EVALUATING TIME AVAILABLE FOR COMPACTION OF HMA

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EVALUATING TIME AVALABLE FOR COMPACTION OF HMA

Road sector development has rapidly increased in Sri Lanka after the civil war. Asphalt concrete is widely used for the construction of roads due to speedy construction, durability, riding quality and easy to apply compared to other materials.

The primary objective of this research is to find the time available for compaction of hot mixed asphalt concrete with effect of wind velocity, lay down temperature, and ambient temperature. The secondary objective is to check the value 135^0C as the minimum lay down temperature for tropical climates. In this study, cooling time was measured in laboratory and field with different asphalt layer thickness, base temperature, and ambient temperature with different mixtures and lay down temperatures.
According to standard specification for construction and maintenance of roads and bridges, it has specified that the breakdown and the intermediate rolling shall be carried out at temperature not less than 135^0C and 115^0Crespectively. The final rolling shall be completed before the temperature of the mix falls below 90 ^{0}C.
According to the field data, cooling rate at 12.30 pm to 1.30pm was low during day time and that time was more suitable for asphalt laying and also found that HMA lay down temperature below 135^0C was not significantly affected to compaction of HMA because compaction density can be achieved applying more roller passes and compaction effort. But in laboratory test, stability of HMA below 115^0C was contradict to the specification. So that the value of 135^0C not for minimum lay down temperature of HMA and recommended to complete all the compaction process before reaching 115^0C and final rolling complete before 90^0C during day time in western province.

Key words: Temperature of Asphalt, HMA, TAC, Asphalt compaction

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LIST OF ABBREVIATIONS

Abbreviation	Description
HMA	Hot Mixed Asphalt
TAC	Time Available for Compaction
SLS	Sri Lanka Standard
ICTAD	Institute of Construction Training and Development
ABC	Aggregate Base Course
RDA	Road Development Authority
ASSHTO	American Association of state Highway Transport officials

1 INTRODUCTION

The two types of pavements used in Sri Lanka for pavement construction. Such as;

1) Rigid pavements
2) Flexible pavements

Rigid pavements are very rare in Sri Lanka and they consist of very stiff reinforced or roller compacted concrete surfacing over comparatively much softer ground. However, the flexible pavements are most common in the country and consist of three main layers from top to bottom, consisting of the bituminous surfacing, road base and sub base. Sometimes the sub-base is not laid. The shear strength, stiffness and the quality of the material of the layers decrease in the downward direction of the pavement.

The top most layer of a flexible pavement is an asphalt concrete surfacing or any other bituminous surface dressing like Double Bituminous Surface Treatment (DBST), Single Bituminous Surface Treatment (SBST) or traditional metal and bitumen application.

The most popular bituminous surface treatment in Sri Lanka is HMA due to its very good riding quality, durability, fast construction, construction easiness compared to other materials.HMA has higher stiffness or stability, resistance to adverse climatic conditions and is able to maintain consistent quality during manufacturing and lying.

The construction of quality asphalt pavement is the most important factor for compaction. During the compaction process, the material gets closer to each other expelling air voids by aggregating bituminous binder and a little filler. The HMA mixture consists about 95% aggregate by weight and ideally 3% - 5% of air voids. Aggregate helps HMA structure to lock together and bitumen is a binding agent to bind the aggregate and produce a mixture that stable and strong after compaction process is over. The typical cross section of HMA road pavement structure is shown in figure 1.1.

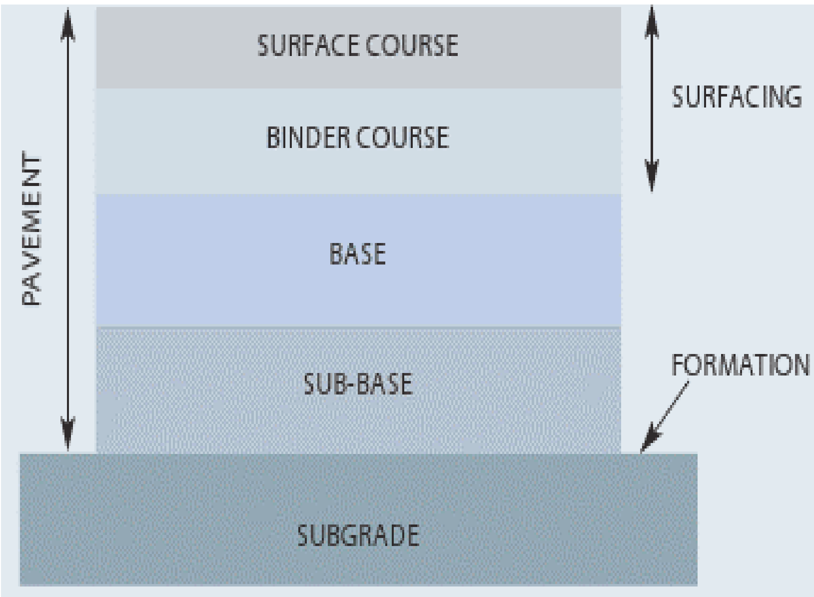

Figure1. 1 HMA road pavement structure

Temperature is the most important factor for compaction of hot mixed asphalt. The compaction temperature of the HMA is directly imposed to the workability of the HMA mixtures. The compaction density of the HMA for laying process is directly affected on ensuring quality of pavement in the field. The ratio between the volume of HMA (Hot mixed asphalt) samples taken from core cutting of newly laid hot mixed asphalt pavement and the samples prepared in laboratory to follow the Marshall method should not be less than 97%. However, in some construction locations, HMA compaction density does not match this requirement due to inadequate mixing and lay down temperature. In such situations, moisture damage of HMA can occur, weakening the sub grade which would result settling the pavement. Due to the above mentioned, cracks are formed on the surface of HMA increasing the air voids weakening the HMA surface which results in reducing expected life of the road pavement.

1.1 Problem Identification

Mixing temperature of HMA is dependent on the hauling distance and environmental condition of the site. In standard specification of ICTAD it has noted that the lay down temperature should not be less than 135°C. Since Sri Lanka is a tropical country, most of the locations' room temperature is about 32°C where day time road surface temperature increases to more than 60°C and wind speed vary with 0 - 20 km/h. Most of our technical person shaves limited knowledge about the time available for compaction of HMA. They only consider if the laying temperature of HMA meets the specification. However, some sites are far away from the asphalt mixing plant and hauling distance may be over 100 Km. In addition to that, some trucks may get delayed due to mechanical faults and vehicular traffic as well. Often, there are no proper HMA transport trucks to retain the temperature constantly and few of them use covering up tarpaulin to protect the heat dissipation. Due to the HMA laying process, it takes more time to lay down asphalt trucks and as a result, there are waiting asphalt trucks in long Queues. Due to the above reasons most of the suppliers tend to heat HMA over limits in order to meet the specifications and deliver to the sites.

1.2 Objectives

The primary objective of this research is to find the time available for compaction of HMA in the effect of wind velocity, lay down temperature, and ambient temperature. The secondary objective of this study is to check the value 135^0c, the minimum lay down temperature as specified in ICTAD for tropical climates.

1.3 Scope of work

This study is to be focused only to study the asphalt lay down minimum temperature and time available for compaction of HMA in day time for provincial roads in Western province.

