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The Development of Workability Measurement for Asphalt Mixture Using Transducer by Torque

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Abstract: Continuous increase in the volume of traffic in recent times has resulted in demands for research advancement relating to the properties of material, in a way of measuring the workability value of Hot Mix Asphalt (HMA). While the literature presents a trend in the laboratory asphaltic mixer research, this research seeks to use a transducer and heat regulator to evaluate mixing temperature as a measure for the value of mixture workability at different temperatures. This paper shows that a transducer could measure the workability value through the value of torque. In addition, the study has enabled the selection of a suitable paddle that has offered a wide range of torque values at a specified speed for all mixes investigated.

***Key words**: Hot mix asphalt; Torque; Transducer; Workability.*

Introduction

The increasing nature of Traffic volumes, tyre pressure, and loading in recent times has placed more pressure on engineered roads. A well-designed and constructed road will not only support regional and national development of a country, but also assist in sustaining the infrastructure for the lifespan it is designed for. In order to achieve this, an adequate mix design is essential. The pavement industry has been stressing the need to achieve reliability in measuring the value of workability in a rational and convenient manner. While the property development of late, has resulted in the need for improvement in the research relating to the workability of Hot Mix. Literature has shown that little efforts have been directed at the influence of the mixing temperature on measuring the workability value of (HMA) [1, 2]. In relation to previous researches which have placed focus on measuring the workability of HMA, a number of scholars have evaluated the workability of asphalt concrete by torque or a number of indicators obtained from the gyration compactor and porosity. While some scholars measure workability by torque [3-5], others evaluate workability by some indicators from the gyration compactor and porosity [1, 6-9]. Measuring workability by a number of indicators from the gyration compactor and porosity to produce the desirable pavement could be achieved by developing asphalt concrete mixer which uses electric transducer, at the same time measures the workability value by means of torque within a period of time. Since the research can be underpinned by the theory of mixing, it is considered as the theoretical basis for the proposed device. The reason is that this research aims at developing a prototype mixer for measuring asphalt concrete workability.

Research Objective

The research objective is to develop a workability measuring device for evaluating mixing temperatures and the workability value of Hot Mix Asphalt (HMA) using a transducer and heat regulator.

The Scope of Research

The initial stage is to develop the machine components, followed by the verification of the machine to ensure that it is accurate, efficient, valid and reliable to use. To add, this research also involves selecting one out of the three types of paddles which provides the best wide range of torques throughout the seven different mix designs. The mixtures were further mixed with bitumen 60/70 & 80/100 penetration grades because these are the ones commonly used in Malaysia. The developed mixer was used to blend the mixtures at six different temperatures of 120℃, 130℃, 140℃, 150℃, 160℃, and 170℃. With regards to workability assessment using the gyratory compactor, Gudimettla et al. [4] note that gyratory compactors are not sensitive to viscosity. Additionally, bitumen viscosity is beyond the scope of this paper. Hence this paper does not focus on comparing workability assessment done by gyratory compactors.

Workability Devices

The Need for Improved Workability Device

The HMA industry is constantly exploring technological improvements that will enhance the material's performance, increase construction efficiency, conserve resources, and advance environmental stewardship. It is plausible that one approach to achieve these goals would involve the development of improved prototype machines, as well as initiating innovative methods and materials. Previous researches have highlighted the need for improvement on the device to measure workability [5, 7, 10]. One of the empirical studies that support the necessity of this present research is Marvillet & Bougault [3], in which the authors have contributed to the development of device for measuring and comparing the workability and compactibility of various asphalt mixes. Additionally, Gudimettla et al. [4] contribute to the

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development of device to measure workability of asphalt mix, other than evaluate a device to measure the workability of mix asphalt mix, due to changes in asphalt concrete's characteristics.

