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An overview of asphalt mix designs using various compactors

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Abstract. Generally, road network is a well-thought-out vital transportation medium that is in place throughout the world. As such, utmost care is taken in providing the best possible safe and comfortable and yet cost-effective road transportation system. One of the areas that scrutinized is the performance of asphalt mixtures in the flexible pavements. Traditionally, laboratory asphalt mixture designs are based on Marshall Method whereby the asphalt mixtures are compacted using a 4.5kg drop weight hammer. Although the volumetric properties are reasonably accepted, the actual achievement of the roller compacted volumetric properties at the site is still farfetched. This is because the laboratory mix designs developed using a Marshall Drop weight compactor and in the field, the asphalt layer is compacted using a heavy-duty roller. In recent years, the Superpave Gyrotory Compactor (SGC) have come into play with a static load and kneading approach. This objective of this paper is to look into the existing methods and processes carrying out the asphalt mix designs and review to see if there is or are any mismatch as compared with field compaction protocol.

1. Introduction

The existence of roads and highways are an undeniably a big thing that assist any country in its effort to nation building. Road engineering in general offers a bigger perspective, which is not only on the design and on construction of the roads but on the maintenance after the construction of roads and highways are completed. Typically, road transportation is a well-thought-out vital transportation medium throughout the world. Highway network is one of the major deeds in the history of the highway and transportation engineering and the last few decades' construction of highway has become an aggressive activity in most of the development countries (1).

Malaysia is not exceptional and the road authorities very stringently implement road standards and specifications. For reasons of logistic and travelling, road have become the pulse that generates the country's economic advancement. Road transportation has been a strong stake in supporting the nation's socio-economics, as it is a cheaper medium of transportation, as compared to water and air transportation. In Malaysia, based on the 'Statistik Jalan 2015' by the Road Facilities Maintenance Branch, PWD until up to year 2014, there was a total of 203,788.02 kilometers of roads which made up the whole road network of the country of which more than 80% are paved (2). However, with such a vast road network, the typical problems of rutting and cracking are still prevalent costing the road authorities to spend a lot of money on maintenance and rehabilitation.

Although several factors such as poor road materials, design and construction practises cited for the road failures, the mere fact of formulating mix designs in the lab in line with field procedures was not



explored much. For instance, Marshall compactors are widely used in compacting asphalt mixtures while rollers used at the site. The closest equipment in simulating the field compaction is the super pave gyratory compactor but that it does not even come close to the real time road compaction. As such a mismatch is seen the formulation of asphalt mixtures and compacting them at the site.

1.1. Problem statement

Compaction is the simplest, most economical method of increasing road pavement life and improving its load-carrying capacity. The mix must be compacted to desired degree by increasing the density as well to reduce the porosity. Once the density is achieved with the needed degree of compaction then the air voids will be reduced (3). However, Hot Mix Asphalt (HMA) compaction may also be affected by other subjective factors not only the method of compaction, but also the characteristics of the materials used in the materials or mix design, construction conditions, environmental conditions (4). Moreover, quality control from logistic or delivery from plant to site may contribute to result of thickness and in-situ density as a part after compaction process.

Occasionally, researchers found out that method of compaction especially in the laboratory resulted in final mix that delivered to production plant as well. Conventionally in the laboratory, asphalt mixture designs based on Marshall Method by 4.5kg drop weight hammer with certain number of blows. Although the volumetric properties are acceptable within range, the impact compaction used in Marshall Method does not simulate mixture densification as it occurs in a real pavement using a heavy-duty roller. Over the time, the use of Superior Performing Asphalt Technology or Superpave is profound in 90's is increasing around the world especially in United States (US). Another new mechanism of compaction has been introduced with machine namely as Superpave Gyratory Compactor came up with static load and kneading action.

Even though SGC presented the volumetric properties consistently as compared to Marshall Method, yet still quite a mismatch procedure compaction at in-situ. Problem encountered on rutting developed a tiny groove produced in the asphalt concrete layer may result in riding quality on the pavement surface, as well serious risk in security (5). The number of vehicles in Malaysia increased over the last few decades. The trailers have been designed according to the logistics goods to be delivered (6) with the environmental factor such as aging and deterioration of pavement faster than the design life (7). The primary mode of failure in Malaysia is mainly cracking and rutting. (8). While Asphaltic concrete ACW 20 or AC14 roads failed predominantly through top-down and fatigue cracking (9).

1.2. Objective

The primary objective of this paper is to review the current practices in the designing of asphalt mixtures and the compacting procedures used. This could assist researchers to have a better understanding of the laboratory compaction procedures and the field compaction methods.

