ISSN: 0128-7680
Pertanika J. Sci. & Technol. **18 (1)**: 13 – 22 (2010)

Analysis of Stone Mastic Asphalt (SMA) Slab Dimensions for Evaluation of the Newly Developed Roller Compactor (Turamesin)

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ABSTRACT

Stone Mastic Asphalt (SMA) is one type of asphalt mixture which is highly dependent on the method of compaction as compared to conventional Hot Mix Asphalt (HMA) mixture. A suitable laboratory compaction method which can closely simulate field compaction is evidently needed as future trend in asphalt pavement industry all over the world is gradually changing over to the SMA due to its excellent performance characteristics. This study was conducted to evaluate the SMA slab mixtures compacted using a newly developed Turamesin roller compactor, designed to cater for laboratory compaction in field simulation conditions. As the newly developed compaction device, there is a need for evaluating the compacted slab dimensions (which include length, width, and thickness), analyzing the consistency of the measured parameters to verify the homogeneity of the compacted slabs and determining the reliability of Turamesin. A total of 15 slabs from three different types of asphalt mixtures were compacted, measured, and analyzed for their consistencies in terms of length, width, and thickness. Based on study the conducted, the compacted slabs were found to have problems in terms of the improperly compacted section of about 30 mm length at both ends of the slabs and the differences in the thickness between left- and right-side of the slab which were due to unequal load distribution from the roller compactor. The results obtained from this study have led to the development of Turamesin as an improved laboratory compaction device.

Keywords: Asphalt mixtures, laboratory compaction, roller compactor, slab, stone mastic asphalt

ABBREVIATIONS

COV – Coefficient of Variation
HMA – Hot Mix Asphalt
n.d. – not dated
SMA – Stone Mastic Asphalt

INTRODUCTION

With a total land area of 329,758 km², Malaysia was linked by 73,402 km of roads in 2002 (Economic Planning Unit, 2004), with about 78% of the total road network comprise of paved roads, and the remaining are unpaved roads of natural soil or gravels (Hussain and Abd. Aziz, 2004). As compared to 1995, there was an increase of about 16.4% in the total road network system in 2003. Similarly, the number of vehicles between 1987 and 2002 grew from 3,674,484 to 12,021,939, with an average increasing rate of about 8% per year or three times more than in 1987 (Road Transport Department, 2003). Due to this massive traffic growth and higher axle loads,

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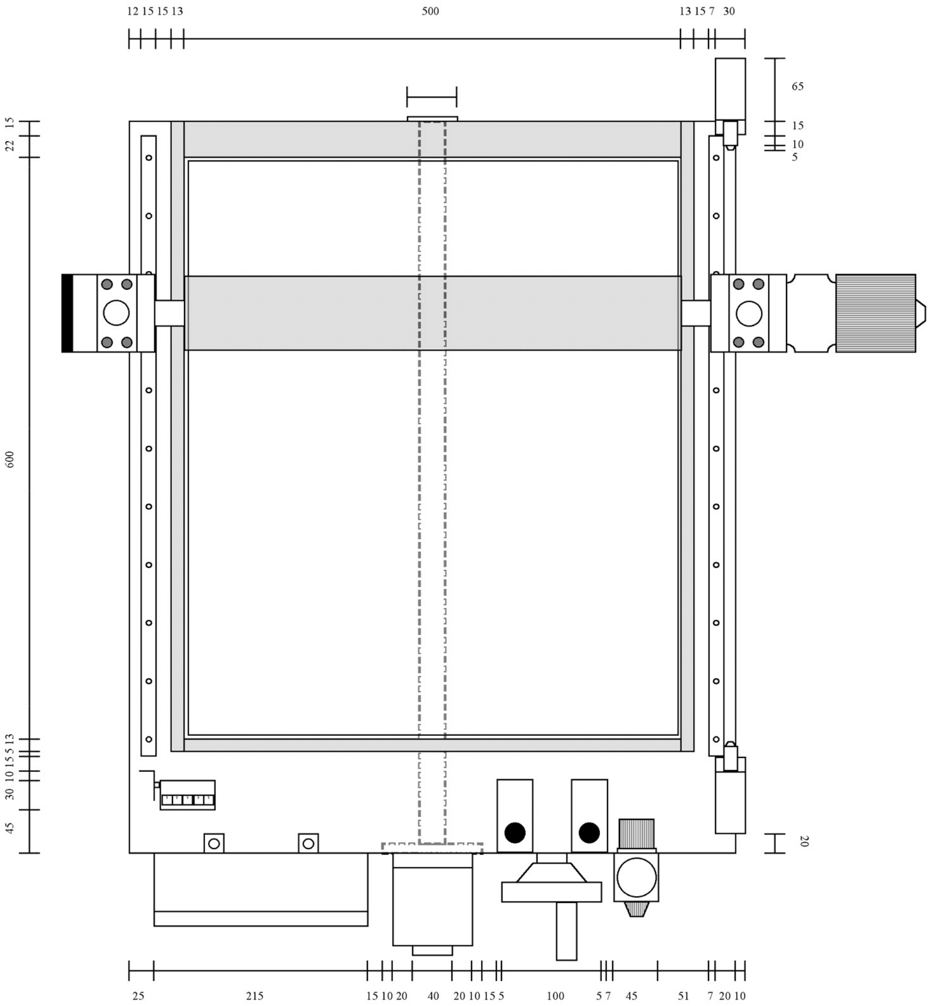
Fig. 1: Turamesin device

