

# Effect of Single Face Compaction on Stability and Flow of Asphalt Specimen

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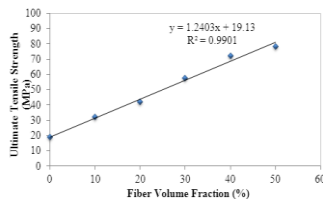
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## Graphical abstract



## Abstract

Recent research on the performance of bond strength between pavement layers results in the preparation of double layered specimen becomes inevitable. Double layered specimen may be in field scale or laboratory scale. Marshall mixture design method is normally adopted to prepare double layered specimen in laboratory, incorporating the compaction of binder course at both faces and followed by a single face compaction of wearing course. Due to that, compaction at single face only will raised potential scepticism over the quality of the compacted mixture. This paper focused on the performance of stability and flow for single face compacted wearing course specimen prepared using Marshall procedure at a thickness of 50mm for Asphaltic Concrete mixture of nominal maximum aggregate size 10 mm (AC10) and Stone Mastic Asphalt of nominal maximum aggregate size 14 mm (SMA14). The stability and flow was investigated with the increasing compacting effort. The stability and flow at optimum compacting effort was also checked. From the research, it was noticed that stability increased with compacting effort while flow shows a decreasing trend. A stability and flow value of 12.8 kN and 2.27 mm as well as 10.4 kN and 2.61 mm was recorded for AC10 and SMA14 respectively at optimum compacting effort. Such observation may be accounted to the aggregate gradation in the mixture besides the binder properties of two different binders used. Despite the adoption of single face compaction in specimen preparation, at optimum compacting effort, the stability and flow values was also found to be within the range as specified by local specifications.

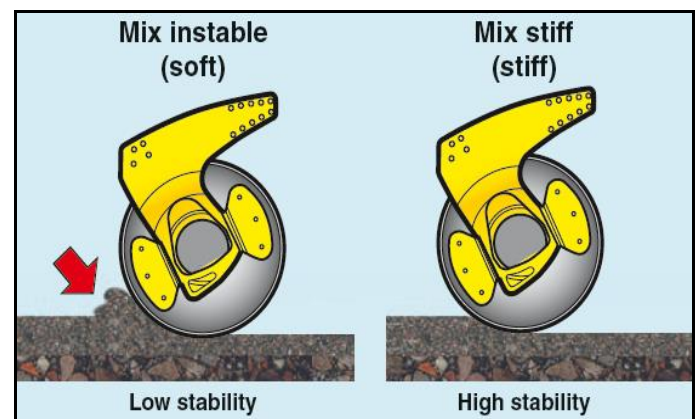
**Keywords:** Single face compaction; Marshall properties; stability; flow

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## 1.0 INTRODUCTION

Stability and flow are two main parameters often used in asphalt mixture design. Laboratory measured stability may not related to the field stability in many cases, where most practitioners relate distresses like rutting as a consequences of insufficient stability within a mixture and request to increase the stability of a mixture during the production [1]. However, the laboratory measured stability remains important in guiding the selection of optimum bitumen content (OBC) in a mixture with the increasing of asphalt content. At the same time, stability of asphalt needs to be maintained to ease the compaction as in Figure 1. Stability of an asphalt mixture therefore needs to be well taken care of to ensure the stiffness of the mixture during the application of heavy compaction equipment for compaction works. Flow is a parameter normally measured alongside with stability. It is the deformation of asphalt mixture upon subjected to loading. Flow value need to be kept optimum to ensure the workability of the mixture, and at the same time the durability of the end product in term of

premature cracking due to excessive air voids present in the mixture.



**Figure 1** Difference in mixture stability and the consequences upon subjected to compaction on site [2]

Recently, research and investigation on the performance of bond strength between pavement layer interfaces have been studied extensively by the researchers worldwide [3-6] following some of the real cases [7, 8] reported incorporating poor bond between pavement layers. Preparation of double layered specimens therefore becomes unavoidable. A typical method which is currently adopted worldwide is to construct a field scale test lane to simulate the condition on site as closely as possible, then to perform coring of specimens at certain location of interest to obtain the test specimens [9]. But, a major drawback of this method is that large amount of research funding is normally required. It is therefore preparation of laboratory scale specimens is often preferred especially for smaller research institute or if the interest in the research area is still at a preliminary stage.