2 LITERATUREREVIEW

2.1 Compaction of HMA

Compaction of HMA is very important for the life of road pavement. The most important and directly related parameters for the compaction of HMA are rolling procedures, techniques, temperature of the mix, mix properties, soundness and stiffness of the underlying base, type and numbers of rollers. Out of that temperature is the very important factor for compaction of hot mixed asphalt. The temperature influences workability of the HMA below presents some information gathered from literature review.

This literature review covers published research reports, journal articles, and other documents which discuss the Time available for compaction of HMA and lay down temperature of HMA in different site conditions and temperature influencing properties of the HMA.

2.2 Bitumen

This substance is called bitumen or asphalt cement. In UK, term “bitumen” and in USA, term “asphalt cement” are used for this substance. The term “HMA” is a mixture of bitumen and aggregate. The term “bitumen” comes from the Latin and the term “asphaltos” comes from the Greek. Bitumen takes from crude oil and it consists of organic liquids. The properties of bitumen are higher viscous, dark brown to black and sticky. The bitumen is capable of diluting carbon disulfide, and is primarily composed of highly condensed polycyclic aromatic hydrocarbons with having a molecular weight of 1800 – 3000.

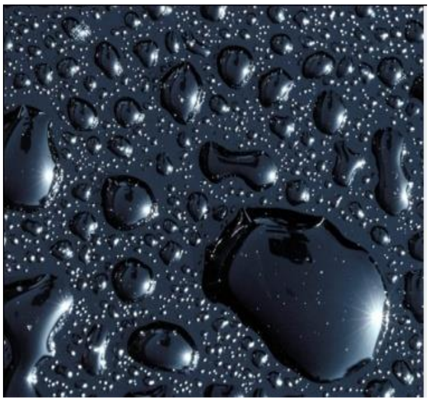

Figure 2. 1: 60/70 penetration grade Bitumen

2.2.1 Measurement of Bitumen Properties

Properties of bitumen are measured using the standard test methods. Bitumen hardness or softness is measured by penetration test. To measure depths of a standard needle that penetrated into the sample in 1/10th of a millimeter. Here the test is carried out to the standard procedure described in AASHTO: T 49.

Another measurable property of bitumen is the softening point. This indicates that temperature at which the substance attains a particular degree of softening under specified condition of test. The apparatus used for measuring the softening point of bitumen is Ring& Ball test. The test is carried out to the standard procedure described in AASHTO: T 53-89.

Ductility test indicates tensile properties or a measure of ductility. This test indicates that bitumen can be stretched in thin film without braking. This helps measure the binder coating around the aggregates. The ductility test indicates the distance in centimeters of a standard briquette of bitumen can be stretched in thread before break. The test is carried out to the standard procedure described in AASHTO: T 51-89.

Flash & fire point test is another important test carried out for bitumen. In the process of HMA preparation, bitumen gets heated in higher range of temperature. The test enables to identify the inflammability nature of the bitumen. The fire point is the observing temperature in which material gets ignited and burns for 5 sec. under specified condition of test. The test is carried out to the standard procedure described in AASHTO: T 48-89

2.3 Hot Mix Asphalt Concrete (HMA)

Hot mix asphalt concrete (HMA) production is carried out by heating the bitumen (asphalt binder) to reduce the viscosity and the aggregates should be heated to remove the moisture prior to mixing. Mixing is the process which is performed with the heating of aggregate at 150^0C – 170^0C and bitumen at 140^0C - 170^0C. The mixture of HMA temperature should remain within the limits of 145^0C -170^0C. Hauling, laying and compaction of HMA are carried out while the HMA is at sufficient heat. HMA is commonly used on highways, racetracks and airfields.

2.4 Asphalt mix design

The mix design decides the proportions of bitumen, coarse aggregate, fine aggregate, filler and amount of air voids which provide a strong, durable and stable pavement that serves for a design period without premature failure.

The main aim of the mix design is to determine the optimum quantity of bitumen binder that will hold the mineral aggregates together as a compact layer providing maximum strength to resist deformations and durability. The mix should have minimum air voids to allow volumetric changes during the working range of temperatures. In addition to this, site specific requirements should also be satisfied by the designed mix.

2.4.1 Type of Mix design

Different types of mix design have been developed in the world to suit different requirement. Some of mix designs have been developed by modifying previous or existing mix design methods. Out of available mix designs, following three mix design methods are more popular in the world.

- Marshall mix design
- Haveem mix design
- Super pave mix design

2.4.1.1 Marshall Mix design

Mr. Bruce Marshall was a former bituminous engineer with the Mississippi State Highway Department, originally conceived the concept of the Marshall method of mix design. The Marshall Mix design was further developed by the U.S. Corps of Engineer and applied to airfield pavements and later adopted for highway pavements.

The Marshall Mix design was the most commonly used before introducing the Super pave mix design system, and nowadays most commonly used design method in the world wide.

This procedure was recommended by the Asphalt Institute and they have published the procedures in detailed through the Manual of "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types (Manual Series – 2, MS-2)". The Marshall Mix design process is as follows.

2.4.1.2 Selection of aggregates

Local highway agencies were specified in the aggregate properties in each country. These requirements were adopted in Sri Lanka as listed below in table 2.1and the required gradation of the aggregate for dense grade HMA mixture listed below in table 2.2.

Table2. 1 properties of aggregates

Material Property	Percentage (%)
Los Angeles Abrasion Value (LLAV)	Not more than 40
Aggregate Impact Value (AIV)	Not more than 30
Flakiness Index FI	Not exceeded 35
Water Absorption	Not more than 2

Source: (ICTAD 2009)

Table2. 2Gradation of Aggregate for HMA

Aggregate gradation Sieve Size		Binder Course	Wearing Course Type I	Wearing Course Type II	Wearing Course Type III	Wearing Course Type IV
mm	µ m					
28		100	100	-	100	100
20		90 - 100	85 - 100	100	93 - 100	95 - 100
14		-	-	82 - 92	-	-
10		56 - 82	66 - 94	61 - 81	59 - 94	58 - 84
5		36 - 58	46 - 74	41 - 66	38 - 69	36 - 66
2.36		21 - 38	35 - 58	27 - 48	25 - 48	23 - 49
1.18		15 - 32	26 - 48	20 - 40	20 - 40	-
	600	10 - 26	18 - 38	15 - 35	15 - 32	-
	300	6 - 20	11 - 28	10 - 25	10 - 23	5 - 19
	150	3 - 13	7 -20	7 - 17	4 - 15	-
	75	1 - 7	3 - 12	5 - 9	3 - 12	3 - 8

Source: (ICTAD 2009)

2.4.1.3 Selection of asphalt binder (Bitumen)

The binder needs to comply with specification requirements. Bitumen is the hydrocarbon product and density at room temperature usually lies between 1.01 to 1.04 g/cm^3. Bitumen is black or brown in color. They are substantially non-volatile and soften gradually when heated. Bitumen is graded according to their penetration depth. The properties of bitumen used in HMA as follows in table 2.3.