Marvillet and Bougault were the first to develop a workability meter in which the five interchangeable springs were used to determine the torque. The electrical signal was converted to numerical values and subsequently expressed in the unit of torque. Using a similar device, Gudimettla et al. [5] evaluated a prototype device used to identify the influence of change in mix characteristics on the workability of HMA. Their study suggests that the workability of HMA is affected by the aggregate type, nominal maximum aggregate size, binder type, and temperature. However, their findings show that the gradation shape does not have any significant impact on the workability of the HMA. The authors have converted the amperage to torque. Recently, Mogawa [11] have presented a workability measurement device which does not have a temperature control system for maintaining temperature during mixing (it could be used to measure the temperature but not to maintain it). Following Marvillet and Bougault [3]; Gudimettla et al. [4] and Gudimettla et al. [5], the paddle of the present machine rotates while the bowl is fixed. On the contrary, the bowl in Mogawe's [11] machine rotates while the paddle fixed. The area for future research suggested by most authors is a clear testimony of the need for further research, in terms of workability device that can be used to measure workability on road construction sites, the relationship between workability and compaction, and the effect of temperature on workability. Gudimmetla et al. [5] call for a refinement of the prototype as it relates to the designs of paddle and bowl. As the European Asphalt Pavement Association [12] notes, it is often difficult to establish the conformity between registered process input parameters and laboratory tested output. It is therefore important to measure the workability of the mix design to verify this claim. Another improvement in the device is to include an additional temperature sensor to provide a better measure of temperature during the mix process. The authors call for the development of the device that would yield better results and which would be user-friendly. Their work indicates that workability is an important element in obtaining the desired HMA's smoothness and density within a compacted pavement, along with the fact that temperature, as well as the constituents in the mix influence the workability of Asphalt mix and that the compactibility of HMA is related to workability. Literature has shown that the workability test is currently conductible in the laboratory; hence the need to develop a suitable device for conducting workability tests on site and to investigate the relationship between workability and compactibility of HMA on site.

The purpose of numerous researches conducted on the asphalt mix is to achieve the production of improved mix design of road pavement structure with increased bearing capacity [13] alongside the changing climatic conditions experienced in many parts of the world. Research into asphalt mix is crucial because every now and then new roads are being built and the old ones are being reconstructed, leading to the increasing demands for bituminous mix and the requirements for its quality. Bearing this in mind, this research is in serious attempt to present the production of an improved mixer for the measurement of workability via torque, using a Rotary torque transducer. According to Datum Electronics company [14], torque transducer is suitable for general applications. In addition, it is compatible with common drive traits or test beds. Its transmission system provides a digital output directly proportional to torque. More importantly, it has a high acuracy of 0.1 percent.

Developing Workability Device

While the major objective of this paper is to present a newly developed workability measurement device, this research also focuses on selecting the best rate of revolution of paddles and types of configurations. It is interesting to note that the transducer in the present device transmits digital data, providing the end-users with clean and definite data transmission. The temperature control system on the present device does not only allow for the temperature of asphalt mix to be measured, but it also enables the mixing temperature to be maintained.

Research Materials

This research study used locally available granite aggregates provided by the Kajang Rock Quarry in the state of Selangor, Malaysia. Three gradations of granite aggregate are selected based on Malaysian Public Works Department (PWD) [15] and Malaysian Specification AC14, namely the highest point, midpoint and lowest point of percentage by passing, used to produce hot asphalt concrete with specific gravity of 2.606, 2.607 and 2.608 gm/cm^3 respectively. There are several reasons for the closeness of the values for specific gravity. First of all, the total percentage of combined aggregates (coarse and fine) is 100%. Secondly, the proportion of coarse and fine aggregated between upper, center and lower limit is the same, which is shown in Table 1.

The combined aggregates include coarse aggregates, fine aggregates and mineral filler according to the PWD requirements. This study complies with sectionn4.3.3.2 (b) of PWD Malaysia, [15] standard specification for road works on flexible pavement and a mineral filler used for the purpose of asphalt pavement. For the fact that that hydrated lime has been used extensively as mineral filler in HMA mixtures for many years in Malaysia because of its property of maintaining a good adhesion between the aggregate and the asphalt cement. Portland cement was used as a filler to test its effectiveness in this study.

