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Effect of rainfall on the compaction of dense-graded hot mix asphalt

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Abstract. Unpredictable tropical weather particularly rainfall can possibly interfere the compaction work of asphalt pavement. Heavy rainfall often leads the asphalt to cool and harden quickly and become difficult to compact. This study evaluates the effect of rainfall on the compaction properties of hot mix asphalt (HMA). A dense-graded mix of AC14 was prepared using 60/70 PEN bitumen and compacted at different temperatures. A handy steel roller was used to compact the slab samples with the size of 305 mm × 305 mm × 50 mm. The cooling rate and time available for compaction (TAC) were monitored using thermocouple under different levels of artificial rainfall and wind speed generated in the laboratory to simulate the wet conditions. The slabs were then cored at 100 mm diameter and tested for the volumetric properties. The result shows that environmental conditions and mix temperature determines the cooling rate and final density of the asphalt pavement. In addition, the TAC decreases as the compaction temperature reduces. Alternatively, working under light and moderate rainfall during the asphalt paving operation reasonably achieves the required degree of compaction (DOC). However, paving works under heavy rainfall reduce TAC, compactibility and density of the asphalt mat.

1. Introduction

Compaction of hot mix asphalt (HMA) is the most crucial work of producing high quality and longevity of asphalt pavement. It is carried out to ensure the asphalt achieves the required density, low air void, design thickness and stability. Based on the Specification for Road Works by Malaysian Public Works Department (PWD) [1], the compaction should be done immediately when HMA is placed. Furthermore, the temperature proposed at the commencement of rolling should be not less than 130°C and the compaction should be stopped when the mixture temperature reaches 90°C particularly for asphalt made of 60/70 PEN bitumen. There are several factors that can affect the compaction temperature such as environment, materials used and construction method [2-4]. Even though asphalt compaction should be performed in dry and hot condition, but sometimes the unforeseen rainfall events and strong wind may occur and delay the paving operations. Malaysia with tropical climate receives an average annual rainfall of 2700 mm [5]. As reported by the Malaysian Meteorological Department, current intensity of rainfall in Malaysia can be categorized into light, moderate and heavy rain, which is considered to significantly affect the cooling rate of the HMA particularly during the monsoon season. Extreme monthly rainfall intensity obtained from reliable data provided by Meteorological department exhibited increasing trends, where the annual maximum precipitation per month is approximately about 269.2 mm to 335.8 mm from October to December [5]. Such excessive rainfall could possibly disrupt and delay the construction of HMA, by means of temporarily ended the ongoing compaction works [6-7]. Previously, a number of studies have been conducted on the compaction of asphalt mixtures under wet conditions [6,8-9]. Excessive amount of rainfall has been identified to shorten the time available for compaction (TAC) depending on intensity and length of exposure [8]. TAC can be defined as a period taken by the HMA to cool and stiffen to the point where it can absorb the applied compaction energy without stripping the aggregate [10]. Others highlighted on the effect of various compaction temperatures by applying different compaction methods for different types of mixture [2, 10-13]. These variations can give a significant impact on asphalt materials which in turn can drastically affect the pavement performance. However, the current climate change is altering the rainfall patterns globally which could directly or indirectly affect the compaction activities undertaken in road works [14]. The establishment of various methods, constants and variables by previous researchers in simulating the wet conditions could provide variability in the data presented as well as the findings. Though, understanding the factors affecting compaction is an important step in achieving this goal. Hence, there is a need to provide better understanding on the asphalt compaction in relation to initial compaction temperature and rainfall in accordance to the current precipitation pattern. Additionally, this could help to assist better decision rather than the replacement of asphalt paved during unforeseen rain events. Therefore, this study focuses on the impact of rainfall on the compaction properties of dense graded HMA including degree of compaction (DOC), cooling curve and TAC.

2. Laboratory works

2.1. Marshall mix design

Marshall mix design was conducted to determine the optimum bitumen content (OBC) for dense-graded AC14. Bitumen grade of 60/70 PEN, granite aggregate and 2% hydrated lime were selected for the Marshall sample preparation according to the Malaysian Public Works Department (PWD); Standard Specification for Road Works [1]. The aggregate and bitumen were mixed at the temperature of 165°C. The loose sample was then determined for theoretical maximum density (TMD) and compacted samples were tested for volumetric properties and Marshall stability. Based on the data obtained, the OBC was selected at 4.9%. Table 1 shows the Marshall parameters verified for AC14 according to the PWD specification.

