parameters (Air voids, Bulk Relative Density, Theoretical Maximum Relative Density, binder content, indirect tensile strength, stability and flow of the mix. The results obtained for the N12-19 carriageway, were analysed for a random sample referred to as BTB 166. Core densities, laboratory voids content and binder content are the three Marshall parameters used for the statistical judgement summarized; the other properties which aren't controlled statistically did comply with the requirements of the specifications before proceeding with the statistical method.

Throughout this paper, the focus is on the difference between lab voids and in-situ voids. For n = 8 positions, $voids_{LAB}$ and $voids_{IN\text{-}SITU}$ of the BTB 166 random sample are calculated as follows:

$$Void_{LAB}\,[\%] = [(TMRD - BRD_{Marshall}) / TMRD]*100$$

$$Void_{IN\text{-}SITU}\,[\%] = [(TMRD - BRD_{IN\text{-}SITU})) / TMRD]*100$$

Where:-TMRD is the theoretical maximum relative density of the mix, BRD is the bulk relative density of the mix, $BRD_{in\text{-}situ}$ is the core bulk relative density.

Table 1 and Figure 1 show results of the lab AVC and insitu AVC determined for BTB 166. It can be seen that there are significant differences between field and lab void contents of the bituminous mix.

2.2 Statistical judgment

Statistical calculations were conducted on parameters for the judgment i.e. core densities, binder content and lab voids, as per COLTO [13]. The Judgement Plan B was done for Lab void content and for insitu void content. The evaluation returned 'accepted' result for Lab AVC but 'rejected' for insitu AVC.

Table 1. Lab voids and In-situ voids comparison based on Marshall Test results for a random sample BTB 166

Section	East Bound	East Bound	East Bound	East Bound	East Bound	East Bound	East Bound	East Bound
Position (8 positions)	25+880	26+029	25+947	26+111	26+307	26+220	26+614	26+766
Offset	9.5 R	10.5 R	10.1 R	9.3 R	10 R	8.5 R	9.2 R	9.5 R
Marshall Density = BRD (kg/m^3)	2623	2620	2625	2619	2627	2620	2622	2623
Core density = $BRD_{IN\text{-}SITU}$ (kg/m^3)	2583	2570	2576	2528	2504	2545	2504	2543
Rice Density =TMRD (kg/m^3)	2740	2740	2736	2736	2739	2736	2737	2741
Voids LAB (%)	**4.3**	**4.4**	**4.1**	**4.3**	**4.1**	**4.2**	**4.2**	**4.3**
Voids In-situ (%)	**5.7**	**6.2**	**5.8**	**7.6**	**8.6**	**7.0**	**8.5**	**7.2**

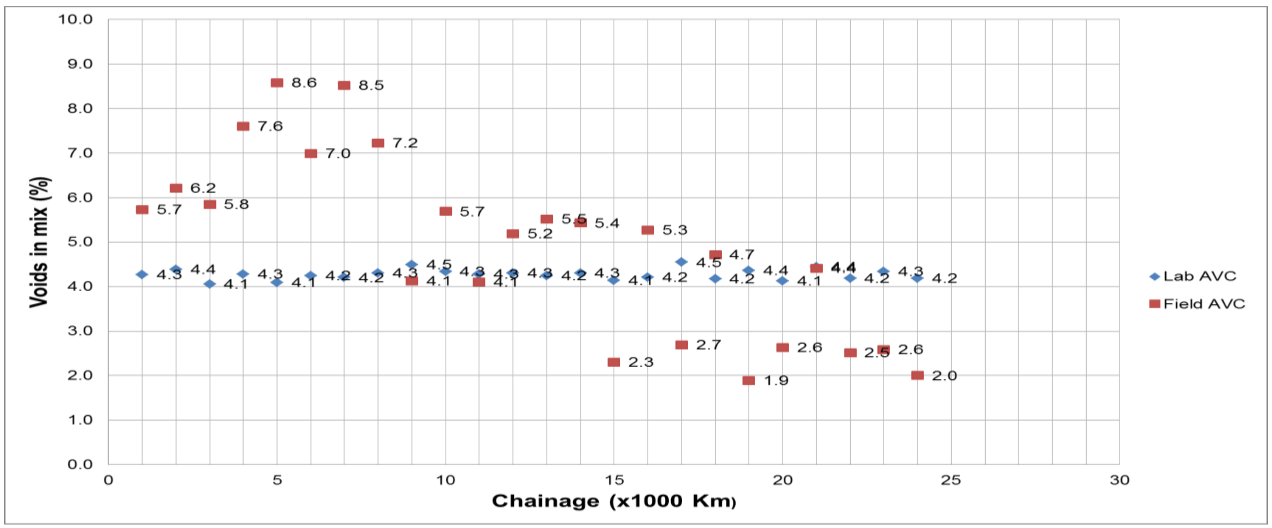

Figure 1. Comparison between Lab and in-situ air void values for BTB166

3. Discussion

Examining the judgment plan B herein called “lab judgment”, one can see that the statistical method combines lab parameters and in-situ parameters to accept or reject a random sample [14]. Among the three parameters of the judgment, core densities are field parameters. The binder content by definition, is the mass of binder expressed as a percentage of the total mass of the mix[15-16] .Throughout this paper, binder content laboratory measurements are assumed to be more or less equal to field values. Therefore, binder content values used for statistical judgments in lab and in-situ values are assumed to be equal. An additional research might be needed to assess the correlation (if any) between the binder contents of in-situ and lab values.