All samples produced are the combination of the aggregates proportioned with bitumen of 60/70 and 80/100 penetrations, having specific gravity of 1.02 and 1.03 gm/cm^3 respectively. It should also be added that the Reclaimed Asphalt Pavement (RAP) material was obtained from Public Works Institute Malaysia (Institut Kerja Raya Malaysia: IKRAM) along the Kajang road in Kuala Lumpur, of which 100% of the materials was used for the research. The basic properties of the aggregates and bitumen are within specification in

Table 1. Proportion of Coarse and Fine Aggregate.

Aggregate Combination	Highest Point %	Midpoint %	Lowest Point %
Coarse	46	53	60
Fine	53	47	40

Table 2. Basic Properties of Aggregate.

Property	Test Result	PWD Requirements	Designation
Aggregate Abrasion Value AIV %	22.6	< 25 %	ASTM : C 131-96
Aggregate Impact Value, AIV %	21.64	< 25 %	BS 812: PART 112:1990
Aggregate Crushing Value, ACV %	22.5	< 25 %	BS 812: PART 110
Water Absorption %	0.65	< 2 %	(BS 812 : PART107:1995)
Specific Gravity each Grading gm / cm³	2.606 2.607 2.608		(BS 812 : PART 107:1995)
Flakiness Index %	13	< 25 %	(BS 812 : PART 105: 1990)
Polish Stone Value , PSV	48	> 40 %	(BS 812 : PART 114: 1989)

Source: BS [16], ASTM [17]

Table 3. Basic Properties of Bitumen, RAP and Viscosity.

Type of test	Test Result 80/100	Test Result 60/70	RAP 100%	Designation
Penetration at 25℃, 100g	91	68	21.5	ASTM D 5
Softening point (℃)	47.5	53	-	ASTM D 36
Ductility at 25℃ (cm)	100	100	-	ASTM D 113
Viscosity at 135 ℃ (cP)	425	537	2875	ASTM D 4402-02

accordance with PWD requirements, as shown in Tables 2 and 3.

Experiment

The initial asphalt mixtures were prepared in accordance with ASTM D 1559 using 75 blows/face compaction standard which is also consistent with the Malaysian standard. The preparation was performed, according to the following procedure. Seven types of mix were designed using the AC14 gradation of three different aggregate fractions. The first three mix designs were the typical dense-graded asphalt concrete using bitumen of 80/100 penetration, The other three mix were similarly graded, using bitumen of 60/70 penetration and the last mix was RAP. The mixtures were identified as mixtures 1 to 7 as shown in Table 3. In this research, 60-70 and 80-100 penetration grades had been used because these are specifically provided in section 4.11 of the Malaysian standard. In addition, RAP was used to ensure that the device could be used in testing hard asphalt concrete. The selected new aggregate proportions and RAP aggregate fraction which were investigated and their specification limits are presented in Table 4.

The asphalt demand of the combined aggregates for mix number 7 (RAP) was determined using a formula [18]. The samples were labelled as mix 1 to mix 7. In stage one, Paddle A was fixed to the device and the motor set at 5 RPM, then the paddle was immersed into mix 1 at 120 ℃, and the torque was recorded during the paddle revolution at the same temperature, where the RPM was adjusted to 10 then 15, 20, 25 RPM and the torque recorded to each speed using the same paddle A, with the temperature increased to 130 ℃ using the heater attached to the device at RPM 5. The same procedure was repeated at 10, 15, 20 and 25 RPM. Another round of procedures was repeated for temperatures 140 ℃, 150 ℃, 160 ℃ and 170 ℃ respectively for mix 1.

The entire procedures were repeated using paddle B and C on mix 1 to complete the tests in stage one. These processes consist of seven stages, and each stage yielded 18 samples, totaling 126 samples and the total weight of each sample was 3600 grams. The data recorded for each sample lasted 60 seconds.