Table 1. Marshall parameter of AC14 mixture [1].

Parameter	Specification (PWD, 2008)	Results	Conformity
Stability, S	> 8000 N	14945 N	Pass
Flow, F	2.0 - 4.0 mm	3.55 mm	Pass
Stiffness, S/F	> 2000 N/mm	4213 N/mm	Pass
Voids in total mix (VTM)	3.0 - 5.0 %	3.9 %	Pass
Voids filled with bitumen (VFB)	70 - 80 %	74.2 %	Pass

2.2. Determination of artificial rainfall and wind speed

In general, the laboratory scale of artificial rainfall simulation has never been well established to reproduce desirable rainfall intensities with reasonably high uniformity distribution. In this study, a set of procedure was established for conducting the rainfall simulation in the laboratory. The procedure includes the reproduction of various artificial rain intensities and wind speed and verified based on the data obtained from Malaysian Meteorological Department [15,16]. The rainfall intensities can be categorized into three different criteria which are light, moderate and heavy rain which depends on the total volume of rainfall measured in one hour as summarized in Table 2. After numerous trials made on the different methods and tools including different shower heads and spray bottle, the use of direct hand

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spray gives the most realistic and comparable result to the meteorological data. With a proper design height and distance towards the asphalt sample, it was found that the hand spray can be easily controlled to achieve consistent rainfall intensities throughout the conditioning process and also adjustable to suit the sample size. The trials were measured based on the number of spray in 1 minute interval and the intensity was monitored for 1 hour period using rain gauge with HOBOware data logger (Figure 1a). On the other hand, the artificial wind speed was also simulated by setting up a consistent distance (approximately 4.3 m) between the electric standing fan (Ø 0.7 m, height; 1.2 m) and the slab sample in a controlled laboratory room. This is to achieve the selected 5.76 km/h as a result of the average wind speed measured in Malaysia from 2007 to 2016 under normal condition and monitored using the portable hand-held digital anemometer as shown in Figure 1b [16]. In addition, the anemometer also was used to measure the humidity, light and temperature. Figure 2 shows the number of spray per minute plotted against rainfall intensity classified under different rainfall criteria. From the plot, the total number of spray selected for the artificial rain is 1, 6 and 12 times representing the light rain, moderate rain and heavy rain respectively.

Table 2. Rainfall criteria [7].

Type of rain	Criteria
Light rain	Rainfall rate < 0.5 mm per hour
Moderate rain	0.5 ≤ Rainfall rate < 4.0 mm per hour
Heavy rain	Rainfall rate ≥ 4.0 mm per hour

(a) (b)

Figure 1. (a) Rain gauge and HOBOware data logger (b) Anemometer.