2. Various Compaction Methods

2.1. Compaction in laboratory

The purpose of compaction in asphalt mixtures is to even out and improve the physical aspects of asphalt mixtures. The influence of compaction in asphalt mixture by the degree of compaction was a dominant quality parameter in asphalt mixtures especially when the mixture is analytically calculated with a low asphalt range to convey resistance to perpetual deformation in mixtures such as dense asphalt concrete (1). It is fine proven that technique of compaction resulted in physical properties of compacted asphalt concrete samples. Asphalt concrete mixtures in the laboratory, is desired to formulate compacted specimens that are narrowly identical to the characteristics of the real road pavement. The site parameters such as traffic loading conditions must be taken into the account in analyzing the best laboratory design that needs to be extended producing in mixing plant and laying it at site (1)(5). Each laboratory compaction method studied endeavors to separate specific engineering properties in order to support in predicting the reaction of a specific mixture to particular field

conditions. The four elementary types of compaction methods are Impact Compaction, Kneading Compaction, and Gyrotory Compaction.

2.2. Marshall impact compaction

Earlier research done on a pavement that was compacted to only 95 percent of Marshall density would on this basis deteriorate twice as fast as if it had been compacted to the minimum requirement of 98 percent (4). The key benefit of the Marshall compaction method is the focus on air voids analysis in the compacted specimens. From the compaction process, obviously Marshall Hammer, create a straight load that results in limited deformation and a fewer even distribution of mixture ingredients (10). These principals to squeeze binder film on the aggregate surfaces and a more intense fatigue fracture. Four elementary types of compaction methods are Impact Compaction, Kneading Compaction, and Gyrotory Compaction.

2.3. Kneading compaction

Hveem has come out in his mix design procedure with kneading method compaction by applying forces on one side of specimen through an irregularly triangular-shaped foot. It is comparable to the Marshall method of compaction, but the Hveem method is concentrated on voids, durability and strength. The primary test results determined that specimens produced via kneading compaction were impervious to permanent deformation, but most penetrating to aggregate characteristics (11). While specimens produced by rolling wheel exhibited less resistance to permanent deformation, and were most sensitive to asphalt characteristics. Samples prepared using the kneading compaction device as are more resistant to permanent deformation, due to expansion of a more through interparticle contact "structure" at least for densely graded aggregates mixtures especially in aggregate angularity and surface texture (5).

2.4. Gyrotory compactor

The basis for gyrotory compaction was a Texas gyrotory compactor modified to use the compaction principles of a French gyrotory compactor and found in the 1930s in Texas (12) and the enhancement was established and applied by the Army Corps of Engineers and the central lab of *Laboratoire central des ponts et chaussées* (LCPC) for bridges and roads in France. Later, Strategic Highway Research Program (SHRP) generating Superpave gyrotory compactor. An underlying premise of the gyrotory protocol selection is to gain the material characteristics from testing validation rather than the effects from the compactor itself.

2.5. Roller compactor

Laboratory half roller compactors compact asphalt slabs to the target mixture densities to simulate those of full-scale compaction equipment. Some of the common name is French roller compactor established by the LCPC (1). Major involvement with laboratory asphalt compaction since the 1950s, not only rolling wheel compaction, but also gyrotory compaction, volumetric design, and failure mechanisms (13). Although the old rolling wheel compactor was a promising method of compaction, the entire set up was very bulky with some good property precision that most approximately simulate those of materials in the highway (14-17). Slabs can be prepared up to desired densities using loads that are comparable to those of site compaction machineries.

2.6. Compaction in roadworks

Compaction is needed to reduce air voids in the HMA mixture through the applied pressure or external forces. The discharge of air permits the mix to reduce volume, thereby increasing the density of the mass. Self-driven compactors deliver the external forces that convey into compaction energy (15). Usually a compaction train entails of more rollers with notable reason to achieve the required density to meet the specifications, as well to provide a smooth surface for riding quality.

2.6.1. Static compaction. Static compaction achieved from the deadweight of the roller. Tandem rollers and pneumatic tired rollers are used for this purpose. The effect of compaction somewhat low as compared to vibratory compaction influence. With tandem rollers, compaction is subjective by the static linear load (kg/cm) of the drum, with pneumatic tired rollers by the wheel load (t) and the tire inflation pressure (MPa) (3). The linear load can be achieved in range of 10-30 kg/cm. The low initial compaction will affected the function of static compaction. Whereby, the kneading and flexing effect from the wheels pneumatic tired rollers achieve a special quality in static compaction. Knowing that, the homogeneous distribution of the mix and closes the pores on the surface can be achieved.