together with environmental and aging effects, there is a growing concern over rapid deterioration of the pavement. The consequences, initially in the forms of surface wear, rutting and cracking, if unattended to, would lead to more serious and irreparable damages, and consequently cause the pavement to lose serviceability life much earlier than expected (Wignall *et al*., 1991). Therefore, efficient techniques in designing and constructing roads are in demand so that the roads will perform better and last longer.

The application of Stone Mastic Asphalt (SMA) mixture is rapidly gaining acceptance due to its performance and excellent resistance to permanent deformation. In particular, an intriguing, alternative solution to overcome pavement problems (such as rutting and cracking) has become common with the use of conventional Hot Mix Asphalt (HMA) mixture. SMA is a gap graded asphalt surfacing material and it is stone-to-stone contact mixtures, whereby a high coarse aggregate content forms a skeletal matrix or interlocks to increase their stability. As a result, coarse stone-to-stone contact is prevalent in the SMA mixtures but it does not occur in conventional HMA. The HMA mixtures also have stone-to-stone contact, but most of this takes place within the fine aggregate particles which do not offer the same shear resistance as the SMA. This has resulted in loads for the SMA being carried by friction between the coarse aggregate particles instead of the asphalt binder and fine aggregates as in the conventional HMA mixtures (Brown and Manglorkar, 1993). Therefore, the SMA is highly dependent on the degree and method of compaction, which are related to the internal structure of the mixtures.

As the application of the SMA is rapidly gaining acceptance, there is a need for suitable laboratory compaction method that can closely simulate field compaction. The presently available laboratory compaction methods have intrinsic limitations due to the different modes in mechanical manipulation of the mixtures and different energy levels of compaction as compared to field compaction. Thus, they do not seem to be able to produce laboratory specimens that can truly represent the mixtures as it exists in the field, especially for the SMA mixtures (Button *et al*., 1992; Consuerga *et al*., 1992; Khan *et al*., 1998). Therefore, the researcher from Universiti Putra Malaysia (UPM), has come out with Turamesin, a newly developed laboratory compaction device, which was designed to provide a solution to the problem of producing laboratory specimens which are representative of materials laid and compacted in the field. *Figs. 1* and *2* show the Turamesin device which has the overall length and width of about 930 mm and 870 mm respectively, whereas the overall height is 474 mm, and the schematic drawing respectively.