Under laboratory scale, the most popular method of preparing the specimen is the Marshall mixture design method though there exist prevalent used of gyratory compactor since the introduction of Superior Performing Asphalt Pavement (SUPERPAVE). Preparation of double layered specimen using this method is discussed in ASTM D6926 [10]. It requires the design of binder course and wearing course mixture at the OBC, then to compact the loose mixture of the binder course with the aid of the Marshall compactor at desired amount of compaction blows per face at both faces. Such compaction is termed double face compaction. Then, the wearing course loose mix will be poured onto the binder course specimen which remain sited in the Marshall mould and begin with the compaction of the loose wearing course. Such method of specimen preparation has been used in the research conducted by Sutradhar [11]. When this methodology is applied, compaction of the loose wearing course at double face becomes impossible. Instead, single face compaction follows, which then later raised scepticism over the quality of the single face compacted wearing course layer.

It is therefore in the interest of this paper to discuss on the performance of stability and flow of the single face compacted specimen. The main objective of this work is to investigate the performance of stability and flow of single face compacted specimen subjected to various compaction blows. At the same time, the stability and flow value at optimum compacting effort is also checked to ensure that they lies between the range of limit as specified in local specification [12]. The scope of the study focused only on two different kind of wearing course mixture which is dense graded hot mix asphalt and gap graded stone mastic asphalt which can be easily encountered in the Malaysian pavement. The subsequent section in this paper will present the results and outcomes of the research work.

## 2.0 MATERIALS

### 2.1 Aggregates

The aggregates used in this research are crushed granite. The aggregates properties were tested and complied with the local specification. The aggregate gradation for the mixture is presented in Figure 2.

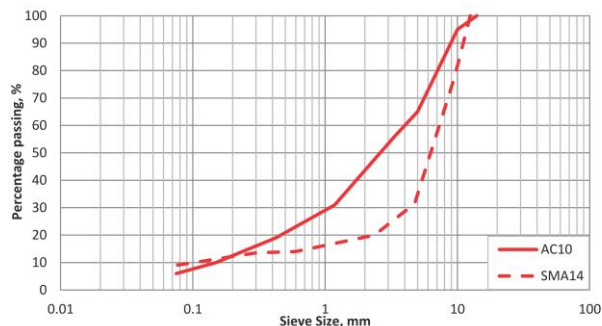


Figure 2 Aggregate gradation for mixture AC10 and mixture SMA14

### 2.2 Filler

Ordinary Portland cement (OPC) is added to the mixture to serve as mineral filler. A maximum amount of 2% is added by weight in accordance with the specification. The amount of filler need to be controlled and treated correctly as there exist possibilities of interaction of asphalt with the filler which can greatly affected the optimum bitumen content of an asphalt mixture[13].

### 2.3 Bitumen

Two bitumen types were adopted to be used as the binding agent in preparing the mixture. For mixture AC10, penetration graded asphalt PEN80/100 was used while for mixture SMA14, the binder is performance grade asphalt PG76. The basic properties of these two types of bitumen are presented in Table 1.

Table 1 Basic properties of bitumen

Properties	PEN 80/100	PG76
Specific gravity (g/cm <sup>3</sup> )	1.030	1.030
Penetration (PEN)	84.7	39.5
Softening point (°C)	41	60
Viscosity @ 135°C (cP)	500	2800

## 3.0 METHODOLOGY

Two mixtures comprising AC10 and SMA14 were investigated in this study. Both mixture types used in this study was designed accordingly to Marshall mixed design method.

### 3.1 Material Preparation

Before sample preparation shall commence, the aggregates used were oven dried for 24 hours and left to cool overnight. Sieving was later done to obtain the different sizes of the aggregates as per the mixture gradation. The crushed granites used were highly angular and irregular in size with rough surface texture, but were relatively dusty. Wash sieve analysis was performed according to ASTM C117 [14] to get rid of excess dust (filler) in the mixture. The filler used in this study, i.e. OPC was also sieved to obtain cement particle which passed British Standard (BS) sieve size 75µm. The different sizes of aggregates were later proportioned according to the mixture gradation to produce Marshall specimen.

