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Single Face Compaction on Laboratory Marshall Specimen towards Satisfactory Degree of Compaction and Thickness

(Pemadatan Satu Permukaan Spesimen Marshall untuk Mencapai Darjah Pemadatan dan Ketebalan yang Memuaskan)

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ABSTRACT

Investigation on the performance of bond strength between pavement layers has gain serious attention from researchers worldwide. Typical method to prepare the double layered testing specimen at laboratory scale is to follow the Marshall procedure or to perform coring on constructed field scale test lanes. For specimen prepared with Marshall procedure, binder course loose mix is compacted at double faces first prior to the application of wearing course loose mix in the compaction mould and perform the compaction of the loose wearing course later. This paper focused on the specimen prepared using Marshall procedure where the upper wearing course is subjected to single face compaction. The feasibility of single face compaction is investigated and the relevant amount of compaction blows is determined to achieve sufficient thickness and degree of compaction. Aggregate is proportioned to achieve a target thickness of 35, 50 and 65mm, at an allowable limit of ±1 mm. For the tested mix incorporating dense graded, open graded and gap graded mix, each mix managed to achieve the required degree of compaction at satisfactory thickness with respective compaction blows.

Keywords: Degree of compaction; double layer; single face compaction; thickness

ABSTRAK

Penyelidikan terhadap prestasi kekuatan ikatan antara lapisan asfal telah mendapat perhatian yang serius daripada para penyelidik di seluruh dunia. Kaedah yang sering digunakan untuk menyediakan spesimen uji kaji berlapis dua pada skala makmal adalah mengikut kaedah Marshall atau pun melalui proses penerasan dalam lapangan uji kaji bagi mendapatkan spesimen berskala lapangan. Untuk spesimen yang disediakan dengan kaedah Marshall, campuran longgar lapisan pengikat akan dipadatkan pada kedua-dua permukaan sebelum campuran longgar lapisan haus diaplikasikan dan dipadatkan pada satu permukaan sahaja. Makalah ini fokus kepada penyediaan spesimen dengan kaedah Marshall dengan lapisan haus dipadatkan pada satu permukaan sahaja. Kemungkinan perlaksanaan pemadatan pada satu permukaan sahaja dikaji dan jumlah pemadatan yang diperlukan untuk mencapai ketebalan dan darjah pemadatan yang mencukupi dikenal pasti. Agregat disediakan pada kuantiti yang tertentu untuk mencapai ketebalan 35, 50 dan 65 mm, dengan batas yang diizinkan ±1 mm. Untuk setiap jenis campuran yang diuji, setiap campuran berupaya untuk mencapai darjah pemadatan yang disasarkan berserta ketebalan yang memuaskan dengan jumlah pemadatan seperti yang dikenal pasti.

Kata kunci: Darjah pemadatan; ketebalan; lapisan dual; pemadatan satu permukaan

INTRODUCTION

Compaction of asphalt concrete is an important process in construction of road and highways. It is normally the last process in a construction but if not carried out properly can have catastrophic effect on the pavement performance and durability. The compaction work needs to be closely monitored to ensure the quality of work within a pavement section to prevent insufficient compaction in the constructed pavement. Insufficient compaction leave behind high percentage of air void content which then initiates rutting to take place in a pavement (Kassem et al. 2012; Roberts et al. 1996). The current practice to evaluate the compacting effort is to check the density of asphalt concrete core in field and to compare it with the laboratory prepared specimens to achieve certain degree of compaction as specified in the respective standard. Density is an important element in the construction of hot mix asphalt. According to Brown (1990), there existed three primary methods of specifying density: Percent of control strip, percent of laboratory density and percent of theoretical maximum density. Density is greatly affected by the air voids in a mix type. For many years, air void content within an asphalt concrete specimen has been measured using the water displacement concept with the aid of saturated surface dry specimens (Cooley et al. 2002). But in conjunction with the introduction of superpave mixture, a new method known as the Corelok Method has been developed (Cooley et al. 2002, 2003). Investigation in this method indicates that the method is capable to measure the air void content within an asphalt mixture with even better accuracy compared to the conventional method.