Note: All units are in millimeter (mm)

Fig. 2: Schematic drawing of Turamesin device

BACKGROUND

Turamesin is used to compact asphalt mix slab using a pneumatically powered steel wheel roller which is used just like the heavy duty steel wheel roller on-site. Different levels of pressure can be applied up to approximately 980 kPa (10.0 kgf/cm^2 or 142 psi) developed by a pneumatic system, and supplied through air compressor. Based on the preliminary studies conducted, Turamesin was developed based on 785 kPa (8.0 kgf/cm^2) of applied pressure and 75 numbers of passes that control the compaction efforts to yield the asphalt mix slab with the closest properties to in-service pavement of 4% air voids (Zaharudin and Muniandy, 2004; Jakarni and Muniandy, 2006). The thickness of the compacted slab can vary from 40 to 100 mm, depending on users' requirement. However, the compaction efforts of 785 kPa of applied pressure and 75 numbers of passes were developed based on the target thickness of the 70 mm slab.

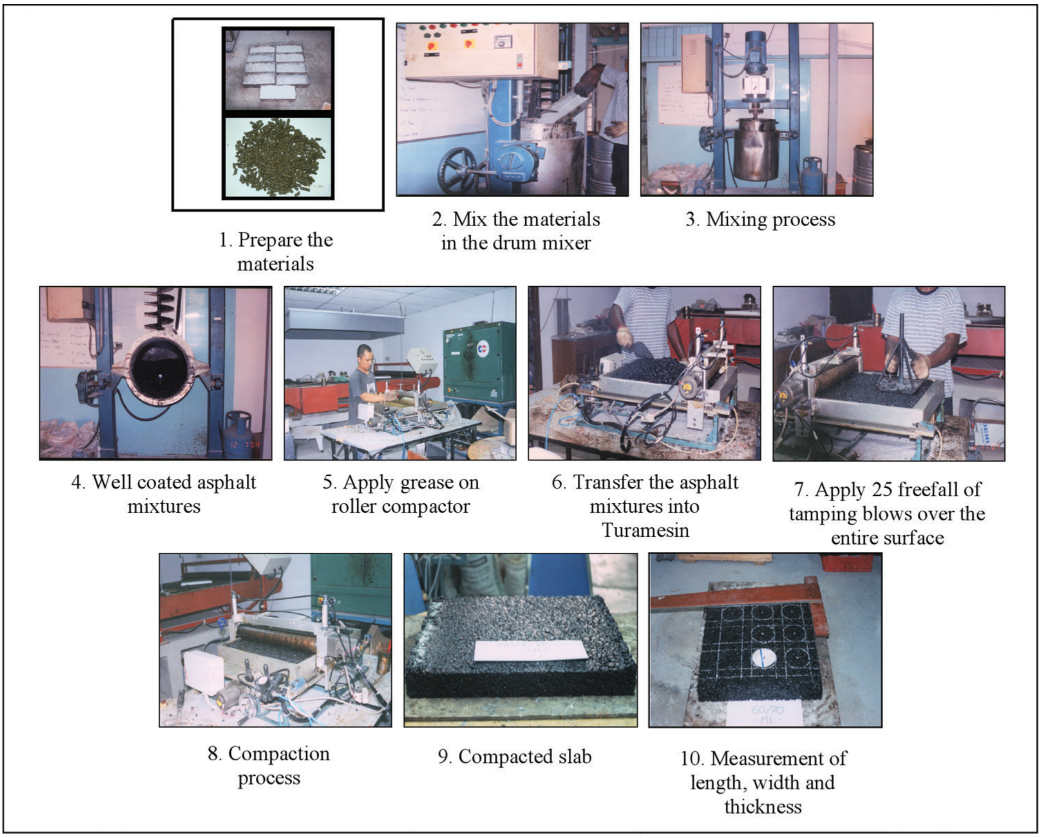
As a newly developed compaction device, there is a need to evaluate the compacted slabs in terms of the slab dimensions and physical properties of the mixtures, so as to verify whether the slabs are uniformly compacted and to determine the ability and performance of Turamesin. This paper reports on the evaluation of the slab dimensions in terms of length, width, and thickness of the SMA mixtures compacted using Turamesin and the consistency analysis of the measured parameters of the slab dimension. This research was basically a sensitivity study to determine if significant differences in length, width, or thickness exist between the slabs and as a part of the verification for Turamesin. The results obtained from this study would lead to the development of Turamesin as an improved laboratory compaction device.