Table2. 3 Requirements of bitumen properties

Requirements of penetration Grade Bitumen		
Type	60 / 70	80 / 100
Property	Requirements	
Penetration 25^0 C 100 gm 5 sec. 1 / 10 mm	60 / 70	80 - 10
Softening Point ^{0}C	48 / 56	47 - 55
Loss on heating for 5 hrs. at 163^0C		
(1) Loss in weight percent	Not greater than 1.0	Not greater than 0.5
(2) Loss in penetration, percent of original value	Not Less than 75	Not Less than 80
Solubility in trichloroethylene, percent	Not Less than 99	Not Less than 99.5
flash point (Cleveland open cup) ^{o}C	Not Less than 232	Not Less than 232

(Source: ICTAD 2009)

2.4.1.4 Compaction of the asphalt mixtures

The mixture of HMA is poured in to the 101.6 mm cylindrical mold and compacted in 4.5 Kg weight Marshall Compaction when dropped from 457 mm for the specified number of blows per specimen. Specified number of blows depends on the traffic condition of the road. When the traffic condition is low, medium and heavy, the number of blows applied per side of the specimen is 35, 50, and 75 respectively.

The guide line published by department of international development in United Kingdom for the design of hot mix asphalt in tropical and sub-tropical countries compaction and mixing temperature is according to overseas road note 19 as shown in Annex 1.

2.4.1.5 Marshall Mix design criteria.

Asphalt institute were recommended in five parameters for Marshall Mix design. They are as follow,

- Marshall stability
- Marshall flow
- air voids
- voids filled with asphalt (VFA)
- A minimum amount of voids(VMA)

Following table 2.4 shows the requirements for stability, flow, air voids and VFA and VMA. While table 2.5 shows the requirements for VMA. A mix design to be adopted must satisfy all these five criteria.

Table2. 4Marshall mix design requirements on Stability, Flow, Air voids, VFA, VMA

Traffic Category	Light		Medium		Heavy	
Compaction, No. of blows per side	35		50		75	
Stability, (KN)	Min.	Max.	Min.	Max.	Min.	Max.
	3.33	-	5.34	-	8.0	-
Flow, 001 in. (0.25 mm)	8	20	8	18	8	16
Air Voids, %	3	5	3	5	3	5
VFA, %	65	75	65	78	70	80
VMA%	Not less than 13		Not less than 13		Not less than 13	

Source: (ICTAD 2009)

Table2. 5Marshall Mix design criteria on VMA

Nominal Maximum Aggregate Size	Minimum Required VMA, %		
	Design Air Voids, %		
	3.0	4.0	5.0
8 (2.36 mm)	19.0	20.0	21.0
4 (4.75 mm)	16.0	17.0	18.0
3/8 in. (9.5 mm)	14.0	15.0	16.0
½ in. (12.5 mm)	13.0	14.0	15.0
¾ in. (19.0 mm)	12.0	13.0	14.0
1 in. (25.0 mm)	11.0	12.0	13.0
1.5 in. (37.5 mm)	10.0	11.0	12.0
2 in. (50 mm)	9.5	10.5	11.5
2.5 in. (63 mm)	9.0	**1.0**	11.0

(Source: ICTAD 2009)

2.5 Effect of Overheating Bitumen on Hot Mixed Asphalt

Effect of overheating bitumen for production of HMA research was done by (NurfazilahBinti 2012), University of Mukah Sarawak, Malaysia. He has found that overheated bitumen was proven to oxidize and harden more as the heating temperatures increase. The tests yielded the maximum heating temperatures for 60/70 penetration bitumen before it starts to lose the HMA properties is 189°C.

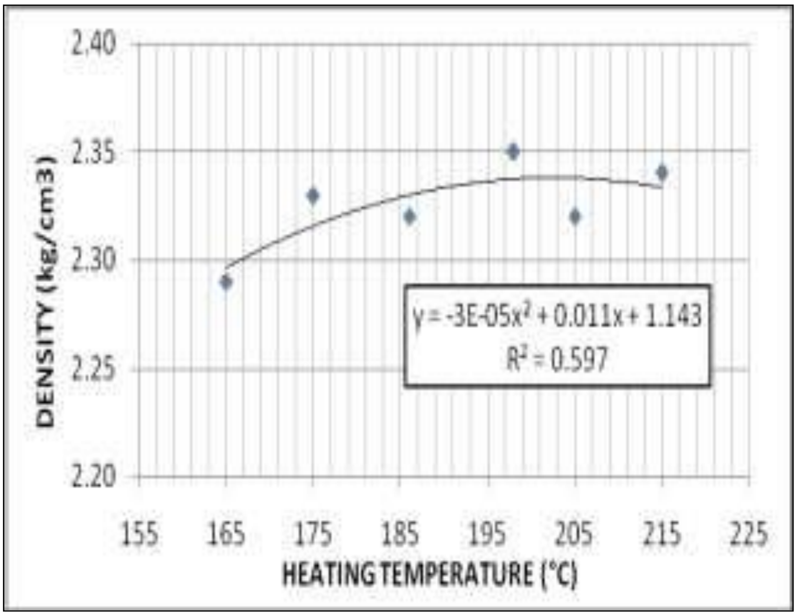

Figure 2. 2Effect of density for heating temperature.

Figure 2.2 shows the density vs. bitumen heating temperatures and maximum density for overheated bitumen when the temperature is at 195°C. When the temperature increases above195°C, density will decrease.

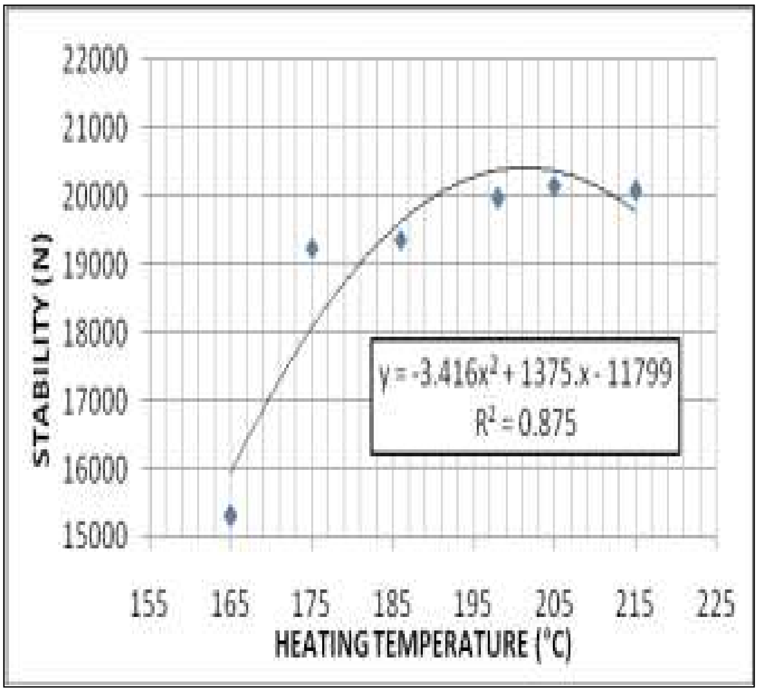

Figure 2. 3 Effect on heating temperature on Stability.