Recently, investigation on the performance of bond strength between pavement layer interface has gain serious interest from researchers worldwide (Mohammad et al. 2012; Raab & Partl, 2010; West et al. 2005). Preparations of double layered specimen in laboratory scale to investigate the possible factors which contribute to the adhesion at the interlayers become unavoidable. A typical method of preparing the double layered specimen is to construct field scale research test lanes with the aid of heavy machineries like paver and rollers, then to perform coring at location of interest to obtain the double layered specimen as did by researchers worldwide (Patel 2010; Wheat 2007). Although field scale prepared specimen may simulate the actual conditions on site as closely as possible, it however normally require large amount of funding which is unaffordable by small research institute. Thus, a laboratory scale prepared specimen is often preferred, where the loose mix is either compacted with a Marshall compactor or a gyratory compactor. For specimen prepared with standard Marshall procedure, binder course loose mix is compacted at double faces first prior to the application of wearing course loose mix in the compaction mould and perform the compaction of the loose wearing course later. This method of specimen preparation has been adopted by Sutradhar (2012). In such methods, preparation of binder course can be done according to ASTM D6926 (ASTM 2010) and ASTM D6927 (ASTM 2010), subjected to double face compaction at 75 blows compaction per face, but compaction of wearing course loose mix will certainly fail to meet the specified criteria. At this stage, the wearing course will only subjected to single face compaction. Consequently, the quality of the compaction of the wearing course might become unconvincing, resulting in the existence of scepticism over the sufficiency and insufficiency of compacting effort performed. As for specimen prepared using gyratory compactor, it would has no similar concern as gyratory compaction involved only compacting the single face of the specimen.

It is therefore in the interest of this research to be carried out to investigate further in the single face compacted specimen using the Marshall compactor. The main objectives of this work were to study the feasibility of specimen subjected to single face compaction using Marshall compactor and then to determine the number of compaction blows at single face to achieve desirable thickness and degree of compaction. The scope of the study focused only on three different kind of wearing course mixture like dense graded hot mix asphalt, gap graded stone mastic asphalt and open graded porous asphalt which can be easily encountered in the Malaysian pavement. The following section in this paper will present the test result for the testing on single face compacted specimen on the density and degree of compaction. The number of single face compaction blows was also investigated for specimen at different thickness to achieve the require degree of compaction.

MATERIALS AND METHODS

AGGREGATES GRADATION

Aggregate used in this research is solely provided by MRP Quarry Pulai, Johor Bahru. Three different kinds of mixes include hot mix asphalt AC10, stone mastic asphalt SMA14 and porous asphalt grading A in accordance with local specification (JKR 2008) was produced. Filler used is ordinary Portland cement at 2% only by weight according to local specification (JKR 2008). The gradation limit for each mix type is illustrated as in Figure 1.

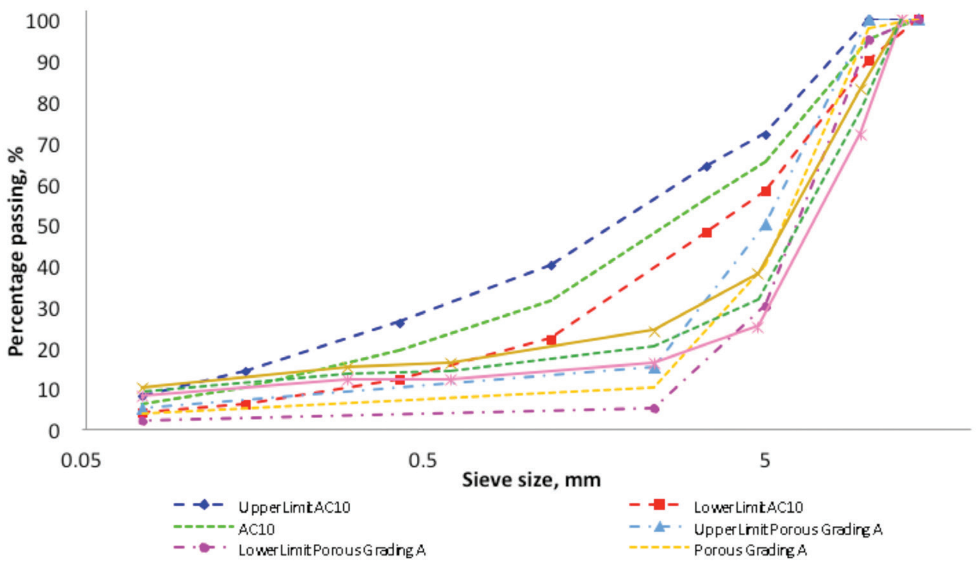

FIGURE 1. Gradation limit for AC10, SMA14 and porous asphalt grading A used in the study

BITUMEN SELECTION

Two bitumen types were used in this study incorporating three different mix types. For hot mix asphalt, the binder selected is penetration graded asphalt PEN80-100 while for stone mastic asphalt and porous asphalt, performance grade asphalt PG76 is used.