Voids content for the lab judgment are lab values. In-situ VC are different from lab VC as seen in figure 1 that there isn’t correlation between lab and in-situ parameters. $BRD_{BRIQUETTE(LAB)}$ is more or less constant (see table 1) because all the briquettes are compacted under same conditions in the lab (same effort-75 blows, same temperature etc.) whereas in-situ compaction ($BRD_{IN\text{-}SITU}$) is influenced by many variable factors such as the temperature (ground temperature, air temperature, wind speed, changing solar flux, etc.), the roller type (speed and timing, number of passes, etc.), the haul distance, haul time, handling time etc.), driver behavior, etc.

For the “in-situ judgment” all the three parameters are in-situ parameters directly linked to the pavement life and may therefore be more realistic. Lab VC parameters aren’t linked to the pavement life and behavior, and since there isn’t correlation between lab and in-situ VC, decisions made based on lab VC may be misleading.

4. Conclusions

Quality control, Marshall parameters determined from construction of N12-19 Carriageway, were evaluated in comparison of laboratory results and in-situ measurements. It was shown that there is no correlation between the laboratory-measured void and in-situ measured void content of the bituminous mixtures.

Statistically analyzed results of a random sample led to *accepted* judgment for lab void content results but gave *rejection* judgment for the in-situ void content results. Based on current practice, the quality control results would approve these results even through the in-situ measurements give rejection judgment. This leads to the need to give consideration on the implications of in-situ measured void content, since the designed life of a pavement depends on in-situ parameters and are directly linked to the designed life and behavior of the pavement.

Acknowledgments

The authors wish to express their appreciation to The South African National Road Agency Limited representative for the N12-19 rehabilitation project and Mr. Estime Mukandila of The South African AURECON for granting the publication of the project results.

References

[1] Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types, Manual Series No. 1. Asphalt Institute, 1962.

[2] Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types, Manual Series No. 2. Asphalt Institute, 1974.

[3] Bahia, H. U., W. P. Hislop, H. Zhai, and A. Rangel. Classification of Asphalt Binders into Simple and Complex Binders. *Journal of the Association of Asphalt Paving Technologists*, Boston, Massachusetts,1998.

[4] Gudimettla, J. M., A. L. Cooley, Jr., R. E. Brown. Workability of Hot-Mix Asphalt, Report No. 03-03. National Center for Asphalt Technologies, Auburn, Ala., April 2003.

[5] Hugo,F. A critical review of asphalt paving mixes in current use with proposals for a new mix. *Proceedings of the first conference on Asphalt Pavements for Southem Africa*,Durban, 1969.

[6] Bahia, H.U., D. Hanson, M. Zeng., H. Zhai, and A. Khatri. NCHRP Report 459: Characterization of Modified Asphalt Binders in Superpave Mix Design. *TRB*, National Research Council, Washington, D.C., 2001.

[7] Yildrim, Y., W. T. Kennedy, and M. Solimanian. Mixing and Compaction Temperatures for Modified Asphalt Binders. South Central Superpave Center Newsletter, 1999.

[8] Khatri, A., H. U. Bahia, and D. Hanson. Mixing and Compaction Temperatures for Modified Binders using the Superpave Gyratory Compactor. *Journal of the Association of Asphalt Paving Technologists*, Vol. 70, 2001,

[9] Hensley, J., and A. Parmer. Establishing Hot Mix Asphalt Mixing and Compaction Temperatures at the Project Level. *Asphalt*, Vol. 12, No. 2. pp 368-395, 1998.

[10] Yildrim, Y., M. Solaimanian, and T. Kennedy. Mixing and Compaction Temperatures for Superpave Mixes. *Journal of the Association of Asphalt Paving Technologists*, Vol. 69, 2000.

[11] Shenoy, A. Determination of the Temperature for Mixing Aggregates with Polymer-Modified Asphalts. *International Journal of Pavement Engineering*, Nottingham, U.K., 2001.

[12] Salomon, D., and H. Zhai. Ranking Asphalt Binders by Activation Energy for Flow. *Journal of Applied Asphalt Binder Technology*, October 2002.

[13] Standard Specifications for Road and Bridge Works for State Road Authorities, Committee of Land Transport Officials (COLTO), pp 8200-1 - 8200-9, 1998

[14] Standard Specifications for Road and Bridge Works for State Road Authorities, Committee of Land Transport Officials (COLTO), Table 8206/1, pp8200-7, 1998

[15].Reinke, G. OnAlaska, Mathy Construction Company, 2004. Personal Communication.

[16] Bahia, H. U., T. P. Friemel, P. A. Peterson, J. S. Russel, and B. Poehnelt. Optimization of Constructibility and Resistance to Traffic: A New Design Approach for HMA Using the Superpave Compactor. *Journal of the Association of Asphalt Paving Technologists*, Vol. 67, 1998, pp. 189–213.