Figure 2.3 shows the relationship between stability and overheated bitumen mixtures and it indicates that the stability increases gradually with the increase of the bitumen heating temperatures and after 205°C it starts to decrease. If the stability is increased and too high, it will effect on the HMA significantly. The instability problem will occur as a result of excess bitumen. When the stability value in the HMA is significantly higher, it will cause stiffness and less durability. When the bitumen gets liquefied, it results in changing its rheological properties (Rheology is the study of deformation and flow of matte) and decrease the stability properties.

2.6 Factors Effecting Cooling of Asphalt

Many researchers around the world have identified, following factors affecting cooling of asphalt.

- Asphalt layer thickness
- Wind Speed
- Ambient temperature
- Solar flux
- Base temperature

The paper published by Wardati Hashmi, MohdRosliHaininb, Norfarah Nadia Ismailc, NurIzzi Md. Yusoffc, MohdEzreeAbdullahd, Norhidayah Abdul Hassanb (2015) has identified the cooling rate of HMA in tropical climate. They have found the effect of solar flux, wind, base and ambient temperature in a laboratory environmental. That illustrates environmental factor directly proportional to cooling rate of asphalt.

The paper published by Dr D.K Sachdeva and Nishantsachdeva (2018) swami keshvanand institute of technology in Jaipur states that, optimum compaction temperature is 140°C and minimum compaction temperature is110°C.The permeability increases to a very high rate as minimum compaction temperature reaches below110°C. This may cause breaking of bonding between aggregate and bitumen. As a result, water may easily penetrate to lower layers of the pavement and damage it before reaching the design life of the asphalt.

2.7 Machines used for compaction.

Asphalt laying and compaction are carried out in two stages. The primary compaction is carried out by the paver and the secondary compaction is done by using static and pneumatic rollers. The required compaction of HMA is necessary to maintain a good condition of the pavement throughout the expected life with minimum damages. The compaction process enables particles to get closer and remove entrapped air in HMA uniformly that results in achieving a higher density. Inadequate compaction results in low stiffness of HMA and reduces the fatigue life which results to accelerate aging process and moisture damage of the pavement. The compaction equipment used for asphalt work is paver screed, steel wheeled rollers and pneumatic-tyred rollers. The condition of rollers and paver used for asphalt work, significantly on the finished surface of the HMA.

The paver which moves in a lower speed, can apply its weight to the HMA and compress the underneath contact ground area to increase the degree of compaction. The steel wheel rollers are further used to compress the under laying HMA to achieve the required compaction. When some rollers equipped with vibratory drums which enable a dynamic load to static roller weight resulting greater compactive effort. Pneumatic-tyred rollers used to create uniform compaction coverage over the width of the roller. Pneumatic roller tyre pressures should be even and wheel bearings should be in good condition. Otherwise uneven tyre pressure will result for variable degree of compaction of the HMA. Figure 2.4 shows used machineries for compaction of HMA.

(a) Asphalt paver

(b) Tandem wheel roller

(C)Pneumatic roller

Figure 2. 4 Asphalt laying and compacting equipment

3 METHODOLOGY

3.1 General

Hot-mix asphalt (HMA) lay down temperature is important for workability and compatibility of the mixture. If HMA mixtures get cooled down below the desirable limit of the temperature, binder becomes more viscous and resistant to deformation.HMA compacting with the above situation leads to non- uniform densities. Further, that will decrease the HMA density reducing the stiffness and fatigue life of the pavement. As a result of the above, moisture damage will occur of the road pavement which weakens the sub grade, reducing the design life of pavement. Therefore, the compaction temperature is very important for HMA. In addition to that, most of the time we are not aware of the time available for compaction of asphalt in different site conditions such as wind speed, solar flux, layer thickness etc. The objectives of this study will be achieved by conducting laboratory tests as well as field tests. These tests aim at investigating time available for compaction of asphalt in different site conditions and identify minimum lay down temperature which satisfy the standard specification of ICTAD (2009) Sri Lanka.

3.2 Field test

In the field, a lot of data was collected during the HMA laid down time. The surface temperatures were measured on already HMA laying surfaces and newly prepared aggregate base course surfaces by using non- contact infrared thermometer in day time (11.30 am to 5.30 pm) in one hour intervals and recorded. These temperatures were measured and recorded with different lay down temperatures of HMA and wind velocities during the paving time with five minutes time intervals over 30 minutes time period for mat thickness 40 mm, 50 mm by using glycerin applied thermometer. These tests were conducted at four sites and out of those, two were of asphalt base and other two were ABC base.

3.3 Laboratory test

In the laboratory two samples were selected with 4.7% and5% bitumen content. Both samples were heated to 160^{o}C and kept in room temperature. Then the cooling rate was observed in 15 minutes intervals over 90 minutes time period.

In order to measure the cooling rate of asphalt due to wind speed in the laboratory, Asphalt specimen slab was prepared. For that, it was selected600mmx600mmx80mm steel box and insert small holes of 20mm,25mm, and 60mm distance from the bottom of the box in three sides. After that the asphalt sample and box were kept in oven and heated to135^{o}C. After heating to sufficient temperature, the box was taken out and fill asphalt up to 40mm by rolling 50mm diameter and 100mm length steel rod generating the same field action on it. Further, the glycerin applied thermometer inserted to the sample to observe the temperature.

After that, a Stand fan was switched on and set to the swing mode to create a wind blowing condition. Then the fan distance change to generate 2.5 km/h wind speed and the wind speed recorded through an anemometer. Then the temperature variation was recorded with 5 minutes time intervals in a 30 minutes time period. This experiment was repeated in,3.5km/h,4.5km/h,5.5km/h wind speeds by changing the fan speed, and distance. This test was repeated for 50mm, 60mm layer thickens respectively.

In order to check the bulk density, stability and flow of the mix, 3 samples were prepared for each 75^{o}C, 90^{o}C, 105oC, 120oC, 135oC, 150oC temperatures respectively for Marshall Test. The same laboratory experiment was carried out and recorded above parameters.

4.1 The temperature variation of different road bases.

The temperature variation with time for Aggregate base course and HMA road surface was measured at Artigala road of western province on 07thof July 2018. The measured results are as shown in the table 4.1

Table 4. 1 Temperature variation of Aggregate Base Course and HMA bases.

Temperature variation of different Road Bases		
Measured Time	Aggregate Base Course (°C)	Asphalt(°C)
11.30 a.m.	45	49
12.30p.m	50	54
1.30p.m	56	65
2.30p.m	50	60
3.30p.m	45	51
4.30p.m	42	44
5.30p.m	37	36

4.2 Temperature variation of HMA with different bitumen content.

The Temperature variation of different bitumen contained HMA samples which kept under room temperature to cool down (26^{O}C) in the laboratory. The measured values in fifteen minutes time intervals over a 90 minutes time period are as shown in table 4.2.

Table 4. 2 Temperature variation with time for different bitumen contents in HMA

Measured Time min.	Temperature ^{O}C	
	4.7% Bitumen	5% Bitumen
0	162	162
15	131	140
30	104	119
45	87	101
60	75	89
75	65	77
90	57	66

4.3 Comparison of cooling rate of HMA for field and laboratory.

The cooling rate of HMA in the field and laboratory were measured. The field measurements were taken at a sunny day environment with a temperature of 29 ^{O}C and no wind blowing situation. The selected HMA layer was50 mm thick without compaction. The laboratory measurement taken at room temperature of 25 ^{O}C and HMA layer thickness of 50 mm. The test results are as shown in table 4.3

Table 4. 3 temperature variation of HMA in lab vs. field. (50 mm layer thickness).