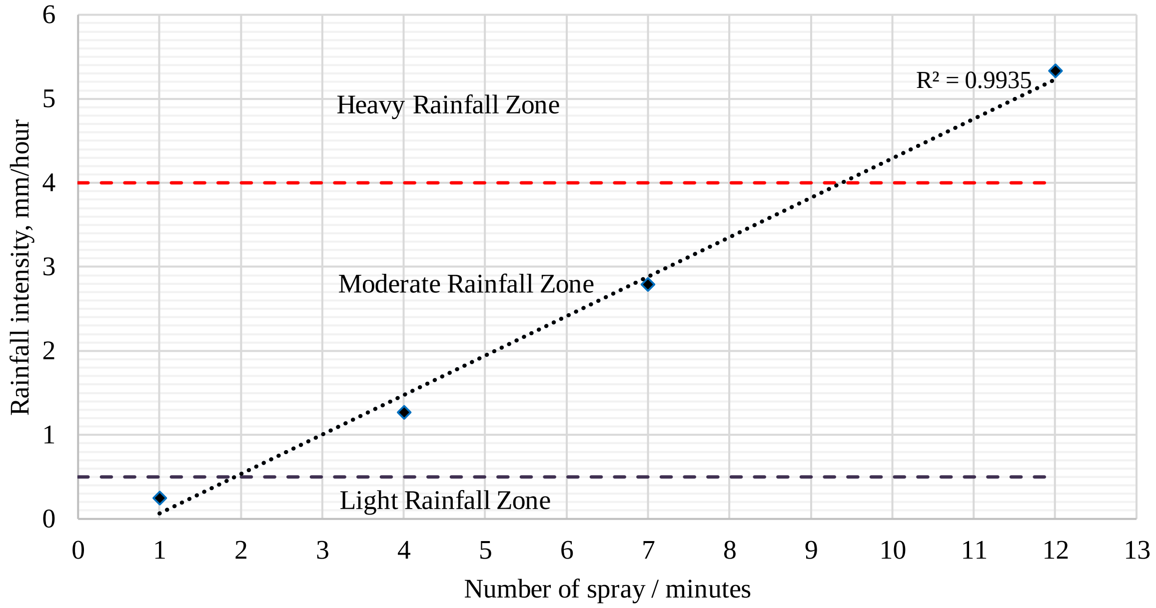

Figure 2. Selection of the optimum number of sprays.

2.3. Preparation of slab and coring samples

An estimated total of 10.5 kg aggregate and bitumen (4.9%) is required for preparing the slab sample with the size of 305 mm × 305 mm × 50 mm. In order to achieve the required DOC for wearing course (98-100%) as specified in the PWD specification, the appropriate rolling number was determined, and the density was compared with the Marshall density. A few trials were conducted at 100, 200 and 300 rolls for the HMA compaction using portable steel roller (28.5 kg). After 24 hours, the slab sample was cored and determined for the volumetric properties and DOC. Table 3 shows that 100 rolls achieves the targetted DOC and was selected as rolling number for the slab samples.

Table 3. DOC result [17].

Rolling No.	Degree of Compaction (DOC), %
100	99.6
200	100.1
300	100.5

2.4. Measurements of TAC and DOC

For TAC monitoring, when the asphalt mixture was transferred into the mold, the rolling started at the selected temperatures i.e. at 152°C, 142°C, 132°C and 122°C. Different temperatures were selected at the commencement of rolling based on the viscosity characteristic. This is to evaluate the effect of different compaction temperatures on the DOC with the TAC affected by the surrounding factors including the rainfall and wind. The temperature of the slab was recorded using thermo-gun for the slab surface and thermo-couples were placed at the middle and bottom sections as shown in Figure 3. The monitoring was undertaken until the temperature reached 80°C (cessation temperature) under dry and wet conditions (light, moderate and heavy rain). The slab samples were then cored and determined for the DOC as compared to the Marshall density. Additionally, it should be noted that the data measured from the temperature monitoring is based on 11.0 kg weight of asphalt mixture produced for the laboratory scale slab sample.

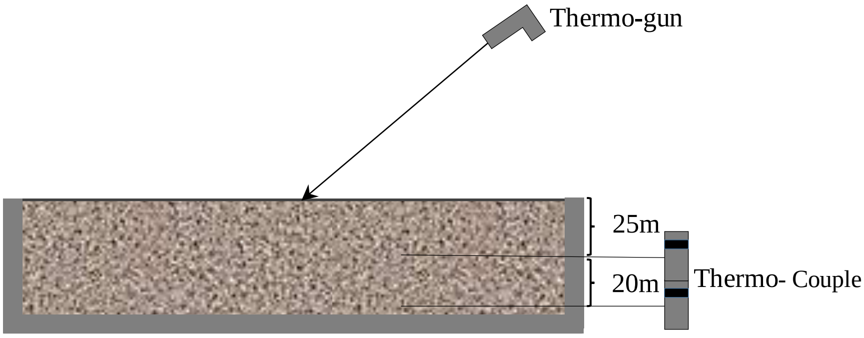

Figure 3. Temperature monitoring of the slab sample.