MATERIALS AND METHODS

Three types of asphalt binders (Grade 60/70, Grade PG76, and Grade 80/100) were utilized to consider a range of the SMA mixtures. The mineral aggregates used consisted of 14 mm nominal maximum aggregates size of granite and limestone as a mineral filler. Palletized cellulose fibres (VIATOP 80-20) were used as an additive and fibres were also added to the asphalt mixtures at a dosage rate of 0.3% by the total weight of the mixtures. Both the suitability of the aggregates and the asphalt binders taken into consideration in this study were determined by evaluating the characteristics of the material through various physical property tests. All the results obtained from the tests were conformed to the specification requirements.

Determination of the optimum asphalt content for each type of asphalt binders was done through the Marshall mix design analysis in accordance with ASTM D1559-89 Standard Test Method for Resistance to Plastic Flow of Bituminous Mixture using Marshall Apparatus and the optimum asphalt content values were found to be 5.60% for Grade 60/70, 6.04% for Grade PG76 and 6.05% for Grade 80/100, respectively. Then, five slabs were prepared for each type of asphalt binders which make up to a total of 15 slabs for the overall study. The slabs compacted in this study were designed to a target thickness of 70 mm. The target value of 4% for air voids was used in calculating the amount of materials required for each slab, based on the volume-density calculations. Each compacted slab was then measured for their length, width, and thickness. Vernier calliper of accuracy 0.20 mm was used to measure the thickness, whereas L-shaped ruler of accuracy 1.00 mm was to measure the length and width, respectively. The application of the L-shaped ruler of accuracy 1.00 mm is considered as sufficient due to the large values of length and width. Each recorded datum was then analyzed to determine the consistency of the measured parameters among the slabs. *Fig. 3* illustrates the sequence of the compaction procedures involved and the brief procedures are explained as follows.

i. Preheat Turamesin mould to a required compacting temperature. Apply grease on the surface of thin-steel plate, inner side of the mould area and collar, and roller compactor to prevent sticking.
ii. Place the thin-steel plate inside the mould.
iii. Transfer the asphalt mixtures from the mixing apparatus into the mould, and the temperature of the mixtures shall be within the compacting temperature range. Spread and level the mixtures uniformly throughout the mould using the level attached at the roller frame.
iv. Spade the surface of the mixtures rigorously with 25 freefall of tamping blows using a tamping plate. Repeat steps (iii) to (iv) when several batches of asphalt mixtures are required to be transferred from the mixing apparatus.
v. Set the required pressure for compaction by adjusting the pressure gauge and place a thermometer at one edge of the loosen asphalt mixtures to record the temperature during compaction.


1. Prepare the materials

2. Mix the materials in the drum mixer

3. Mixing process

4. Well coated asphalt mixtures

5. Apply grease on roller compactor

6. Transfer the asphalt mixtures into Turamesin

7. Apply 25 freefall of tamping blows over the entire surface

8. Compaction process

9. Compacted slab

10. Measurement of length, width and thickness

Fig. 3: Slab preparation and compaction procedures for Turamesin

vi. Release the roller compactor down so it will touch the surface of the mixtures and start compaction when the roller compactor frame is in position, i.e. where it touches the counter. Compaction is completed once the required number of passes is achieved.

vii. Turn the main switch off and allow the slab to cool to room temperature prior to removing it from the mould. Remove the side collars of the mould before sliding the slab off the mould and placing it on a clean, flat surface at the room temperature. Ensure that the thin-steel plate remains on the bottom of the slab while moving it to help support the slab and ensure minimum bending.

RESULTS

Table 1 shows the average, standard deviation, and coefficient of the variations of length and width measured at five different points of each slab. The average was calculated within each slab (using the length at each point), whereas the average, standard deviation, and coefficient of variations were calculated for each type of asphalt mixtures (using the average length of each slab). Based on the data presented in Table 1, it is noted that the variations of length and width between the slabs of the same type of asphalt mixtures was relatively low, as indicated by a small percentage of coefficient of variation. The average length and width of the slab were 589.84 mm and 500.36 mm for Grade 60/70, 590.12 mm and 499.48 mm for Grade PG76 and 589.96 mm and 500.16 mm, respectively.