### 3.2 Specimen Preparation

Preparation of specimen was in accordance with ASTM D6926 [10]. The Marshall specimens were prepared in a standard Marshall mould of 102mm diameter. The proportioned aggregates and bitumen were heated up to the specified temperature prior to the mixing. The mixing and compacting temperature was determined from the rotational viscosity test result which has been conducted beforehand. The tested result was presented in Table 2. As specified by the Asphalt Institute [15], the mixing and compacting temperature are those correspond to a binder viscosity value of  $0.17 \pm 0.02$  Pascal second and  $0.28 \pm 0.03$  Pascal second, respectively. For that, the mixing temperature for mixture AC10 was at  $150 \pm 5^\circ\text{C}$  while the compacting is set to be carried out at  $135 \pm 5^\circ\text{C}$ . As for mixture SMA14, the mixing and compacting temperature was  $175 \pm 5^\circ\text{C}$  and  $150 \pm 5^\circ\text{C}$  respectively. The compaction temperature of both mixtures also agreed to Bomag [2] as shown in Figure 3, which give an indication on the favoured temperature for compaction activities to be performed. During compaction, both types of the loose mixture were subjected to 75 blows of compacting effort per face. Compacted specimen was left to cool at room temperature which then followed by de-moulding of the specimen the next day.

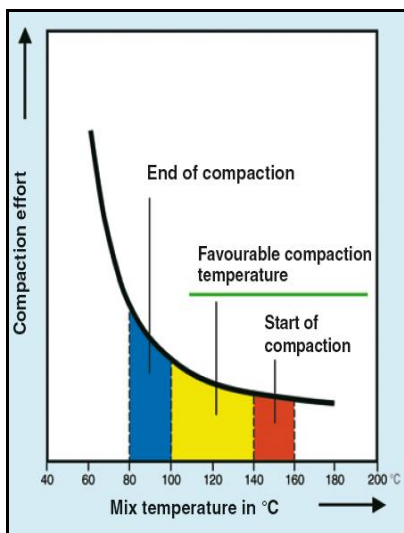


Figure 3 The relationship of compaction temperature and compaction effort [2]

### 3.3 Specimen Testing

Performance test were carried out on the specimens in the effort of determining OBC. For both mixtures, the bulk specific gravity and density of the specimens were determined using ASTM D2726 [16]. Destructive testing on Marshall stability and flow were later conducted with ASTM D6926 [10]. The test results were analysed to determine OBC of each mixture.

### 3.4 Replication of Specimen

With the determined OBC, a new set of specimens at 50mm thickness only for both mixture types were replicated. The procedure remained the same as described in the earlier section,

but the compaction was carried out at single face only at different level of compacting blows under trial and error estimation. The optimum compaction effort was later determined. Similar performance tests were also conducted once the specimens were fabricated.

## 4.0 RESULTS AND DISCUSSION

This section presents the results and discussion in this study. This includes the determination of OBC, the optimum compacting effort and the performance of stability and flow for both mixtures.

### 4.1 Optimum Bitumen Content

The OBC of a particular mixture is determined after Marshall properties and volumetric properties test of a mixture is tested and analyzed. Figure 4 illustrates the amount of dust available in each mixture gradation. As filler has effect on the properties of asphalt concrete mixture, this simple test is therefore necessary. From the aggregate gradation as shown in Figure 2, AC10 and SMA14 possessed an average of 41.0 g and 15.7 g of dust in the selected aggregate gradation respectively, without the amount of fine aggregates passing through BS sieve size  $75 \mu\text{m}$ . It is obvious that there exist a relatively big difference of average dust recorded in the two mixture types. Such difference is accounted by the mixture gradation in which mixture AC10 contained more fine aggregates proportion, especially aggregates smaller than 2 mm in size compare to SMA14. Smaller particle size results in larger surface area in contact compared to larger particle size, which further explained the greater amount of dust attached to the fine aggregates in AC10.