METHODS

Prior to the preparation of specimen, the optimum bitumen content (OBC) for each types of mix is determined. The aggregates used were highly angular and irregular with rough surface texture, but were relatively dusty. Due to that, wash sieve analysis was performed on triplicates sample in accordance to ASTM C117 (ASTM 2004) using the plain water washing method. Once OBC is obtained, Marshall specimen of different thickness was fabricated. The thickness selected was 35, 50 and 65 mm, at an allowable limit of ±1 mm. Initially, the specimen was prepared using 1200 g of aggregates, compacted at both surfaces according to ASTM D6926 (ASTM 2010) at the OBC. The final thickness was then recorded. Back calculation was later performed to obtain the estimated amount of aggregate needed to produce a specimen with the desired thickness as mentioned beforehand. With the estimated amount of aggregates, specimens at respective thickness were fabricated again to ensure that the desired specimen thickness was achieved. Trial and error was performed at times in the effort to obtain the desired specimen thickness. Upon obtaining the amount of required aggregate, triplicate specimen was then prepared at single face compaction only, with a variety of compaction blows. These single face compacted specimens were later checked for the degree of compaction and thickness in order to ensure that the sufficiency of compaction performed on each specimen.

RESULTS AND DISCUSSION

PRELIMINARY TEST

Preliminary test in this research is to determine the OBC of each type of mixes, then to estimate the amount of aggregates needed to produce a specimen at respective thickness. OBC is certainly important in each type of mix as it governs the mix properties and their performance. Neither excess binder nor insufficient binder can be beneficial, it is therefore an optimum need to be determined. The OBC value of the different types of mixtures is tabulated in Table 1. Prior to that, the results from wash sieve analysis showed 41.0, 15.7 and 6.3 g of dust existed in the proportioned aggregates of AC10, SMA14 and porous asphalt grading A, respectively. The dust values gave an indicator on the amount of fine particles passing British Standard sieve size 75 µm attached at the aggregates so as to avoid excess dust presence within the mixture which might later affect the quality of the mixture. Excess dust with greater surface area absorbed the bitumen, hence increased the tendency of the remaining aggregates to not be properly coated with bitumen especially at OBC. Although it was not specified in any related specifications pertaining to the amount of dust to be existed within a mixture, it should be noted that the amount of dust recorded from wash sieve analysis shall not exceeds the proportioned amount. In this study, the amount of dust from wash sieve analysis showed that extra dust particle is needed to be added to the proportioned mixture. Details data on the testing which direct to the OBC value is also shown in Tables 2, 3 and 4, respectively. From the test results, it was clear that at OBC, the required specifications of each parameter was fulfilled, which further ensuring the quality of each types of the mix. Table 5 on the other hand shows the estimated amount of aggregates needed in

TABLE 1. Optimum bitumen content for different types of mixture

Mix Type	OBC
Hot mix asphalt AC10	6.10%
Stone mastic asphalt SMA 14	6.20%
Porous asphalt grading A	5.25%

TABLE 2. Marshall test results and the specifications for hot mix asphalt AC10

Parameter	Specification (JKR 2008)	Value at OBC	
Stability	> 8000 N	13930.2 N	PASS
Flow	2 – 4 mm	3.05 mm	PASS
Stiffness	> 2000 N/mm	4571.46 N/mm	PASS
Voids in mix	3-5%	3.15%	PASS
Voids filled with bitumen	70-80%	79.5%	PASS

TABLE 4. Marshall test results and the specifications for porous asphalt grading A

Parameter	Procedure	Specification (JKR 2008)	Value at OBC
Air void content	ASTM D3203	18-25%	21.6%
Draindown test	ASTM E11	<0.3%	0.0%
Cantabro test	BS EN12697-17	<15%	5.3%

TABLE 5. Estimated amount of aggregates needed to produce specimen of different mix at respective thickness after wash sieve analysis