Time	Temperature in Lab	Temperature in field
0	145	138
5	132	121
10	123	118
15	116	110

4.4 Temperature variation of asphalt with time subjected to wind speed.

The Temperature variations of HMA in different wind speeds and mat thickness in laboratory at room temperature (26^{O}C) are shown in table 4.4.

Table 4. 4 Temperature variation of HMA for different wind speeds and mat thicknesses.

	Layer 40mm				Layer 60mm			
Wind speed \ Time	0	5	10	15	0	5	10	15
Ambient Temp 32^{0}C 0 km/h	145	129	118	112	145	132	123	116
Ambient Temp32.8 ^{0}C 5.0 km/h	138	119	106	99	138	120	109	100
Ambient Temp33.5 ^{0}C 10.0 km/h	140	115	103	96	140	118	105	96
Ambient Temp33.5 ^{0}C 15.0 km/h	135	110	93	86	135	114	95	89

4.5 HMA Temperature variations with time for different lay down temperatures.

The temperature of HMA when delivered to site is depending on plant temperature as well as environmental conditions, supply modes and hauling distance. So that the laying temperatures were different across different HMA truck loads. The table 4.5 shows, HMA temperature variation with time for different lay down temperatures.

Table 4. 5 Temperature variation of HMA with different lay down temperatures.

Time (Min)	Lay down temperature			
	$124\,^{O}C$	$145\,^{O}C$	$128\,^{O}C$	$132\,^{O}C$
0.00	124	145	128	132
5.00	118	139	121	122
10.00	114	131	116	118
15.00	106	125	112	109
20.00	101	115	107	102
25.00	99	112	101	96
30.00	95	109	98	88

4.6 Temperature variation with time for different mat Thickness.

Different asphalt mat thicknesses were laid on Horinton road in Aivssawella on 8^{th} of November 2018 to adjust the Aggregate Base Course layer thickness. The temperature variation recoded in 5 minutes time intervals over a 20 minutes time period for each layer thicknesses of HMA laid on Aggregate Base Course as shown in Table 4.6.

Table 4. 6Temperature variation with various mat thicknesses

Time (Min.)	Mat Thickness, mm			
	45 mm	50mm	55mm	60mm
0	135	130	124	128
5	121	122	118	121
10	111	116	114	118
15	99	104	108	112
20	93	98	101	107

4.7 Effect of compaction temperature on Marshall Parameters

In a laboratory Marshall Samples were prepared in different temperatures and tested in standard procedure. Variation of Marshall Parameters with different casted temperatures are shown in table 4.7

Table 4. 7 Marshall Parameter variation with temperature

Temperature(^{0}C)	Stability (kN)	Va (%)	VMA (%)	Flow (0.25mm)	Bulk Density(gm/cc)	compaction %
75	4.6	6.2	17.3	8.3	2.356	97.8
90	6.8	5.8	16.9	8.7	2.368	98.3
105	7.6	5.4	16.5	9.3	2.378	98.7
120	8.3	4.9	16.1	10.6	2.391	99.2
135	10.5	4.7	15.9	12.9	2.396	99.5
150	11.6	4.2	15.5	13.7	2.408	100

Figure 4. 1 Marshall Samples for different compaction temperature

Figure 4. 2 testing of Marshall Parameters

5.1 Introduction

The observations taken from Marshall Parameters, field and other laboratory testing data on different compaction temperatures were analyzed in order to compare with the values in the standard specification of ICTAD (2009).

5.2 Bulk density

When the temperature of HMA is increased, the bulk density of HMA also increases. Marshal density values has been plotted in figure 5.1 which shows that in low temperatures compaction ability of HMA is less compared to higher temperatures.

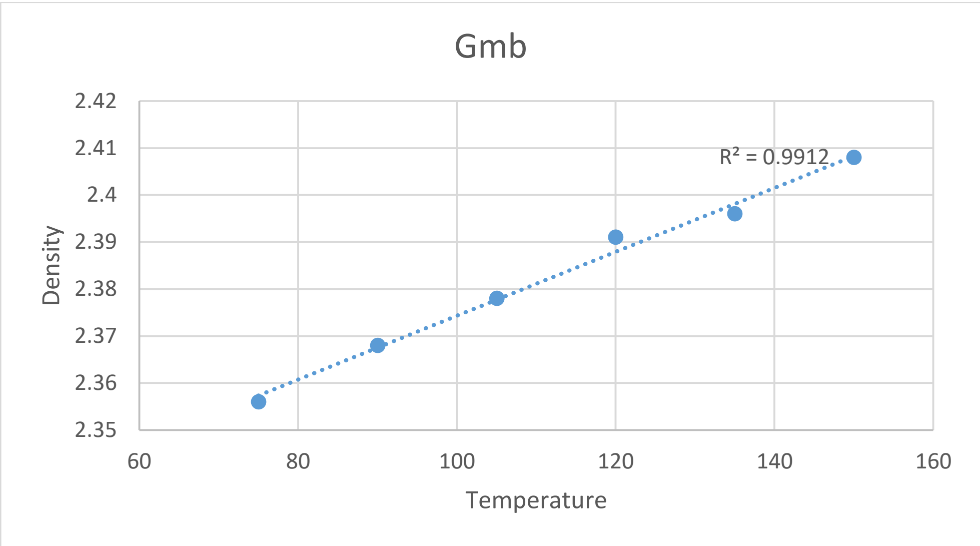

Figure 5. 1 Density variations with Compaction Temperature.

5.3 Air Voids

The relationship between air voids and compaction temperature has been plotted and shown in figure 5.2.It shows that when the temperature increases, the content of air voids have reduced. At the temperature of 115 ^{O}C, the content of air voids are around 5% and when the temperature increases the proportion of air voids also decreases. This indicates that HMA is more workable in low viscous bitumen and it supports to lubricate aggregate particles well at the higher range of temperatures. When the temperature increases the amount of void in HMA decreases. According to the ICTAD Specification, it has specified voids limit between3-5 percent, but in this observation, air voids increased that limit below 118^{O}C temperature. So that compaction must be achieved before cooling to118^{O}C of HMA.