TABLE 1
Length and width analysis

Asphalt mixtures	Slab	Length (mm)						Width (mm)					
		Pt.1	Pt.2	Pt.3	Pt.4	Pt.5	Average	Pt.1	Pt.2	Pt.3	Pt.4	Pt.5	Average
Grade 60/70	Slab 1	589	592	588	591	589	589.80	502	501	502	501	502	501.60
	Slab 2	591	592	592	593	590	591.60	501	502	500	501	502	501.20
	Slab 3	593	591	590	592	589	591.00	502	501	499	499	500	500.20
	Slab 4	589	590	590	589	586	588.80	498	500	499	499	500	499.20
	Slab 5	588	589	588	587	588	588.00	499	499	500	500	500	499.60
	Average						589.84						500.36
	[1]Std. Dev.						1.49						1.02
	[2]COV (%)						0.25						0.20
Grade PG76	Slab 1	591	588	590	589	588	589.20	499	500	498	500	499	499.20
	Slab 2	589	590	591	593	592	591.00	498	499	501	501	500	499.80
	Slab 3	591	590	588	589	589	589.40	499	498	499	499	500	499.00
	Slab 4	590	591	592	594	593	592.00	501	502	500	500	500	500.60
	Slab 5	588	590	589	589	589	589.00	499	499	498	499	499	498.80
	Average						590.12						499.48
	[1]Std. Dev.						1.32						0.73
	[2]COV (%)						0.22						0.15
Grade 80/100	Slab 1	588	586	589	587	589	587.80	499	500	498	501	502	500.00
	Slab 2	589	589	588	590	589	589.00	502	502	501	501	502	501.60
	Slab 3	590	589	589	590	591	589.80	500	499	498	499	500	499.20
	Slab 4	592	591	591	590	590	590.80	499	500	500	501	501	500.20
	Slab 5	590	594	592	592	594	592.40	501	499	500	499	500	499.80
	Average						589.96						500.16
	[1]Std. Dev.						1.75						0.89
	[2]COV (%)						0.30						0.18

Note: [1]Std. Dev - Standard Deviation
[2]COV - Coefficient of Variation

Table 2 shows the average thickness of the left-side and the right-side of the slabs respectively, measured at five different points for each slab, and also the difference in the thickness between the left- and right sides. It is also noted that the average thickness for the left-side and the right-side was 66.56 mm and 60.44 mm respectively for Grade 60/70, whereas these were 67.32 mm and 62.48 mm respectively for Grade PG76, and 65.72 mm and 60.48 mm respectively for Grade 80/100.

DISCUSSIONS

The general procedure for the analysis basically consists of performing a descriptive statistical analysis to determine the average, standard deviation, and coefficient of variation. The analysis is required to determine and analyze the consistency of length, width, and thickness of the slabs. This present work is basically a sensitivity study to determine if significant differences in length, width or thickness exist between the slabs. Similarly, based on length and width analysis, the significant differences between the slabs were also analyzed to determine whether the mould would potentially be affected by the compaction efforts of the roller compactor.

Coefficient of variation (COV) was used to evaluate and compare the variation between the data sets. Based on Volodin and Nom (n.d.), 25% or less is desirable for the cut-off value of coefficient of variation. Since there is no exact cut-off value, a pre-defined cut-off threshold value of 10% was used in this study to control the consistency level of the data sets. Based on the literature related to pavement areas, using the coefficient of variation as part of the data analysis, the selection of 10% as the cut-off value for the coefficient of variation seems to be reasonable (Kandhal, 1989; Wu and Hossain, 2003; Zhang, 2005).

Based on the data presented in Table 1, the variations terms of length and width between the slabs of the same type of asphalt mixtures were relatively low, as indicated by the small percentage of coefficient variation. From the analysis, the small coefficient of variation value, as compared to a predefined cut-off value of 10%, indicated that the length and width of the slabs were consistent with each other. However, the compacted slabs were found to have problems in terms of the improperly compacted section of about 30 mm length at both ends of the slabs (the encircled region) as shown in *Fig. 4*. These portions were not properly compacted due to end restriction of the mould and the roller compacter. However, unlike their length, the width of the slabs was completely covered from one side to another as the roller compactor makes its passes over the slab.