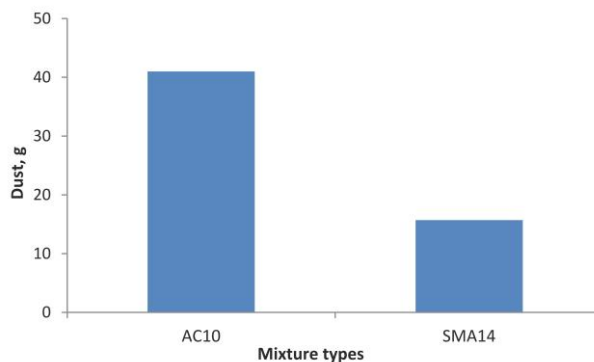


Figure 4 Comparison of amount of dust in each mixtures

The OBC determined from the preliminary test is as in Table 2. Detailed data which resulted in the recorded OBC values were also shown in Table 3. From the test results, it is clear that at OBC, the parameters at the required specifications were fulfilled, which further ensuring the quality of each types of the mixture.

Table 2 Optimum bitumen content of mixture

Mixture Type	OBC
Hot Mix Asphalt AC10	6.10%
Stone Mastic Asphalt SMA14	6.20%

**Table 3** Marshall properties of mixture AC10 at 50 mm under normal compaction

Parameter	Mixture AC10		at	Mixture SMA14	
	Specification [12]	Value OBC		Specification [12]	Value OBC
Stability, N	> 8000	13140.42	> 6200	10476.01	Pass
Flow, mm	2 – 4	2.44	2 – 4	2.63	Pass
Stiffness, N/mm	> 2000	5385.33	-	-	Pass
Voids in total Mix, %	3-5	3.35	3-5	5.0	Pass
Voids Filled with Bitumen, %	70-80	79.0	-	-	Pass
Voids in Mineral Aggregates, %	-	-	> 17	19.3	Pass
Draindown Test, %	-	-	< 0.3	0.00	Pass

**4.2 Optimum Compacting Effort**

Optimum compacting effort refers to the minimum number of compaction blows required for a single face compacted specimen to achieve sufficient degree of compaction. This prevents a particular specimen from excessive compaction which might in turn caused crushing of aggregates at the specimen face subjected to continuous compaction. Table 4 presents the degree of compaction required by mixture AC10 and SMA14 with their respective optimum compaction blows required. Detail information on the subject matter has been published elsewhere [17].

**Table 4** Optimum compaction of each mixture types

Mixture Types	Degree of Compaction	of Optimum blows
AC10	98 <sub>a</sub> %	140
SMA14	94 <sub>b</sub> %	100

a. Marshall density, b. Maximum theoretical density

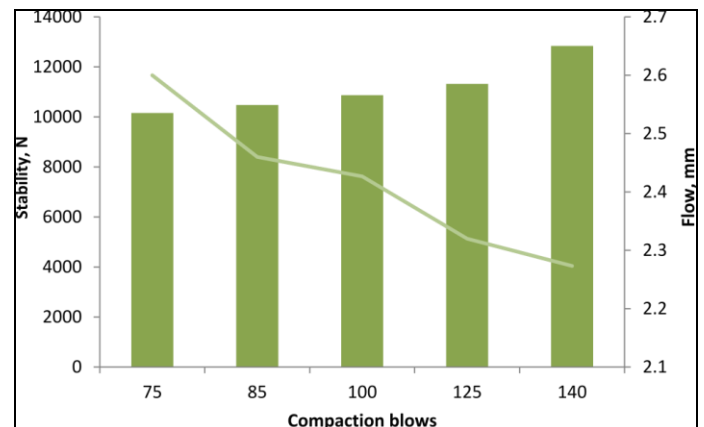
**4.3 Performance of Stability and Flow**

In order to investigate if there were any differences in mean for different compaction methods of single face and double face compaction, a statistical approach of t-test was performed for specimen compacted at optimum compacting effort. The tested hypothesis was that the difference equaled to zero, indicating that compaction at single face and double face has no significant impact on the mixture stability and flow. The test was performed at 95% confidence level and the test results were shown in Table 5. The returned p-values were generally greater than 0.05, indicating that the tested hypothesis was accepted.