3. Results and Discussion

3.1. Cooling curve and TAC

In this study, the cooling curve was monitored under dry, light, moderate and heavy rainfall conditions. The decrease of mixture's temperature was monitored at the bottom, middle and top sections of the slab samples for all conditions. Figure 4 shows the cooling curves of the slab sample under dry condition. Initially, it can be seen that the top section of the slab gives a significant drop on its temperature for the first 5 minutes. This is due to the mixture surface that directly expose to the surrounding with ambient temperature [12]. On the other hand, the temperature on the middle section of the slab shows a steady slope with the longest cooling time of 60 minutes to achieve 80°C compared to the top and bottom sections, with the time observed at 52 and 58 minutes respectively. This could be due to the middle section of the slab sample that was not influenced by the ambient and base temperature which manage to retain more heat compared to other sections [9]. With this respect, the cooling time of the middle section of the slab is selected for the TAC determination. From the figure, the TAC of the slab samples compacted at 152°C, 142°C, 132°C and 122°C is 52 minutes, 48 minutes, 45 minutes and 41 minutes, respectively. The TAC decreases with the reduction in compaction temperature, thus suggests that delays in compacting asphalt mixture could lead to failure in achieving required density and stability. In fact, decrease in compaction temperature may result in large porosity, reduce workability and permeability and prone to experience permanent deformation [4].

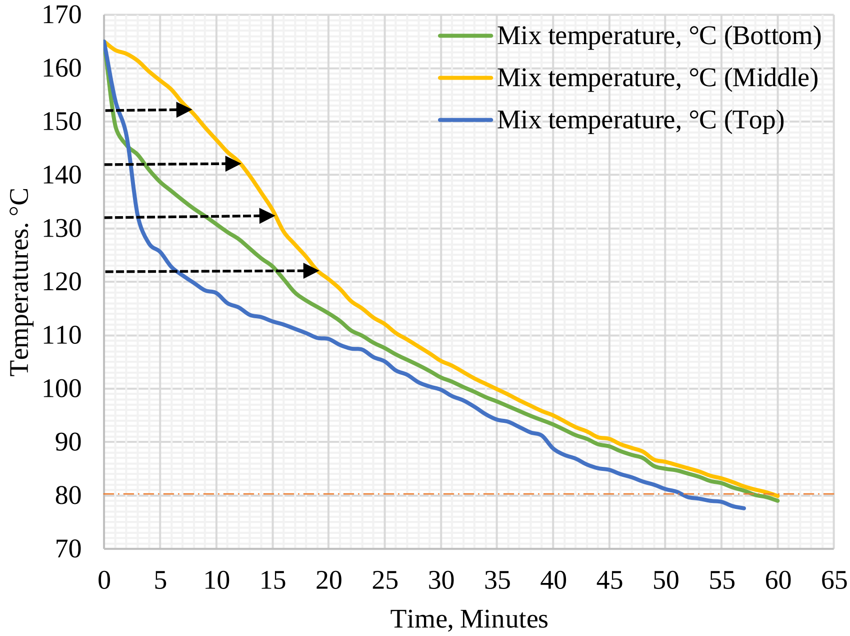

Figure 4. Cooling curves monitored under dry condition (control).

On the other hand, Figure 5 shows the cooling curves of the slab sample monitored under light rain condition. From the results, the bottom, middle and top sections reached 80°C after 41 minutes, 43 minutes and 37 minutes, respectively, where the cooling time reduces averagely by 38% compared to the dry condition. Again, the middle section of the slab was recorded with the longest TAC due to less influenced by the ambient and base temperatures even under light rain. The TAC of the slab samples compacted at 152°C, 142°C, 132°C and 122°C under light rain decreases to 35 minutes, 30 minutes, 27 minutes and 24 minutes, respectively as compared to control samples (dry condition).

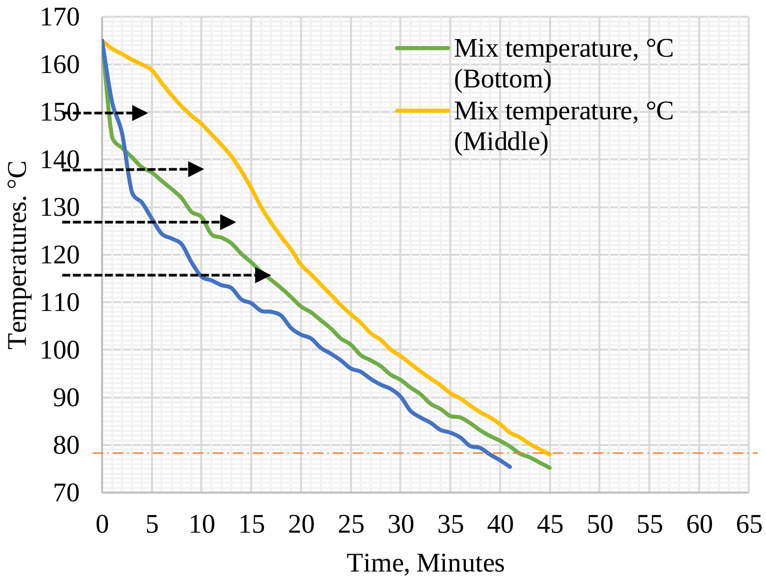

Figure 5. Cooling curves monitored under light rain.