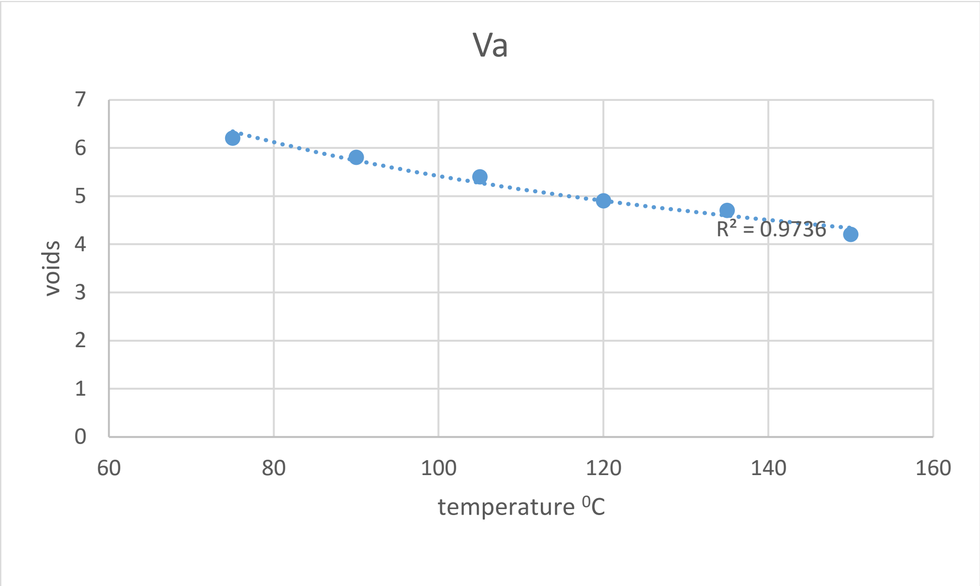

Figure 5. 2Air voids in sample variation with Compaction Temperature.

5.4 Stability

In the figure 5.3 shows the relationship between stability and compaction temperature. When temperature increases 75 ^{O}C to150 ^{O}C stability increases gradually. Therefore, at higher temperatures the viscosity of the bitumen is comparatively low and results in good lubrication of aggregate particle and this produces better interlock between particles in the compaction of HMA. However, in ICTAD specification, it has noted that stability should not be less than 8.0. The figure 4.3 indicates that below 115^{O}C of compaction temperature, stability is not up to the standards per the specification limit. Therefore, the compaction must be achieved before cooling to115^{O}C of HMA.

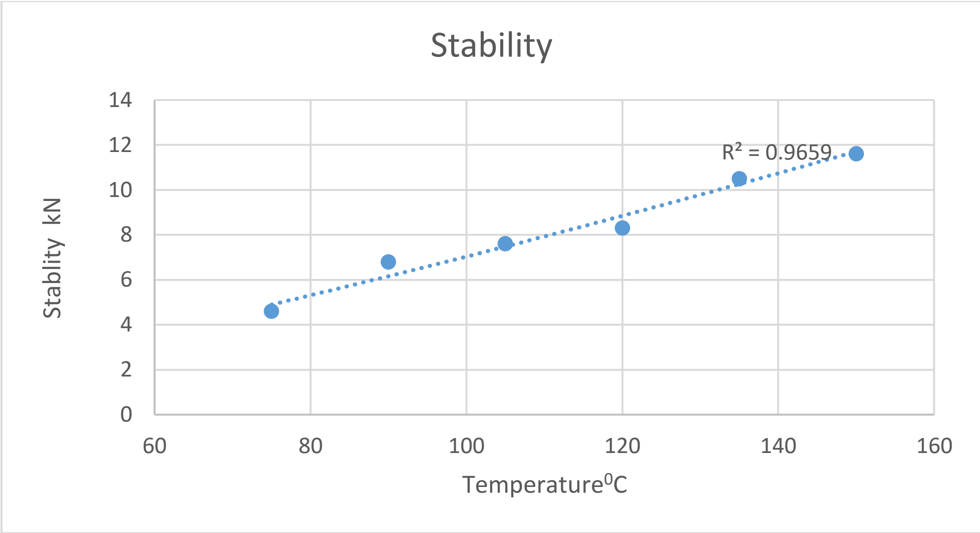

Figure 5. 3 Stability variation with Compaction Temperature.

5.5 Flow

Different compactiontemperaturesoftheMarshalFlowvaluesof0.25 mm have been plotted in figure 5.4. It is shown that the flow values increase when the temperature increases. According to the ICTAD specification, flow values must be kept within the range of 8 -16. Flow values give idea of flexibility of the pavement and when it is more than 16 which indicates the higher deformation. Further that result in deforming the surface drastically and reducing its design life. Moreover, when the value is below 8, that results in making the surface stiffer, forming cracks and moisture damages to the surface.

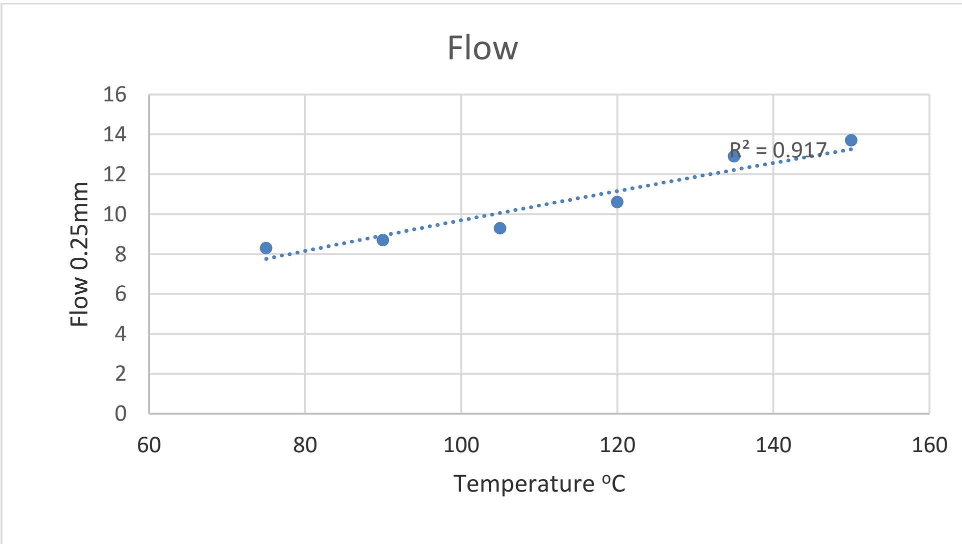

Figure 5. 4Marshall flow Vs Compaction Temperature

5.6 Temperature variation for road base with time.

When the road surface is exposed to the sunlight before laying HMA, surface temperature rises. The rate of increasing surface temperature depends on ambient temperature. When ambient temperature is higher, surface temperature also get increased.

Figure 5. 5Asphalt laying on ABC base

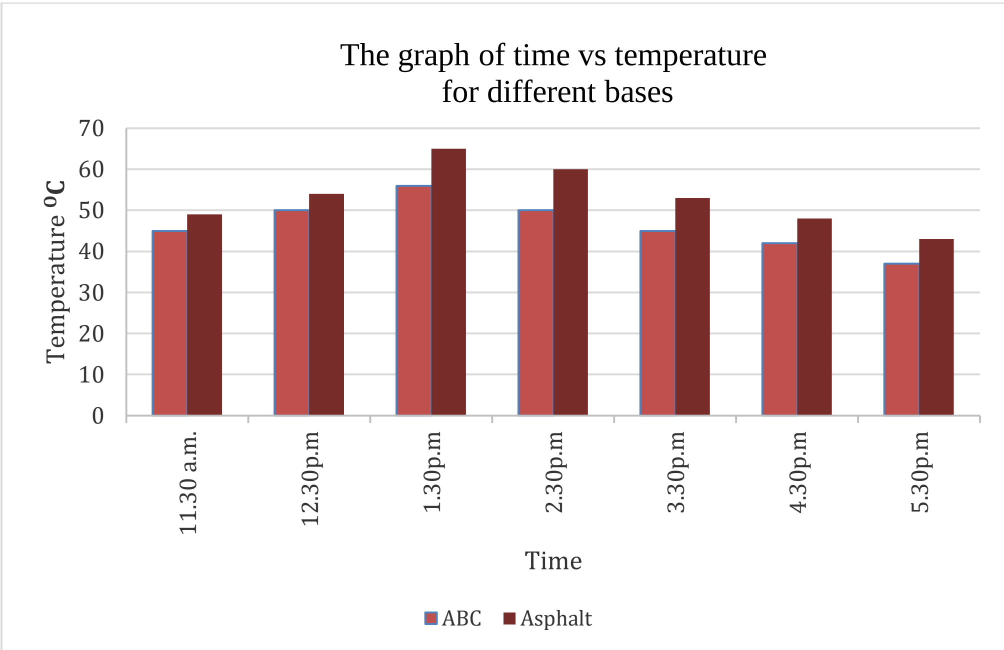

Figure 5. 6 Base temperature comparison for different bases with change of time.