2.7. Rolling wheel compactor

Previously, there were significant findings on the rolling wheel compactor that is practical for the production of asphalt concrete test specimens in a research laboratory with a large number of specimens of various geometries, which been produced on a daily basis. On top of that, the slab dimensions are easily varied and the equipment procedure can easily accommodate the compaction of pavement layers such as overlays (19). The major shortcomings of the rolling wheel compaction method required a big working area as well large amount of materials to be utilized. Typically, for beam fatigue purpose this the slab is compacted using rolling wheel compactor as well as vibratory compactor (20).

2.8. Vibratory compactor

The Vibratory Compactor was designed to simulate the action of vibratory rollers. The vibratory action obtained by compressed air causing a piston to vibrate vertically resulting in the acceleration of the compactor head. The most common method of compacting beam specimens is by the Asphalt Vibratory Compactor (25)(26). Prior to research conducted the conclusions been made that the most common field practice for compacting granular soil was to use a smooth-drum vibratory compactor. On the enhancement part, the additional of additive such as Sasobit® and Evotherm® (22).

2.9. French plate compactor

The French Plate Compactor compacts asphalt mixtures using either one or two smooth, reciprocating, pneumatic rubber tire (23-24). A costly compactor that leading to discontinued of the production of this machine worldwide.

3. Mix design

Generally, there are three types of mix design methods, which are commonly being used. All these three methods are common in the objective of developing an economical combination of aggregates and asphalt. These methods are Hveem, Marshall, and Superpave mix design. The Marshall method is very popular because of its relative simplicity, economical equipment and proven record. The Marshall method seeks to select the asphalt content at a desired density that satisfies minimum stability and range of flow values. The Superpave mix design method was designed to replace the Hveem and Marshall methods. The volumetric analysis common to the Hveem and Marshall methods. The Superpave system ties asphalt binder and aggregate selection into the mix design process and consider traffic and climate as well.

3.1. Gradation

Gradation is the particle size distribution in an aggregate mixture and is determined in terms of the percentage passing or retained on each of the sieves. Gradations are specified to ensure acceptable pavement performance (17).

For the purpose of this research, Hot Mix Asphalt been used and ACW14 mix design was selected as part of the work. The basis of ACW14 was taken from JKR Specification on Flexible Pavement (18). Five mix designs were formulated using five different gradations within the aggregate gradation envelop. Table 1 shows experimental matrix set up.

Table 1. Five selected gradations for ACW14

Sieve Size (mm)	LOWER LIMIT AC 14	UPPER LIMIT AC 14	% PASSING					
			(Median)	(Upper)	(Lower)	(Crossing 1)	(Crossing 2)	
			G1	G2	G3	G4	G5	
20	100	100	100	100	100	100	100	100
14	90	100	95	100	90	100	91	91
10	76	86	81	86	76	84	78	78
5	50	62	56	62	50	57.5	57	57
3.35	40	54	47	54	40	48	46	46
1.18	18	34	26	34	18	30	21	21
0.425	12	24	18	24	12	23	13	13
0.15	6	14	10	14	6	13.5	7.0	7.0
0.075	4	8	6	8	4	8	4	4
Pan	0	0	0	0	0	0	0	0

3.2. Superpave mixture design

Typically, for Superpave Mix design the determination is differ from the Marshall Method. Superpave mix design procedures depend on the traffic level of the pavement for which the HMA being designed. The compaction effort is determined from N_{initial} , N_{design} and N_{max} which respectively giving of 89%, 96% and 98% of Theoretical Maximum Density (TMD) value. The design is working parallel with number of gyrations for specified traffic levels and air temperature. With the same number of gyrations, the higher asphalt content the higher percentage of maximum density. Superpave is a height control concept based on the design required.

The compaction effort obviously determined from the design 7-day maximum air temperature as in Table 2. As stated in Arahan Teknik Jalan 5/85 the temperature is 38°C. Yet following the statistical from Cleveland, Ohio taking the standard deviation at 2°C for normal frequency distribution mean 7 day will exceeds 42°C. The selected air temperature will give 41-43 degree is taken at the designated ESALs at $< 3 \times 10^7$ as shown in Table 2. The pattern on the asphalt content range normally plotted as Figure 1.