Figure 6 shows the cooling curves of the slab samples compacted under moderate rain. The increasing content of water due to moderate rainfall intensity reduces the cooling time to 35 minutes, 34 minutes and 21 minutes for the bottom, middle and top sections, respectively. In addition, TAC at different compaction temperatures, i.e. 152°C, 142°C, 132°C and 122°C decreases to 29 minutes, 25 minutes, 23 minutes and 20 minutes, respectively. The moderate rain has accelerated the cooling process of the mixture particularly at the top section and reduced the TAC significantly as compared to the control sample by an average of 48%. Nevertheless, it can also be observed that the cooling time of the bottom and middle sections are comparable, thus indicates that moderate rain has increased the cooling rate of the middle section towards when reaching 80°C.

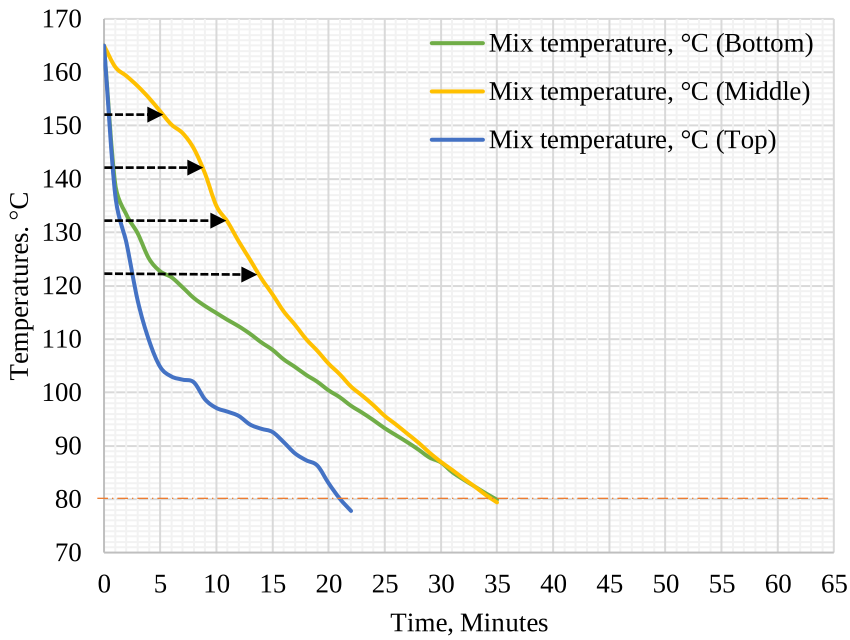

Figure 6. Cooling curves monitored under moderate rain.

Figure 7 shows the cooling curves of the three sections compacted for the slab sample under heavy rainfall. The cooling time at the bottom, middle and top sections of the slab reduces to 25 minutes, 24 minutes and 7 minutes, respectively. Due to the heavy rain, the top section of the slab samples has rapidly cooled and significantly reduced the TAC. Similar trend was observed for the bottom section, where the temperature drops drastically at the first 2 minutes, from 165°C to 130°C. The TAC measured for the samples compacted at 152°C, 142°C, 132°C and 122°C decreases to 24 minutes, 22 minutes, 20 minutes and 18 minutes, respectively. Under heavy rainfall, the asphalt mixture was estimated to cool averagely at 55% faster than the control sample. On the other hand, the cooling rate of the middle section increases when the temperature reaches less than 100°C. This shows that heavy rain has increased the heat release rate of the material particularly at the top and middle sections and reduced the TAC as compared to the bottom section.