The temperature variation with time for different bases is shown in figure 5.6. In day time, surface gets heated when absorbing solar flux. In ABC base, the heating rate was low compared to asphalt base. When the Sun rises, solar flux emits and at noon time it gets maximum. But the maximum value in surface temperature was observed between 1.30 pm-2.pm. So that, most favorable time for asphalt laying was between 1.30 pm to 2. 30 pm. During this period asphalt cooling rate was low and take maximum time for compaction compared to other time periods in day time.

5.7 Temperature variation with bitumen content

Figure 5.7 shows that the temperature variation with time of asphalt samples with different bitumen contents. When the bitumen content is higher, the respective sample cooling rate reduces. When the bitumen content increases, volume of voids fill in the HMA mix by the bitumen and coating rate of the mineral aggregate has increased. So that the heat absorption is increased and cooling rate reduced for higher bitumen consisted asphalt which retains temperature for a longer time and increased TAC for HMA.

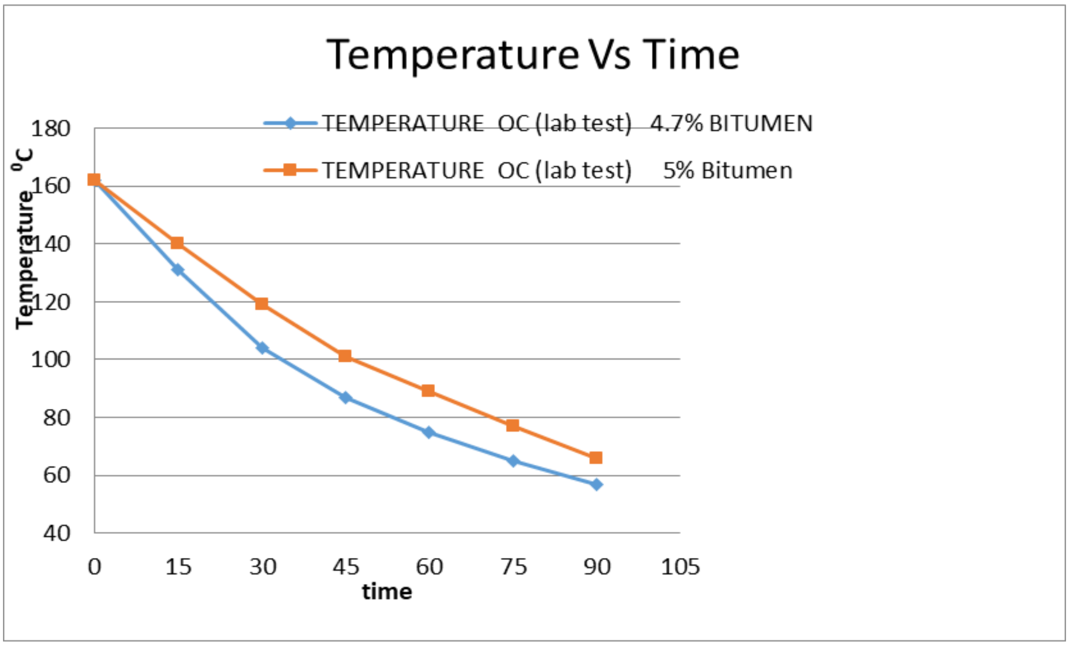

Figure 5. 7 Temperature variation time for different bitumen content

5.8 Temperature variation with time for wind speed

In figure 5.8, it shows that the temperature variation with time for HMA due to various wind speeds. It shows that, at higher speeds of wind blowing, the cooling rate of HMA rapidly increases with compared to 0 km/h. Wind speed makes more impact to the cooling rate of HMA rather than the layer thickness

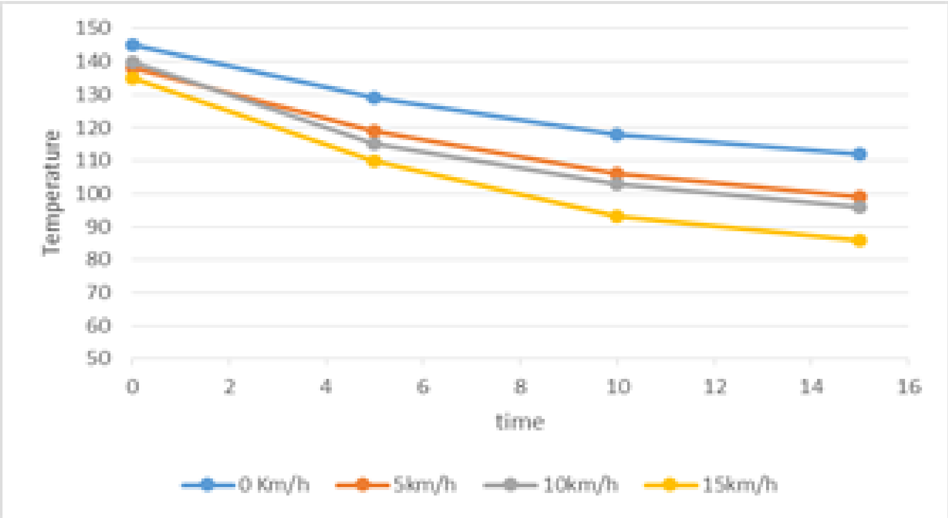

Figure 5. 8 Temperature vs time for different wind speeds

5.9 Comparision of cooling rate for different mat thickness.

As in figure 5.9,it shows thecooling rate of asphalt for different layer thickness in room temperature. When temperature ishigher, cooling rate also gets a higher value and decreases at 130C^0. The figure shows that when thelayerthickness is higher, cooling rate reduced compared to HMA with less layer thichnes.When the layerthickness was higher,it has moreheat absorption capacity withlessheat dissipation rate. Threfore, when thelayerthickness are higher, time availablebfor the compaction HMA increases.

