

## TRAFFIC OPENING TIME AND TIME AVAILABLE FOR COMPACTION FOR FRESH ASPHALT LAYER USING SLAB SPECIMENS MODEL

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40°C

85°C

( )

270 100

52 5

%75

**Abstract** The Time Available for Asphalt Compaction (TAC) and the Traffic Opening Time (TOT) are highly affected by the mix temperature. These two time intervals are considered as major elements in compaction process. TOT is the time from laying asphalt to the point where the paved road is opened for traffic flow. This time is estimated at the surface temperature of value less than 40 °C at which the reduction rate becomes constant. While the time available for compaction (TAC) is the time from laying to that at which the mixture temperature is 85 °C which is called End Compaction Temperature (T<sub>E</sub>). In local

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practice, the asphalt paving control mechanisms quoted from the locally used specifications are normally the limits of the delivery and laying temperatures. There are no items to predict these control elements and to be specifically related to the local conditions. This study aims at providing technical specifications for these elements using laboratory and field tests. Study parameters include: layer thickness, mixing temperature, wind velocity, layer confinement and solar radiation. Hot Mix Asphalt (HMA) slab specimens with fixed dimensions are used in all tests as model for asphalt layer and are compacted using manually operated steel roller. HMA is composed of binder layer with max. aggregate size of  $\frac{3}{4}$ ". Temperature measurements are taken from slabs at different positions (middle, corner and surface). The laboratory test results showed ranges for the TOT from 100 to 270 minutes and for TAC as 5 to 52 minutes. Heat losses at different cases are estimated. The losses can reach 75% of mixing temperature. As a validation measure, temperature measurements were taken from variety of paving projects at the field. The field results confirmed to a large extent the Laboratory tests results.

**Key Words:** Binder Layer, Compaction, Traffic Opening Time (TOT), cooling time, End Compaction Temperature ( $T_E$ ), Time Available for Compaction (TAC), Heat loss.

### **1. Introduction**

There are many elements to be considered during the pavement construction; mainly during compaction. The Time Available for Asphalt Compaction (TAC) is one of the major controlling elements in this process. The TAC can be defined as the period taken by the asphalt mix to cool and stiff to the point where it can absorb the applied compaction energy without allowing the aggregate particles to move[1]. The Hot Mix Asphalt (HMA) temperature at this point is called End Compaction Temperature ( $T_E$ ). Beside that, the Traffic Opening Time (TOT) is also an important element regarding asphalt compaction. One main factor affecting the two elements is the HMA temperature itself. When reducing the HMA temperature, the chance of reducing the air voids content will be lower than at higher temperature. This stems from that bitumen is a visco-elastic material.

#### **1.1 Study Problem**

Based upon the aforementioned brief discussion, it is obvious that the TOT and TAC are important control elements for asphalt compaction. In local practice, the control mechanisms quoted from the locally used specifications are normally the acceptable limits of the delivery and laying completion temperatures. Research is needed to validate these such limits in order to be specifically related to the local conditions, i.e. material characteristics, environmental conditions and compaction mechanisms to suite locally environmental conditions.

## **1.2 Study Objectives**

The aim of this research is to investigate the TOT and TAC for HMA and considering major parameters affecting compaction process.

More specifically, the study work is intended to achieve the following objectives:

1. To investigate how the cooling time of HMA is affected by the following main parameter: layer thickness, mixing temperature, wind velocity, confinement, solar radiation and shade.
2. To determine the Time Available for the Compaction procedures (TAC) to reach the compaction end temperature ( $T_E$ ) limits. This is supposed to lead to a better control during compaction process.
3. To investigate the amount of heat losses related to each affecting parameter from the tested HMA.
4. To investigate the values of the Traffic Opening Time (TOT) at which the temperature variation becomes negligible and the paved road is opened for traffic flow.
5. To propose specifications to be used in the local industry related directly to the asphalt compaction procedures.

## **2. Methodology**

The objectives of this study are achieved by conducting laboratory and field tests. These tests aim at investigating the TAC and TOT at different cases related to the previous mentioned influencing factors considering the study limitations. The study methodology is discussed briefly below:

### **2.1 Laboratory tests arrangement**

Laboratory test program is designed in order to provide the necessary data. The program considers the influence of all above mentioned parameters (Point 1 in Study Objectives). Table 1 shows the matrix for the laboratory test program. The study scope covers the investigation of binder asphalt mixture with max. aggregate size of  $\frac{3}{4}$ ". Laboratory produced HMA slab specimens were used as HMA model for temperature measurements. The slab specimens are produced by heating the binder mixtures, to mixing temperature value as in the testing program (130 °C, 145 °C, 160 °C). The used HMA slabs in the test program are of constant dimensions and variable thickness (4, 6, 8 cm). The slabs are manually (by hand) compacted to a constant number of passes using a steel-wheel roller. The temperatures are measured by digital thermometer from the HMA slab specimens at three different positions over a period of time as it cools. These positions are located at:

- 1- the middle of the slab at depth equal half of slab thickness.