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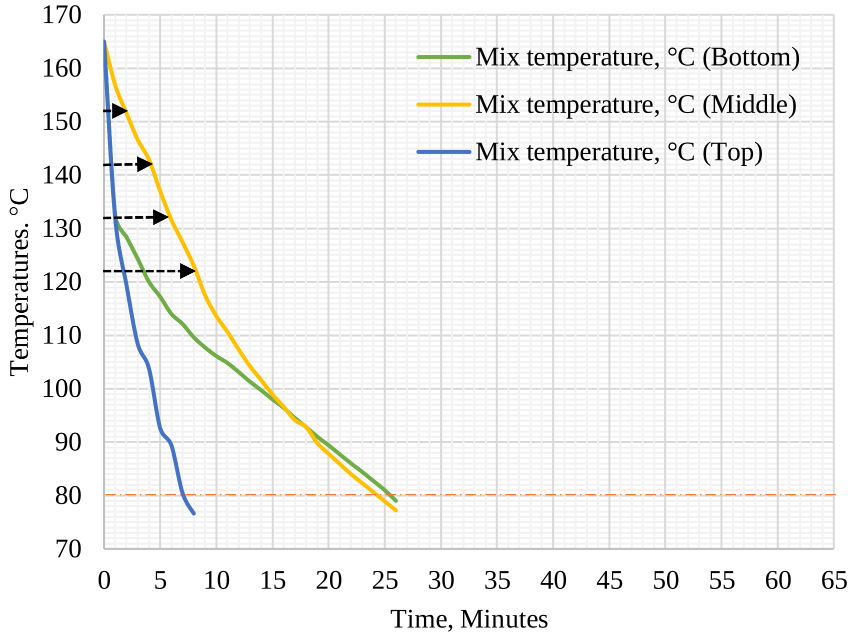

Figure 7. Cooling curves monitored under heavy rain.

Thus, the findings confirm that initially (after laydown process) the ambient and base temperatures are critical factors in affecting the cooling rate of the asphalt mat particularly at the top and bottom sections. However, with the additional cooling mechanism by direct exposure to the severe environmental condition, the cooling phenomenon or heat dissipation will significantly occur at the top section and eventually affect the middle section which increase the cooling rate and make it difficult to achieve the required compacted density. Figure 8 summarizes the time available for the compaction measured under various conditions. Based on the figure, it can be seen that by initiating the breakdown rolling when the pavement temperature reaches the minimum temperature requirement, there is a chance of having failure in the compaction work due to the limited TAC during installation. As stated earlier, the findings were obtained based on the laboratory scale sample and simulated rainfall conditions. Therefore, generalization of the findings towards the exact field work should be made with other supporting data that is currently not included in the paper. However, it is expected that the trends observed reflect the outcome of the TAC for large scale paving work.

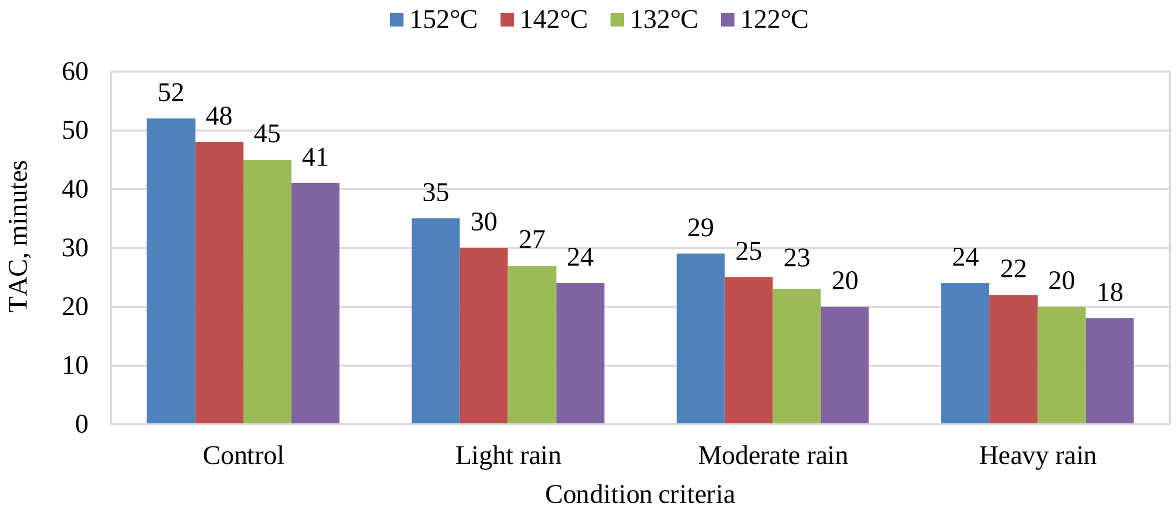

Figure 8. TAC at various compaction temperatures and condition criteria.