Mix type	Desired thickness (±1 mm)	Measured thickness (mm)	Aggregate weight (g)
AC 10	35	34.8	587.7
	50	50.0	847.8
	65	64.5	1098.3
SMA 14	35	35.1	552.6
	50	49.5	814.2
	65	64.8	1065.7
Porous asphalt grading A	35	35.9	517.2
	50	50.2	741.2
	65	65.0	964.8

this research to produce a specimen at the corresponding thickness. The measured average thickness of triplicate specimens was also recorded. Despite the amount of aggregates recorded, it was still at times difficult to obtain the exact thickness as required. This is because thickness of specimen is not only governed by the amount of aggregates, but also the flakiness index and the angularity of the aggregates. From the flakiness test on the aggregates, flakiness index of 15% was obtained. This relatively high percentage of flakiness index will serve less significant purpose in defining the thickness of the specimen, but to contribute in the weight of specimen only. An allowable limit of ±1 mm is thus adopted to compensate this problem.

HOT MIX ASPHALT AC10

Marshall density for AC10 determined at OBC is 2.310 g/cm^3. The mixture is prepared using the gradation as shown in Figure 1. According to JKR (2008), for a constructed pavement on site, the required compacted density should achieve 98-100% Marshall density. In another words, there is a maximum allowable of 2% extra air void permitted in the specimen besides the maximum allowable voids in mix of 5% as from the specification. In this study, the targeted degree of compaction for specimens compacted in single face is at 98% only, which is equivalent to 2.264 g/cm^3. Figure 2 shows the results of single face compaction at different number of compaction blows and the respective

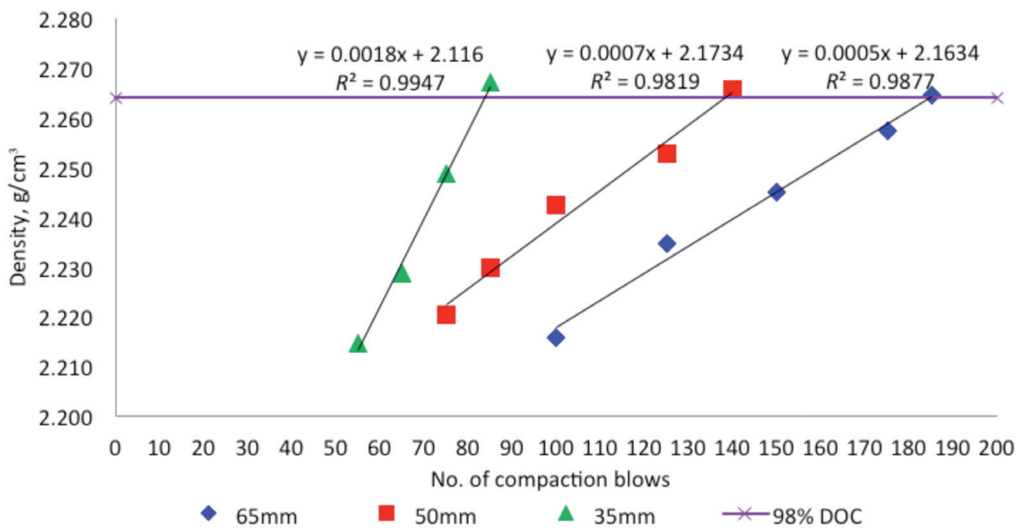

FIGURE 2. Relationship of compaction blow and density for AC10 specimen of different thickness

density for specimen with different thickness. Different compaction blow is adopted for different thickness of specimen in order to ensure the sample is compacted to the required degree of compaction. From the figure, it is clearly shown that the density and compaction blows for AC10 possessed high correlation, with R^2 value of at least 0.98 for specimen tested at their respective thickness. At single face compaction of 85, 140 and 185 blows, the AC10 mixture manage to achieve 98% degree of compaction for specimen with 35, 50 and 65 mm.

STONE MASTIC ASPHALT SMA 14

Figure 3 shows the density of SMA14 specimens of various thicknesses subjected to different compaction blow. Likewise, the aggregate gradation to prepare this mixture was as shown in Figure 1. For a constructed SMA pavement, the pavement should be compacted to at least 94% of maximum theoretical density as specified (JKR 2008). From the theoretical maximum density test conducted based on ASTM D 2041 (ASTM 2011), the value of maximum theoretical density of the mix recorded was 2.244 g/cm^3, as indicated in the purple line in Figure 3. The data as shown in Figure 3 after several trial and error attempts marked a 50, 100 and 125 compaction blows at single face only, respectively, for specimen of 35, 50 and 65 mm thick to achieve the targeted 94% maximum theoretical density. The plotted graph also showed high correlation between density and compaction blow, with R^2 value ranged from 0.96 to 0.99.