Table 2. Selection number of gyrations for SGC

Traffic (ESALs)	Design 7-day Maximum Air Temperature (°C)											
	< 39			39 - 41			41 - 43			43 - 45		
	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}
$< 3 \times 10^5$	7	68	104	7	74	114	7	78	121	7	82	127
$< 1 \times 10^6$	7	76	117	7	83	129	7	88	138	8	93	146
$< 3 \times 10^6$	7	86	134	8	95	150	8	100	158	8	105	167
$< 1 \times 10^7$	8	96	152	8	106	169	8	113	181	9	119	192
$< 3 \times 10^7$	8	109	174	9	121	195	9	128	208	9	135	220
$< 1 \times 10^8$	9	126	204	9	139	228	9	146	240	10	153	253
$> 1 \times 10^8$	9	143	235	10	158	262	10	165	275	10	172	288

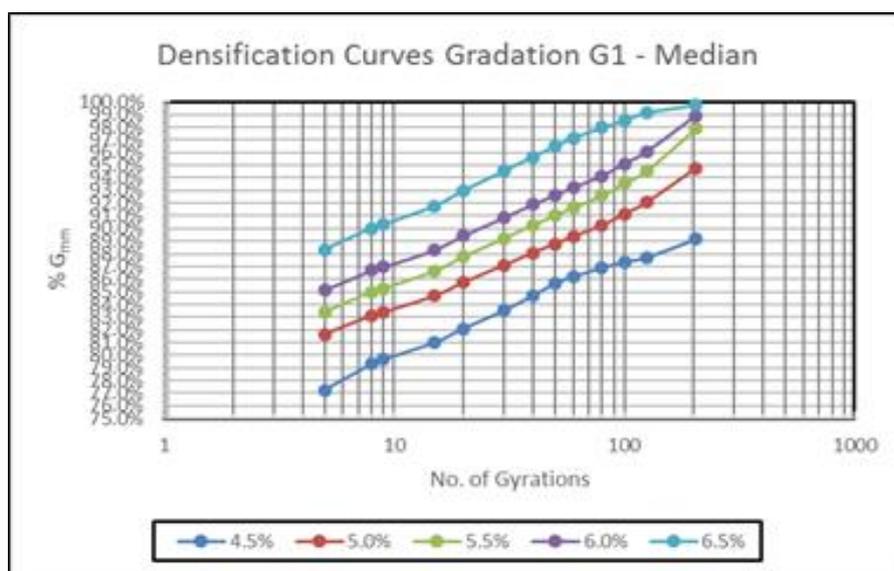


Figure 1. Typical pattern of SGC Optimum Asphalt Content

After the determination of Optimum Asphalt Content (OAC) at 96% of TMD, Superpave requirement was verified that the compaction and volumetric properties are satisfactory based on the 4% air voids, Voids in Mineral Aggregates (VMA) and as well Voids Filled with Asphalt (VFA) based on Table 3.

Table 3. Superpave Compaction Effort

Design ESALs (million)	Required Density			Voids in the Mineral Aggregate (%) Minimum					Voids Filled with Asphalt (%)	Dust to binder Ratio
	(% Theoretical Maximum Specific Gravity)			Nominal Maximum Aggregate Size(mm)						
	N _{ini}	N _{des}	N _{max}	37.5	25.0	19.0	12.5	9.5		
< 0.3	≤91.5								70-80	
0.3 to < 3	≤90.5								65-78	0.6-1.2
3 to < 10		96	≤98	11.0	12.0	13.0	14.0	15.0	65-75	
10 to < 30	≤89.0									
≥ 30										

4. Overview on asphalt mix designs based on various compactors

A laboratory mix design supports in predicting the in-service performance of the asphalt mixtures through various performance evaluation tests. The compaction in the laboratory for specimen fabrication expected to simulate the properties of the pavement in the field. It is desirable that the laboratory compaction of specimens should be a true indicator of field performance in regards to particle orientation, air void content, permeability and mechanical properties (23).

A second method that is often used to specify compaction requires that the contractor compact the asphalt mixture to some minimum percentage of the theoretical maximum density (TMD). This is a direct method of specifying maximum in-place air voids and an indirect method for controlling compaction. This method involves taking a sample of the asphalt mixture during construction and conducting tests to measure TMD (ASTM D2041). The bulk density of the asphalt mixture is measured after the compaction and compared to TMD value. This comparison provides a direct measurement of in-place voids. For instance, a mixture compacted to 93 percent of TMD will have 7 percent air voids.

Regardless of material and time saving, the stability and flow from the Marshall applications being the prime variables in the performance of an asphalt sample as well for gradation and degree of compaction in whichever types of compactors. The OAC is traditionally estimated using Asphalt Institute Method or equivalent such as UPM's in-house method of averaging out the maximum binder contents based on Marshall Stability, Bulk Density and 4% VTM and the additional parameter of Resilient Modulus value.

It is observed that new mix designs should consider actual approaches in practice such as the roller compaction for mix designs. The current JKR (PWD) perspective only conforms and comply to using Marshall Compactor and Superpave Gyratory Compactors. New approaches in laboratory mix designs using roller compactor technology should be deliberated. It will become highly practical for the flexible road pavement construction.

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