3.2. Degree of compaction (DOC)

For HMA, high compaction temperature is required to provide better compactibility and stability to the mixture. Figure 9 shows the DOC of compacted samples at different compaction conditions and temperatures. Overall, the DOC of the slab samples compacted under all conditions are found to comply with the PWD specification (in the range of 98%-100%), except for the slab exposed to heavy rain with the commencement of rolling temperature at 122°C. This shows that the specified minimum compaction temperature for the initial rolling determined by the various cooling mechanisms including the rainfall intensity and wind speed. As can be seen for both control (dry) and light rain conditions, the DOC decreases approximately from 100% to 98% when the compaction temperature decreases from 152°C to 122°C accordingly. This confirms that higher compaction temperature can produce higher density mixture compared to the minimum compaction temperature requirement. However, the samples compacted under the moderate rainfall produce unexpected result where the DOC seems to be less affected by the various compaction temperatures with comparable DOC values. Similar observation was made by the previous researcher who presumably due to the presence of water that infiltrates into the mixture through air voids thus increased the density of the compacted samples [8, 18]. However, the hot asphalt can turn the puddle into steam and affect the bitumen-aggregate adhesion, leading to premature surface defects. Therefore, the light and moderate rain intensities do not indicate any detrimental impact on the compaction work, where the density is not adversely impacted. In fact, the execution of the compaction process under both conditions can still result in proper compaction. On the other hand, samples conditioned with heavy rain clearly need higher compaction temperature or sufficient TAC in order to achieve the target density as to compensate the increase in the cooling rate. The heavy rain accelerates the cooling rate and hardens the mixture and causes difficulty in getting proper compaction. In fact, the presence of water during compaction works started at temperature 132°C could possibly breaks the bonding between bitumen and aggregates, thus reduces its adhesion properties [19]. For this reason, large void content in the mix could potentially reduce the strength of the asphalt mixture [20]. Though high compaction temperature seems promising, but too high asphalt mat temperature at the commencement of rolling for field compaction (with lack of mix confinement) could cause premature failures such crack or a wavy surface as a result of thermal segregation. This is particularly in regard to a tender mix (low viscosity) that will move excessively under the action of steel roller or varies in stiffness due to temperature difference during the rolling process.

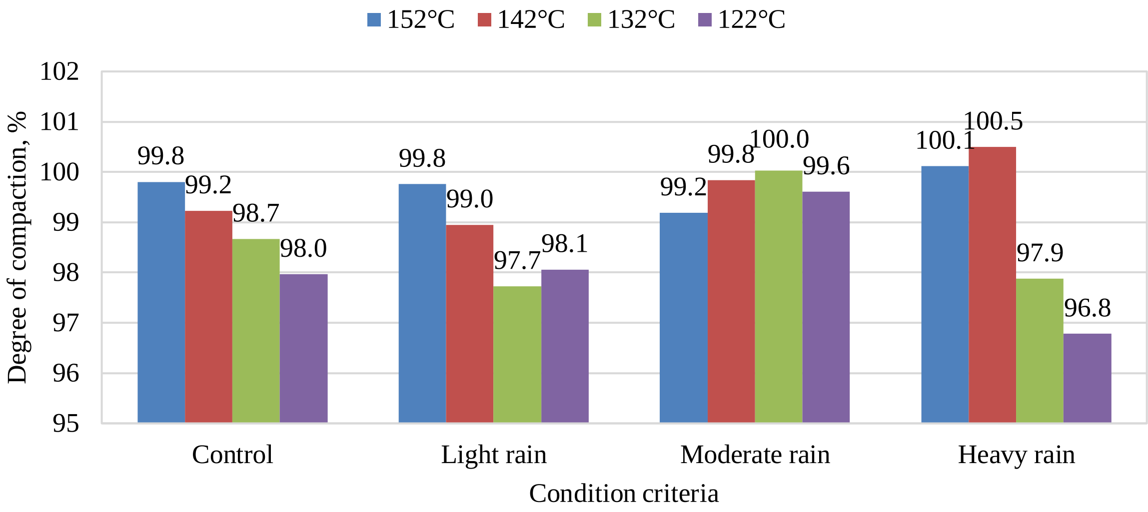

Figure 9. DOC at various compaction temperatures and condition criteria.