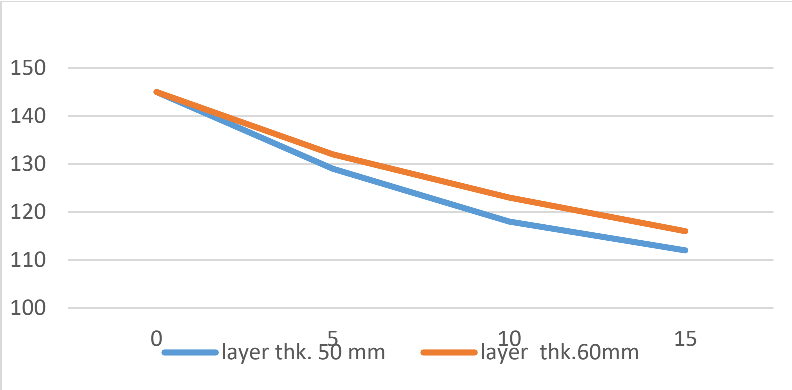

Figure 5. 9 Cooling rate of asphalt Vs. different layer thickness.

5.10 Field Analysis

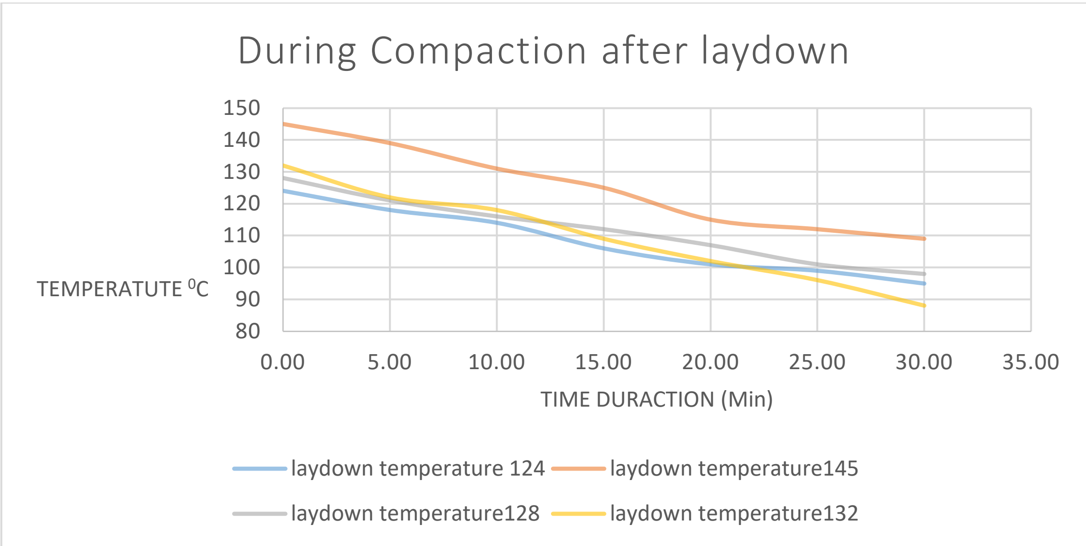

Figure 5. 10 Temperature variation Vs different lay down temperature

The figure 5.10 shows the, compaction temperature variation with time for different lay down temperatures in the field. In the field when asphalt lay down in 145 ^{O}C, it cools in first 5 minutes at a rate of 1.2 ^{O}C/min and then next 5 minutes' cools at a rate of1.6 ^{O}C/min and reach to 131^{O}C within 10 minutes. Therefore, during the laying time, when the compaction is carried out by using asphalt paver, cooling rate was low and when applying dynamic roller for compaction, it increases. According to literature review, 85% degree of compaction achieve in paver and 91% using dynamic roller. According to the ICTAD specification, intermediate rolling should be finished before 110 ^{O}C and final rolling finished before 95^{O}C.

6 CONCLUSION AND RECOMMENDATIONS

These studies proposed the time available for compaction of hot mixed asphalt and evaluate the minimum compaction temperature for HMA. Compaction time depends on initial laying temperature, wind speed of the surrounding, base temperature and type of it, intensity of solar flux, ambient temperature and layer thickness. Temperature has significant impression on compaction of HMA as well as hot mix properties.

During this study, it was realized that Marshall Parameters considerably change with compaction temperature. For instance, when temperature increased, density also increased with no significant effect of the ICTAD (2009) specification recommended values. When temperature increases, air voids decrease. However, in accordance with ICTAD (2009) specification, it has a range of 3-5 percent. At compaction temperatures below 118^{O}C that limit was greater and do not comply with our standard. Other parameter of Marshall is the stability, at a temperature of 115^{O}C observation is 8 KN and below that temperature it has been less than 8 and contradicts to specification. Flow values varied in between 8-16 and within the specified limit. In the field more samples were tested in different site condition and lay down temperature below the standard specification giving required degree of compaction as per the standard.

On the basis of above study following conclusions can be made. The best suitable minimum compaction temperature of HMA is about 115^{O}C and more, considering above mention factors in the field. So that lay down temperature could be below135^{O}C without significant effect of laying and compaction of asphalt. However, the compaction must be completed before reaching temperature around 115^{O}C. Compaction densities of asphalt can be achieved when apply more roller passes and apply more effort during compaction. Further it can be recommended to develop mathematical model to consider above parameters to estimate the time available for compaction of asphalt.

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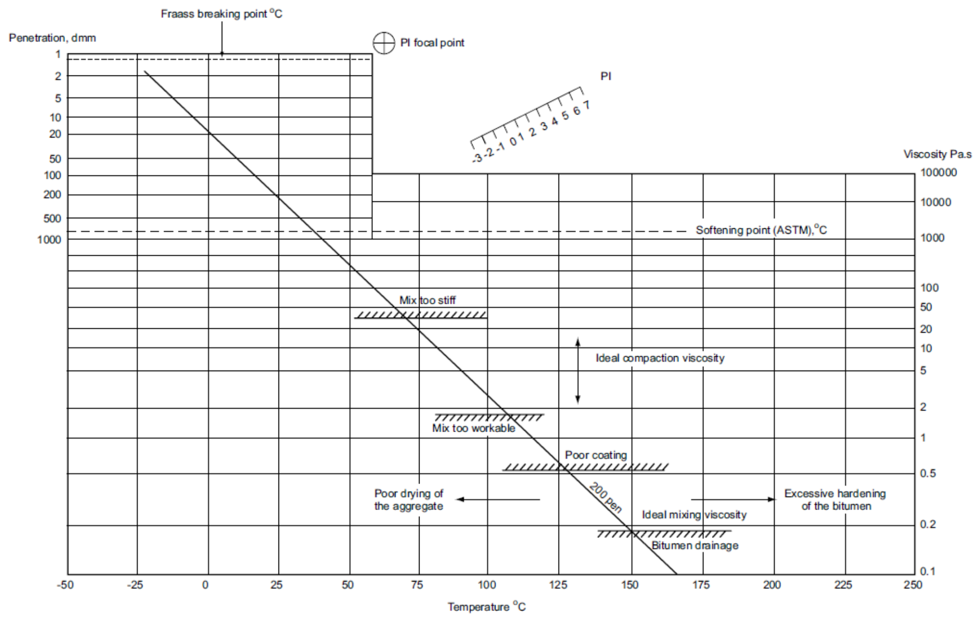

Figure B2 A bitumen test data chart showing 'ideal' bitumen viscosities for optimal mixing and compaction of a dense bitumen macadam (Shell Bitumen Handbook, Whiteoak, 1990)