POROUS ASPHALT GRADING A

Unlike AC10 and SMA14 which solely check on the density of the mixture itself for the degree of compaction, another consideration to check for porous asphalt is the air voids content in the mixture. Porous asphalt is a special mix as it is purposely design to contain high void composition of around 22% after compaction (Heystraeten & Moraux 1990). The void composition need to be closely monitored in order to ensure the performance and advantages of porous asphalt on site. The range of air voids content in porous asphalt differs accordingly to the local authority but generally range from at least 15% to a maximum of 25% (Lu et al.; UNHSC 2009). In Malaysia, the designed and in place air voids should be in between 18 and 25% (JKR 2008).

Figure 4 shows the air void content of porous asphalt specimen subjected to different compaction blows. A reverse trend is observed compare to the plot of density against compaction blows. As compaction increased, the air void content decreased. To check on the degree of compaction of porous mix, at least 97% density of laboratory mix design at OBC should be achieved as stated in local specification (JKR 2008). A plot in Figure 5 shows that every specimen tested in this study has actually exceed 97% density and in fact more than 100% density except for specimen of 35 mm at 35 blows of compaction. In another words, most of the specimens are over compacted whilst in the midst of trying to maintain the desired thickness of the specimen. A relatively low R^2 value was observed from the linear plot of density and air void content against compacting effort for porous asphalt specimen at 35 mm. Such observation may be accounted to the maximum aggregates size requirement that needs to be fulfilled within the 35 mm specimen, which is considerably thin. The nature of porous asphalt comprising predominantly coarse aggregates further contributes to this. Despite that, the porous mixture still manages to maintain the required air void content as specified.

DISCUSSION

For the tested types of wearing course mixture, a similar trend when plotting the density against number of single

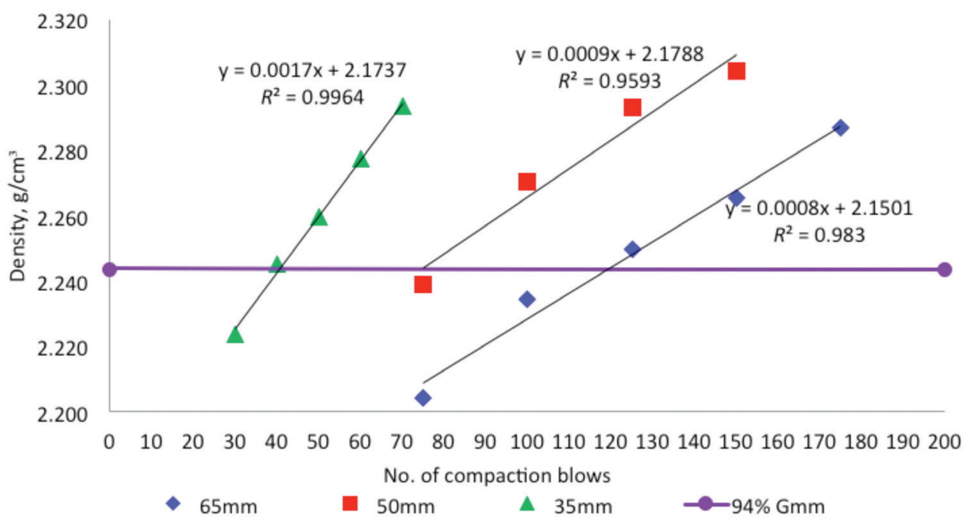

FIGURE 3. Relationship of compaction blow and density for SMA14 specimen of different thickness

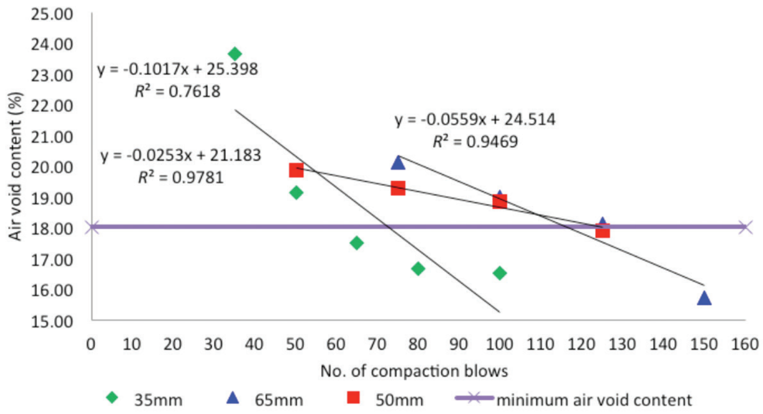

FIGURE 4. Air void content of porous asphalt grading A at respective compaction blows