Slabs compacted in this study were designed to a target thickness of 70 mm. In the analysis, only the thickness along the length of the slabs was measured on both the left and right sides. The thickness along the width of the slabs was not included in the analysis since the end portions of the slabs along the width were not properly compacted. Based on the data given in Table 2, there was a significant difference in the thickness between the left-side and right-side although the variation of the thickness for each respective side of each asphalt mixture was relatively low, as indicated by the small percentage of coefficient of variation. Theoretically, there should be no difference in term of thickness as the slab was designed to a target thickness of 70 mm throughout the entire section.

Therefore, a hypothesis testing involving One-Sample t-Test procedure is required to determine whether there is any evidence of significant difference in the thickness between the left-side and right-side. The following hypotheses were then established.

i. The null hypothesis, H_o
   H_o: $\mu_{(Ln-Rn)} = 0$ (The average difference in the thickness between left-side and right-side is zero).

ii. The alternative hypothesis, H_1
   H_1: $\mu_{(Ln-Rn)} \neq 0$ (The average difference in the thickness between the left-side and right-side is not zero).

TABLE 2
Thickness analysis

Slab	Asphalt mixtures Grade 60/70			Asphalt mixtures Grade PG76			Asphalt mixtures Grade 80/100		
	Average Left-Side Thickness (mm)	Average Right-Side Thickness (mm)	Difference in Thickness between Left-Side and Right-Side (mm)	Average Left-Side Thickness (mm)	Average Right-Side Thickness (mm)	Difference in Thickness between Left-Side and Right-Side (mm)	Average Left-Side Thickness (mm)	Average Right-Side Thickness (mm)	Difference in Thickness between Left-Side and Right-Side (mm)
Slab 1	66.00	60.20	5.80	67.80	62.00	5.80	66.00	60.40	5.60
Slab 2	68.20	61.20	7.00	67.40	63.20	4.20	65.80	61.20	4.60
Slab 3	65.80	61.40	4.40	69.20	63.20	6.00	65.60	59.80	5.80
Slab 4	67.60	60.20	7.40	67.00	62.80	4.20	66.40	60.60	5.80
Slab 5	65.20	59.20	6.00	65.20	61.20	4.00	64.80	60.40	4.40
Average	66.56	60.44	6.12	67.32	62.48	4.84	65.72	60.48	5.24
[1]Std. Dev.	1.28	0.89	1.17	1.45	0.87	0.97	0.59	0.50	0.68
[2]COV (%)	1.92	1.47	19.14	2.15	1.39	20.12	0.90	0.83	13.06

Note: [1]Std. Dev - Standard Deviation
[2]COV - Coefficient of Variation

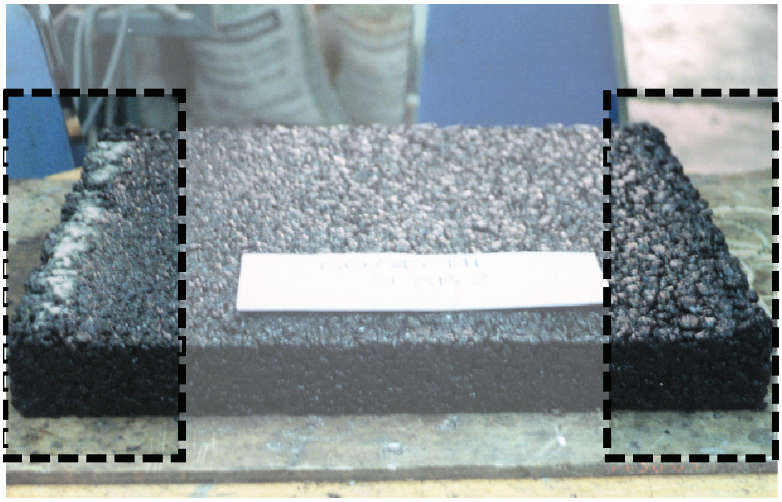
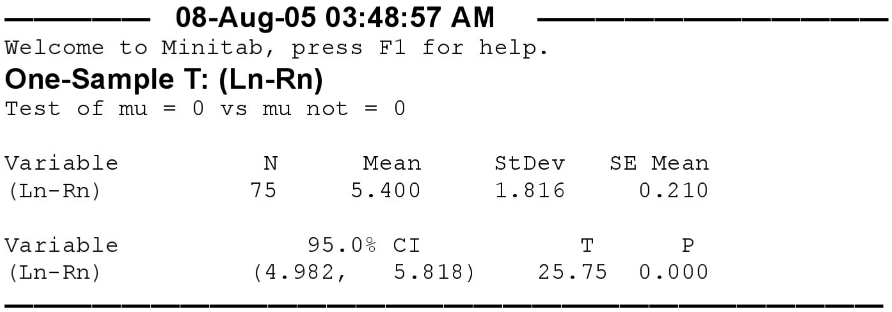