This procedure aims at obtaining the best paddle and rates of revolution suitable for mixing the materials. In addition, the

Table 4. Job Formula for Blended Mix.

Mix Designation B.S Test Sieve	Power ^ 0.45	Wearing Course AC 14 80/100 Penetration Mix1 Pass	Mix2 Pass	Mix3 Pass	60/70 Penetration Mix4 Pass	Mix5 Pass	Mix6 Pass	Specification Passing Limits PWD	RAP Passing Mix7	Specification Limits PWD (Type 1)
20.0 mm	3.85	100	100	100	100	100	100	100	100	100
14.0 mm	3.28	100	95	90	100	95	90	90 – 100	95	80 – 95
10.0 mm	2.82	86	81	76	86	81	76	76 – 86	86	68 – 90
5.0 mm	2.06	62	56	50	62	56	50	50 – 62	67	52 – 72
3.35 mm	1.72	54	47	40	54	47	40	40 – 54	56	45 – 62
1.18 mm	1.08	34	26	18	34	26	18	18 - 34	33	30 – 45
425 µm	0.68	24	18	12	24	18	12	12 – 24	20	17 – 30
150 µm	0.43	14	10	6	14	10	6	6 - 14	11	7- 16
75 µm	0.31	8	6	4	8	6	4	4 – 8	6	4 – 10
Filler OPC %		2	2	2	2	2	2	2	-	-
Bitumen Content %		4.92	4.71	4.62	5.08	4.82	4.74	4 - 6	5.6	5 – 7

Table 5. Calibration Parameter for Workability Device.

Torque Shaft Calibration Calculator			
Parameter	Symbol	Value	Units
Shaft OD	D	0.2	m
Shaft ID	d	0	m
Young's Modulus	E	2.07E+11	pa
Poisson's Ratio	σ	0.285	
Gauge Factor		2.08	
Max Torque	T	100000	Nm
T*16000*GF*(1+σ)*D		8.55E+08	
T*16000*GF*(1+σ)*d		0.00E+00	
((D^4)-(d^4))*π*E		1.04E+09	
Calibration Value		0.822	mV/V

$$\mathrm{mV/V} = \frac{Torque(Nm) * 16000 * Gauge\_Factor * \ (1+\sigma)}{\left(\frac{\mathrm{D}^4 - \mathrm{d}^4}{\mathrm{D}}\right) * \ \pi * \text{Young's \_Modulus(pa)}}$$

procedure was able to ascertain that the transducer was working accurately.

To ensure the accuracy of the research, we calibrated the workability device using the parameter provided by Datum Electronics as shown in Table 5 and the calibration formula is provided below.

Consideration for Selecting the Machine Components

Table 6 presents the summary of literature and sources used in the selection of the Components for the workability device.

Fig. 1 presents the workability device connected to a laptop installed with a software. Fig. 2 presents paddle A, B and C used to conduct the research. Fig. 3 presents the range of torque to each mix, derived from the relationships between the rates of revolution and specific speed. The revolution for each type of paddle is on the horizontal axis and the torque is on the vertical axis (KNm unit). From visual observations of all the mix, the wide range of torque can be clearly determined, where the wide range as shown in mix 1 was at speed 5 and 15 RPM, mix 2 displayed the wide range for paddle B at 15 RPM, while in mix 3, paddle B was at 10 RPM and paddle A at 25 RPM. Similarly, for mixes 4 to 7, paddle B was at the speed of 20 RPM, paddle B at the speed of 15 RPM, paddle B at 20 RPM and paddle A at 25 RPM, respectively. The following explains how the values of torque yielded by paddle A, B and C were obtained. In Mix 1 at the temperature of 120^{o}C and RPM5, paddle A=5.80, B=19.71 and C=3.89. At the same temperature but RPM10, A=5.98, B=19.47 and C=3.92. At RPM15, A=6.04, B=20.37 and