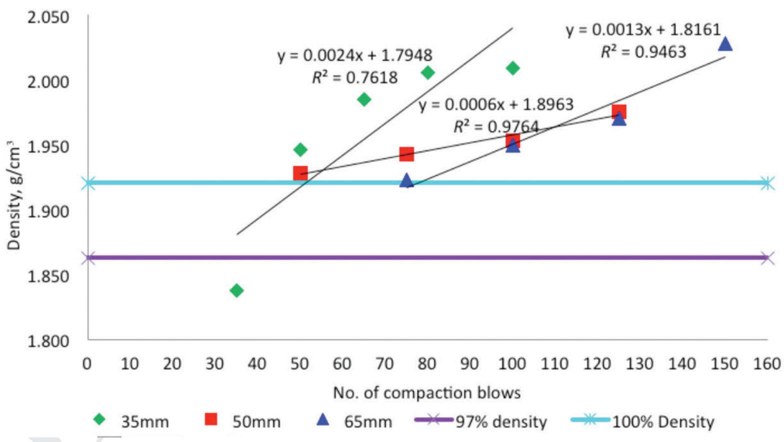

FIGURE 5. Relationship of compaction blow and density for specimen of mixture type porous asphalt grading A at different thickness

face compaction blows shows an increment in density as the compaction blows increased. The relationship must be linear, with a positive slope at the beginning that may reach to a plateau towards the end. This is because as the compacting effort increases, the specimen subjected to compaction would eventually reached to a state where extra compacting effort seemed to contribute no improvement in the density of the specimen. For that, the relationship between density and air voids in relative to compacting effort was plotted linearly in this research. This relationship is further enhanced in the presence of high correlation between the two tested variables. As single face compacting effort increased, the entrapped air in the mixture is being forced to escape from each of the mix type. The finer fractions of aggregates will then occupying the existing voids, hence producing a denser mix in a given volume of specimen. At the same time, as the thickness of the specimen increased, the compaction difficulties also increased in a proportional manner. In a thicker specimen, the impact of the compaction is reduced and is not as effective as compaction in a thinner specimen. In order for the thicker specimen to achieve sufficient degree of compaction, the compaction blows need to be increased. This explained the scenario that for the three mixture types of wearing course tested, the thickest specimen, i.e. specimen at 65 mm experienced the largest compaction blow at single face in order to achieve the targeted degree of compaction.

Another interesting finding in the single face compaction shows the ease of compactability of asphalt wearing course specimen increased from dense graded mix to gap graded mix and eventually to open graded mix. In dense graded AC10, maximum compaction blows are adopted to ensure 98% of Marshall density is achieved in all specimen thickness. In fact, the actual maximum compaction blows selected for AC10 specimen at 65 mm during testing is only at 175 blows. But, the required degree of compaction cannot be fulfilled. During the analytical part of the tested data, extrapolation was done to obtain the required number of compaction blows and laboratory test was redone to further validate the extrapolation results. As for gap graded SMA14, the number of compaction blows required to compact the specimen at different thickness to sufficient degree of compaction is much lesser compare to the dense graded specimen. In open graded porous asphalt grading A, specimen compacted at respective compaction blows manage to achieve more than 100% density of the laboratory specimen. Such peculiar observation may be explained by the fact that porous asphalt, which contains a large portion of single size aggregates in the mixture, might have experienced certain degree of aggregate crushing at the particular face of specimen subjected to compaction. Crushing of aggregates reduced the aggregate size which then further filled up the void in between the larger aggregates. The end result is that the porous specimen exhibits significantly higher density than it supposed to be.

CONCLUSION

From the tested results, compaction of asphalt specimen at single face only is feasible if the compaction blow is properly altered. For the mixture types tested in this study, a series of conclusion relating compacting effort to achieve sufficient degree of compaction incorporating a variety of specimen thickness can be drawn. For hot mix asphalt AC10 to achieve 98% degree of compaction, 85, 140 and 185 compaction blows at single face is required for specimen of 35, 50 and 65 mm thickness, respectively. As for stone mastic asphalt SMA14 to achieve 94% degree of compaction, 50, 100 and 125 compaction blows at single face is required for specimen at 35, 50 and 65 mm thickness. Finally, for porous asphalt grading A to achieve 97% of degree of compaction, 50, 75 and 100 compaction blows at single face is required for specimen thickness of 35, 50 and 65 mm.