4. Conclusion

The findings obtained from this study evaluate the execution of the compaction works under various rainfall conditions and the selection of temperature during the initial or breakdown rolling. From the results, the cooling rate of the middle section of the asphalt slab was found lower compared to the top and bottom sections due to the air temperature, base temperature and wind speed that govern the cooling rate of the mix. Lower initial compaction temperature resulted in lower DOC due to limited time available for the compaction. In addition, compaction of the asphalt mix in light and moderate rainfall conditions were found acceptable to obtain the desired DOC, provided that the TAC was sufficient. Nevertheless, heavy rainfall during the rolling operation will shorten the TAC and jeopardize the asphalt mix as it cools quickly. In order to verify the laboratory measured TAC, further evaluation on the large quantity of asphalt materials used in field paving work is currently undertaken for better conclusion where the results could not be presented in this paper. The authors believe that this evaluation is necessary on the basis of direct relationship that exists between surface area to volume ratio and heat loss in materials. Overall, it can be concluded that rainfall condition and temperature at the commencement of rolling are essential factors that affect the compactability of asphalt mix.

5. References

[1] Public Works Department 2008 *Standard Specification for Road Works – Section 4: Flexible Pavement* Public Works Department Ministry of Works Malaysia Kuala Lumpur JKR/SPJ/2008
[2] Lee S J, Amirkhanian S N and Kwon S Z 2008 The effects of compaction temperature on CRM mixtures made with the SGC and the Marshall compactor *Cons. Build. Mat.* **22**(6) 1122-1128
[3] Khan Z A, Wahab H I A A, Asi I and Ramadhan R 1998 *Cons. Build. Mat.* **12**(6-7) 373-384
[4] Gao Y, Huang X and Yu W 2014 *J. Wuhan University of Technology-Mater. Sci. Ed.* **29**(5) 956-959
[5] Jabatan Meteorologi Malaysia 2017 *Mean Monthly Rainfall* Malaysia Kuala Lumpur
[6] Hashim W, Arshad A K, Shaffie E and Noh N M 2018 *Inter J. of Civil Eng. Technol.* **9**(7) 1887-1895
[7] Seboru M A 2015 *Ameri. J. of Civil Eng.* **3**(3) 51-63
[8] Sunarjono S, Pamungkas R S and Hardikasari M 2014 *Proc., Int., Conf., of Eng., Technol., Ind., App.*147-151

[9] Hashim W, Noor M N M, Shaffie E, Rahman Z A and Arshad A K 2018 *IOP Conf. Ser.: Earth Env. Sci*. **140**(1)
[10] Hashim W, Hainin M R, Ismail N N, Yusoff N I M, Abdullah M E and Hassan N A 2016 *J. Tek.* **78**(4) 97-104
[11] Pérez-Jiménez F, Martínez A H, Miró R, Hernández-Barrera D and Araya-Zamorano L 2014 *Cons. Build. Mat.* **65** 264–269
[12] Wang Y, Zhu S, Asce M and Wong A S T 2014 *J. Cons. Eng. and Management* 1–11
[13] Chang C M, Chang Y G, and Chen J S 2009 *J. Transp. Eng.*, **135** 297–304
[14] Mills B N, Tighe S L, Andrey J, Smith J T and Huen K 2009 *J. of Trans. Eng.* **135**(10) 773-782
[15] Jabatan Meteorologi Malaysia 2017 Rain intensity criteria Malaysia Kuala Lumpur.
[16] Jabatan Meteorologi Malaysia 2017 *Mean Surface Wind Speed* Malaysia Kuala Lumpur.
[17] Ismail S, Hassan N A, Yaacob H, Hainin M R, Ismail C R, Mohamed A and Idham M K 2019 *IOP Conf. Ser.* **220** 1-10
[18] Hu J, Wang X and Guo R 2011 *Ad. Research on Comp. Ed., Simul. Model* 170-173
[19] Yilmaz A and Sargin Ş 2012 *The online J. of Sci. & Tech.* **2**(1) 1-6
[20] Moreno-Navarro F, García-Travé G, Rubio-Gámez M D C and Martinez-Echevarria M J 2014 Analysis of the moisture susceptibility of hot bituminous mixes based on the comparison of two laboratory test methods. *Dyna* **81**(183) 49-59

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