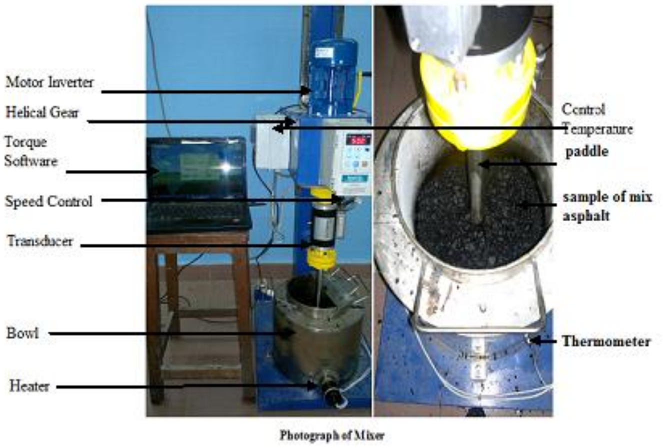

Fig. 1. Photograph of Workability Device Connected to Computer Installed with Software.

Fig. 2. Photograph of Three Types of Paddle Used in Research.

C=3.65. At RPM 20, A=6.47, B=22.22 and C=3.42. Finally, at RPM25, A=6.6, B=20.65 and C=4.09. Other values of torque for the remaining six mixtures at various temperature and RMP 5-25 were obtained.

Fig. 3 also shows the graphs for mixes 1 -7, and outputs of the data in Table 6 produced using the Excel software. It was found that paddle B produced the highest value for range 1 to 7 at RPM 5, 10, 15, 20 & 25. The second highest values were produced by paddle A and the least values had been produced by paddle C. For this reason, paddle B was selected for use as a component of the workability device.

Conclusions

In this paper, we present the workability measuring device for evaluating mixing temperatures and the workability value of Hot Mix Asphalt (HMA) using a transducer and heat regulator. We also present the procedure for the selection of the paddle, from three types of paddle for use as a component of workability machine. The workability measurement is based on a transducer attached to the

Table 6. Bases for Selecting the Components of Workability Device.

S/N	Components	Reference	Remarks
1	Paddle	Gudimettla et al. [5]; Mogawa [11]; FHWA [19]	Three different types
2	Motor	Marvillet & Bougault [3]; Gudimettla et al. [5]	Rotational speed of 22 RPM , 15 RPM
2	Transducer	Datum Electronic Company [14]	Company Recommendation
3	Bowl	AST Standards [17]; AASHTO [20]; Kett [21]	Based on quantity of sample (5 liter)
4	Heater	AASHTO [20]; Kett [21]; Sanchez-Leal [22]; Cominsky et al. [23]	Suitable for HMA
5	Thermometer	AST Standards [17]; AASHTO [20]; Kett [21]	10 ℃ to 232 ℃