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REFERENCES

ASTM C117. 2004. *Standard test method for materials finer than 75-mm (No. 200) sieve in mineral aggregates by washing*. United States: American Society for Testing and Materials.

ASTM D2041/2041M. 2011. Standard test method for theoretical maximum specific gravity and density of bituminous paving mixtures. United States: American Society for Testing and Materials.

ASTM D3203/3203M. 2011. Standard test method for percent air voids in compacted dense and open bituminous paving mixtures. United States: American Society for Testing and Materials.

ASTM D6926. 2010. Standard practice for preparation of bituminous specimens using Marshall apparatus. United States: American Society for Testing and Materials.

ASTM D6927. 2010. Standard test method for Marshall stability and flow of bituminous mixtures. United States: American Society for Testing and Materials.

ASTM E11. 2009. Standard specification for woven wire test sieve cloth and test sieves. United States: American Society for Testing and Materials.

Brown, E.R. 1990. Density of asphalt concrete – how much is needed? National Center for Asphalt Technology. Report 90-03.

BS EN12697-17. 2004. Bituminous mixtures - test method for hot mix asphalt - Part 17: particle loss of porous asphalt. The British Standard Institution, United Kingdom.

Cooley, L.A., Prowell, B.D. & Hainin, M.R.2003. Comparison of the saturated surface dry and vacuum sealing methods for determining the bulk specific gravity of compacted HMA. *Journal of Association of Asphalt Paving Technologists* 72: 56-96.

Cooley, L.A., Prowell, B.D., Hainin, M.R. & Buchanan, M.S. 2002. Bulk specific gravity round Robin using the Corelok vacuum sealing device. National Center for Asphalt Technology, Report 02-11.

Heystraeten, G.V. & Moraux, C.1990. Ten years' experience of porous asphalt in Belgium. *Transport Res. Rec.: J. of the Transportation Research Board* 1265: 34-40.

JKR. 2008. Section 4: Flexible pavement. Standard Specification for Road Works: Jabatan Kerja Raya.

Kassem, E., Scullion, T., Masad, E. & Chowdhury, A. 2012. Comprehensive evaluation of compaction of asphalt pavements and a practical approach for density predictions. *Transportation Research Journal: Journal of Transportation Research Board* 2268: 98-107.

Lu, X., B. Sandman & P. Redelius. *Aging characteristics of polymer modified binders in porous asphalt pavements*. http://www.nynas.com/Global/Bitumen%20for%20paving%20applications/UK/Aging%20Characteristics%20of%20Polymer%20Modified%20Binders%20in%20Porous%20Asphalt%20Pavements.pdf.

Mohammad, L.N., Mostafa, A.E., Bae, A., Patel, N., Button, J. & Scherocman, J.A. 2012. Optimization of tack coat for HMA placement. *NCHRP Report No 712*.

Patel, N. 2010. Factors affecting the interface shear strength of pavement layers. MsC Thesis, Louisiana State University (unpublished).

Raab, C. & Partl, M. 2009. Laboratory study on interlayer bonding using cationic tack coats. *7th International RILEM Symposium on Advanced Testing and Characterisation of Bituminous Materials*. Rhodes, Greece.

Roberts, F.L., Kandhal, P.S., Brown, E.R., Lee, D-Y. & Kennedy, T.W. 1996. *Hot Mix Asphalt Materials, Mixture Design, and Construction*. 2nd ed. National Centre for Asphalt Technology.

Sutradhar, B.B. 2012. Evaluation of bond between bituminous pavement layers. MsC Thesis, National Institute of Technology, Rourkela (unpublished).

UNHSC. 2009. UNHSC design specifications for porous asphalt pavement and infiltration beds. University of New Hampshire Stormwater Center.

West, R.C., Zhang, J. & Moore, J. 2005. Evaluation of bond strength between pavement layers. National Center for Asphalt Technology, Report 08-05.

Wheat, M. 2007. Evaluation of bond strength at asphalt interface. MsC Thesis, Kansas State University (unpublished).

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