Fig. 4: Improperly compacted sections of slab



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————————  08-Aug-05 03:48:57 AM  ————————————————————
Welcome to Minitab, press F1 for help.
One-Sample T: (Ln-Rn)
Test of mu = 0 vs mu not = 0

Variable          N      Mean     StDev   SE Mean
(Ln-Rn)          75     5.400     1.816     0.210

Variable              95.0% CI            T      P
(Ln-Rn)          (4.982,   5.818)     25.75  0.000
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Fig. 5: MINITAB statistical analysis

Based on MINITAB statistical analysis, for a given sample size, n of 75 and level of significance, α of 0.05, the t-statistic, T was found to be 25.75 whereas the p-value was found to be 0.000 *(Fig. 5)*. The critical t-values were found to be ±1.9924, based on the (75-1) degrees of freedom and the area in the two tails of (0.025 + 0.025). Therefore, based on the value of t-statistic, T of 25.75, critical t-values of ±1.9924 and also p-value of 0.000, the null hypothesis, H_o is rejected at the level of significance, α of 0.05. The analysis shows that significant statistical difference exists in the thickness between the left-side and right-side. The average difference in term of thickness was 5.40 mm, as compared to the theoretical difference in the thickness of zero.

The difference in the thickness of the left-side and right-side was due to the unequal load distribution of the slab from the roller compactor during the compaction process. The motor, which is attached to one side of the roller compactor, has caused additional load and thus reduced the thickness on the respective side. Therefore, a proper adjustment should be made to balance the weight of the roller compactor so that an equally distributed load can be applied on the surface of the slab.

Moreover, the thickness of the slab was found to be less than the target thickness of 70 mm. This could possibly be attributed to many factors; nevertheless, it was most likely due to the whole process of sampling, mixing, transferring the asphalt mixtures as well as compacting which had caused some mixtures to be left behind. Although the thickness was found to be less than the target thickness of 70 mm, it had no significant effect on the slab properties. A tolerance of ±10 mm offset from the target thickness is allowed since the measurements of thickness were recorded manually. However, careful measurements should be taken prior to the compaction process so as to minimize the amounts of leftover mixtures.

CONCLUSIONS

Based on the statistical analysis conducted, the compacted slabs were found to have an average area of 590 mm of length by 500 mm of width and their thickness ranged from 60 mm to 68 mm. On the average, the variability of the measured parameters of length, width, and thickness for all the slabs were generally low. Therefore, it could be concluded that the mould of the Turamesin was rigid enough to withstand the compaction efforts from the roller compactor. However, the compacted slabs were found to have improperly compacted section of about 30 mm in length at both ends of the slabs and the difference in the thickness between left-side and right-side of the slab. Therefore, the roller compactor of Turamesin should be adjusted so that an equally distributed load could be applied over the slab during the compaction process. Motor, which is attached to one side of the roller compactor, should be removed or balanced on the other side to eliminate the problem in terms of the differences in thickness.

ACKNOWLEDGEMENT

The authors would like to thank the Department of Civil Engineering, Universiti Putra Malaysia for providing the required facilities and support to this project and to all the people who were directly and indirectly involved in the project for their help and co-operation given throughout this study.

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