**Table 5** T-test results for different compaction method

Mixture	Properties	p-value
AC10	Stability	0.601
	Flow	0.150
SMA14	Stability	0.869
	Flow	0.925

Marshall stability can be defined as the maximum load capable to be sustained by the asphalt specimen at  $60 \pm 1^\circ\text{C}$  subjected to a loading rate of 50.8 mm/min. Flow on the other hand, refers to the deformation of the sample upon loaded and is normally reported alongside with the Marshall stability test. Figure 5 and Figure 6 presented the Marshall stability and flow for mixture AC10 and SMA14. From the figure, a reverse trend of increasing stability and decreasing flow can be observed as the number of compaction blows increased. As the compacting effort increased, the impact from the compaction compressed the loose mixture, forcing the entrapped air out from the mixture under compaction. This eventually caused a reduction of total air void content in a mixture and resulted in a denser specimen. The closely packed structure of aggregates in the compacted specimen enhanced the structural integrity of a specimen with increasing compacting effort, which minimized the deformation (flow) when specimen is loaded. Consequently, this explained the phenomenon of higher stability with lower flow. A one-way ANOVA test was conducted to determine if the number of compaction blows have significant effect on the stability value of each mixtures at  $\alpha$  level of 0.05. The returned p-value was presented in Table 6. From the test, the p-value was less than 0.05 for both mixtures. This indicates that the compacting effort is significant in affecting the mixture stability.



**Figure 5** The Marshall stability and flow for mixture AC10

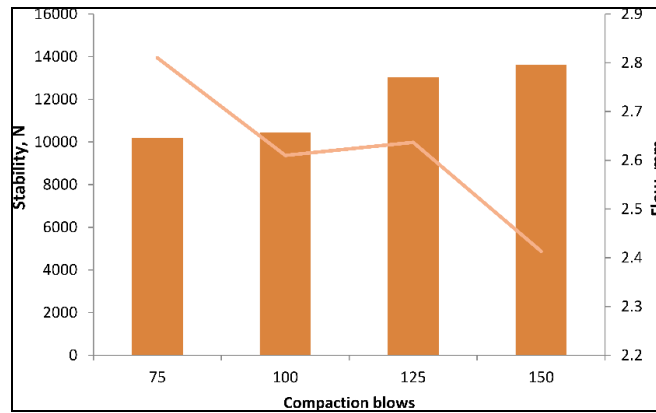


Figure 6 The Marshall stability and flow for mixture SMA14

Table 6 One-way ANOVA test results on the effect of compaction blows on stability

Mixture	Source	DF	SS	MS	F	p
AC10	Blows	4	13194878	3298719	4.49	0.025
	Error	10	7340201	734020		
	Total	14	20535079			
SMA14	Blows	3	27754932	9251644	5.30	0.026
	Error	8	13962780	1745347		
	Total	11	41717712			

Comparing the stability value of between the two mixture types, it can be noticed that AC10 possessed slightly lower stability compare to SMA14. There are several possible explanations for this. Despite the higher density in mixture AC10 compare to SMA14 due to the nature of porosity within the SMA14 specimen, it is actually that the remaining air void and the existence of larger portion of coarse aggregates in SMA14 which contributed to the stability of the mixture. Upon subjected to loading, the existence of voids provide an interlocking mechanism between the coarse aggregates present in the mix. Inter-particle friction of the aggregates which is highly angular with rough surface texture prevents the aggregate to slide across each other easily. At this stage, both adhesion provided by the binder and friction between aggregates can contribute to the stability of the mixture, but the later is to be more dominant. Concerning the types of binder, AC10 used penetration grade asphalt PEN 80/100 while SMA14 used polymer modified asphalt PG76. According to the basic properties of the bitumen tabulated in Table 1, PG76 binder have lower penetration and higher softening point and viscosity compared to PEN 80/100. Lower penetration indicates that the bitumen is stiffer and less fluid. Higher softening point and viscosity further enhanced the performance of PG76 to bind the aggregates especially at higher temperature. As Marshall stability test is carried out at temperature of  $60 \pm 1^\circ\text{C}$ , binder PEN 80/100 with softening point of  $41^\circ\text{C}$  will failed to provide the binding quality as per PG76. Cohesive nature of the binder also increased with the viscosity, in which PG76 is a much viscous binder than PEN80/100. As for the flow values of both mixtures, the higher percentage of air voids present in mixture SMA14 enable higher flow, which explained the higher value compared to mixture AC10. Finally, it is worthwhile to note that

the stability and flow for both mixtures managed to fulfill the threshold value as specified in the local specification despite being compacted at single face only.