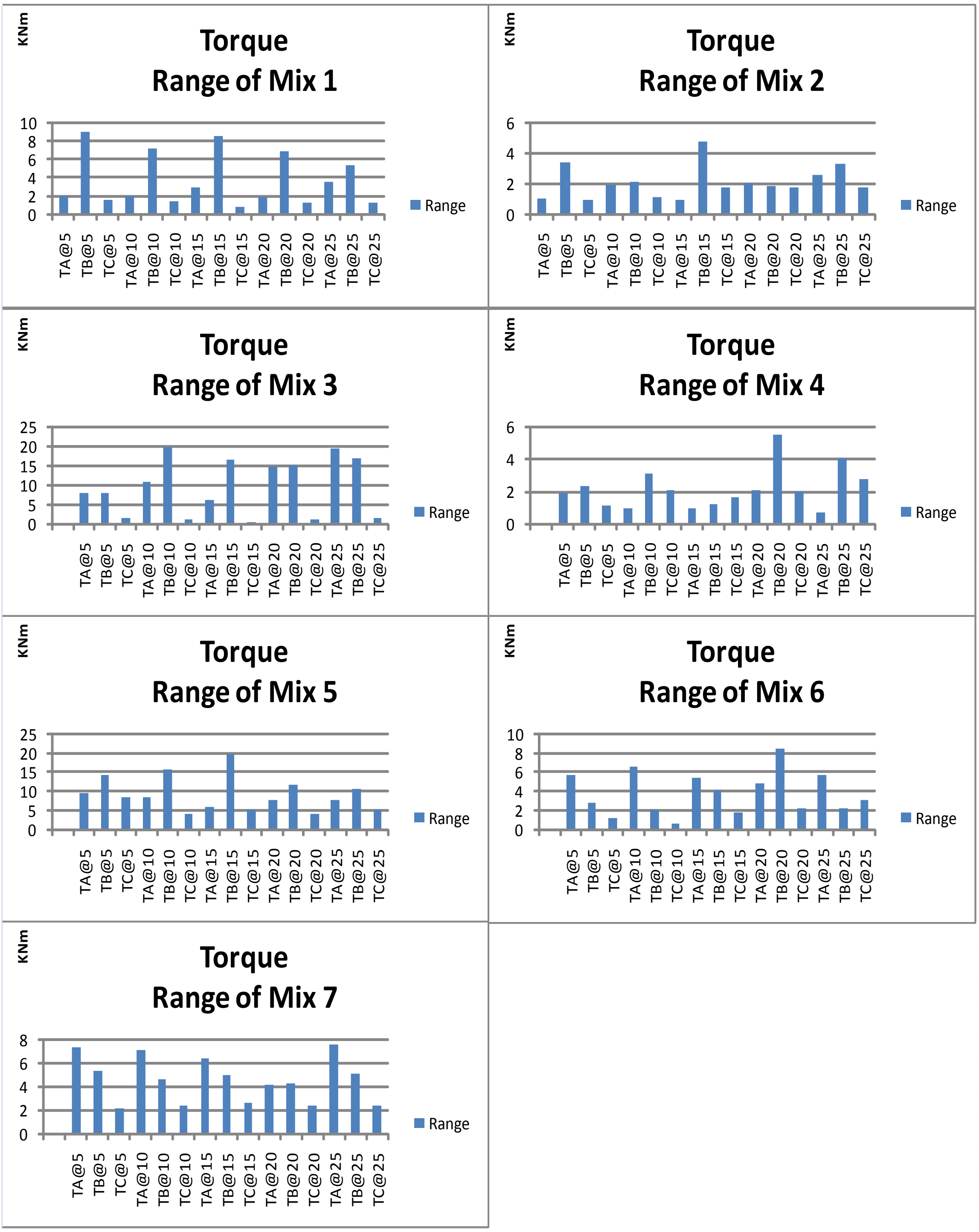

Fig. 3. Range of Torque to each Mix.

machine and from this, several conclusions have been made. The developed laboratory workability mixer by utilizing the transducer has proven to be effective and has provided accuracy in the measurement of the value of workability (torque value) in a direct manner, without having to proceed with any conversion to collect the workability values from all asphalt concretes tested in this study.

With regards to the selection of paddle which offers a wide range of torque, it is obviously clear from the results that paddle B at speed 10 RPM is suitable for all mixes examined in this study. It is interesting to note that the quality of the developed mixer to measure the workability is seen in the joint-utilization of a transducer as a tool to predict the workability value in a reliable manner. Being equipped with a heater and temperature regulator, it is portable to be carried to the site, making it more mobile and easy to handle. Underpinned by the theory of mixing, the developed mixer reduces the time spent in measuring torque using a transducer.

A well-designed and developed mixer could determine the values of torque for the AC14 gradation which was used in this study. This can be achieved because the value of torque is influenced by any change of the mixture components. The efficiency of a paddle applied in today's 3D laboratory mixers such as Infratest or Freundle as compared with the output of a mixing plant is subject to considerable further research.

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