## 5.0 CONCLUSION

Based on the laboratory test results and analyses, the following conclusions can be drawn.

- i. There is generally no significant difference for an asphalt specimen to be compacted at double face or single face only. However, it is necessary to determine optimum compacting effort to avoid over compaction of a specimen.
- ii. The stability of a mixture types increased and the flow decreased with the increasing single face compaction blows. At optimum compacting effort of single face compaction, the stability (12.8 kN for AC10 and 10.4 kN for SMA14) and flow (2.27 mm for AC10 and 2.61 mm for SMA14) value for mixture AC10 and SMA 14 managed to stay within the range as specified in local specification.

## Acknowledgment

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## References

- [1] F. L. Roberts, P. S. Kandhal, E. R. Brown, Lee D-Y and T. W. Kennedy. 2009. *Hot Mix Asphalt Materials, Mixture Design, and Construction*. 2nd ed. National Centre for Asphalt Technology: Maryland. 217.
- [2] Bomag. *Basic Principles of Asphalt Compaction*. 2nd ed. Bomag GmbH Publisher. 3–4.
- [3] Mohammad. *et al.* 2012. Optimization of Tack Coat for HMA Placement. National Cooperative Highway Research Program, Report 712.
- [4] R. C. West, J. Zhang and J. Moore. 2005. Evaluation of Bond Strength Between Pavement Layers. National Centre for Asphalt Technology, NCAT Report 05-08.
- [5] G. A. Sholar, G. C. Page, J. A. Musselman, P. B. Upshaw, and H. L. Moseley. 2003 Preliminary Investigation of a Test Method to Evaluate Bond Strength of Bituminous Tack Coats. *Journal of the Association of Asphalt Paving Technologists*. 73: 23–52.
- [6] Al-Qadi, S. H. Carpenter, Z. Leng, H. Ozer and J. S. Trepanier. 2008. Tack Coat Optimization for HMA Overlays: Laboratory Testing. Research Report FHWA-ICT-08-023.
- [7] D. H. Chen. 2010. Slippage Failure of a New Hot-Mix Asphalt Overlay. *Journal of Performance of Constructed Facilities*. 24(3): 258–264.
- [8] <http://www.pavementinteractive.org/article/de-bonding-of-hma-pavementscase-studies/>.
- [9] N. Patel. 2010. Factors Affecting the Interface Shear Strength of Pavement Layers. Master Thesis, Louisiana State University.
- [10] ASTM D6926. 2010. Standard Practice for Preparation of Bituminous Specimens Using Marshall Apparatus. American Society for Testing and Materials, United States.
- [11] B. B. Sutradhar. 2012. Evaluation of Bond Between Bituminous Pavement Layers. Master Thesis. National Institute of Technology, Rourkela.
- [12] JKR/SPJ. 2008. Standard Specification for Road Works, Section 4: Flexible Pavement. Jabatan Kerja Raya, Malaysia.
- [13] A. Zulkati, W. Diew, and D. Delai. 2012. Effects of Fillers on Properties of Asphalt Concrete Mixture. *Journal of Transportation Engineering*. 138(7): 902–910.
- [14] ASTM C117. 2004. Standard Test Method for Materials Finer Than 75- $\mu$ m (No. 200) Sieve In Mineral Aggregates by Washing. American Society for Testing and Materials, United States.
- [15] Asphalt Institute. The Asphalt Handbook, Manual Series MS-4. 7th Edition, Lexington, KY.
- [16] ASTM D2726. 2011. Standard Test Method for Bulk Specific Gravity and Density of Non-absorptive Compacted Bituminous Mixtures. American Society for Testing and Materials, United States.
- [17] Yaacob H., Hainin, M. R., and Chang F. L. 2014. Single Face Compaction on Laboratory Marshall Specimen towards Satisfactory Degree of Compaction and Thickness. *Sains Malaysiana*. 43(2).