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- 2- the corner of the slab at depth equal half of slab thickness.
- 3- the slab surface.

### 2.2 Laboratory mixture properties

Before starting the laboratory temperature measurements, tests are done on the main HMA components; aggregates and bitumen. Tests are done according to Ministry of Housing and General Works (MOHW) specifications. The aggregates used are well-graded crushed limestone. The used bitumen type is 60/70 penetration grade with optimum asphalt content = 5.5% in all the laboratory tests. Tables 2 and 3 show the physical properties of the aggregates and the bitumen. Aggregate gradation is presented in Figure 1.

### 2.3 Laboratory test apparatus

The apparatus used in the HMA slab temperature laboratory measurement can be summarized as follows:

#### 2.3.1 HMA slab mold

A steel mold with inside dimensions of 40x40x50 cm is used as shown in Figure (2). Photo of this mold is shown in Figure (3). Figure (2) shows the measurement positions as mentioned above. The HMA slab thickness is determined as that of world wide used binder layer thickness. The remaining mold is filled with a compacted sand heated to 100 °C as heat insulation.

The slab inside surface area is calculated to provide a thickness to length ratio less than or equal to 0.2 stated that this limiting ratio for square slab is to ensure that temperature variations at a mid-slab position can be modeled using one dimensioned plan-wall theory [2,3].

#### 2.3.2 Steel – wheel roller

The manual operated roller is of 8 cm diameter and 39 cm length. The own weight of the roller is 10 kg. The effort can reach 70 kg during compaction with the effort of the person doing the rolling.

Three tests with different number of passes (25, 30 and 35 passes No.) are conducted to verify the adequacy of the proposed manually compaction procedures. These tests aimed to find adequate number of passes needed to achieve the proposed voids ratio in the mix. The tests are conducted on a HMA binder slab of 6 cm thickness and 130 °C mixing temperature. Table (4) presents the percent air voids in the compacted HMA slab specimens for each No. of passes case. A number of 35 passes is selected and fixed through all the laboratory tests.

In previous studies, similar HMA slab specimens were automatically compacted to achieve air voids ratio of 17% [Chadboum et. al., (1998), Fwa, et. al., (1995), Schulz et. al., (1993) and Chadboum et. al., (1998)]. This value is near to that achieved manually through this study.

## 2.4 Laboratory test procedures

The procedures for the temperature measurement can be summarized as follows:

- 1- Heat the asphalt binder mix to the desired mixing temperature as in the test matrix shown in Table 1.
- 2- Heat the mold base material (sand, as shown in Figure 2) to about 100 °C and lay it. The base layer should be leveled and compacted.
- 3- Heat the steel-wheel roller to about 80 °C.
- 4- Record the ambient air temperature.
- 5- Place the hot asphalt mixture in the steel mold, taking care to avoid segregation and loss of material.
- 6- Compact the specimen manually to 35 passes number using the steel – wheel roller.
- 7- Record the time passed from starting HMA laying until finishing its compaction. This time is added to the value of the cooling time.
- 8- Start the record at mid slab position, followed by the corner slab position and finally the surface slab position.
- 9- Record continuously the slab temperature over time in the three positions using the thermocouple thermometer. The test continues to the time that the recorded slab specimen surface temperature reaches nearly the ambient air temperature during the test.

## 2.5 Laboratory test parameters

The main test parameters used in the laboratory test program are:

### 1- The HMA slab thickness (h):

Three different thickness (h = 4, 6 and 8 cm) are used. These values are the ordinary used both locally and abroad and confirm with many worldwide specifications such as ASSHTO [4], ZTV Asphalt StB 94[5], and locally – used technical specification in Gaza Strip.

### 2- The mixing HMA temperature ( $T_o$ ):

Three different mixing HMA temperature are used ( $T_o = 130^\circ\text{C}$ ,  $145^\circ\text{C}$  and  $160^\circ\text{C}$ ). The selection of these values depends on the upper and lower limits of the HMA field laying temperatures according to the local requirements in the technical specifications.

### 3- The wind speed:

Two cases are considered in this study; the existing and non existing of the wind effect during the temperature measurement of the HMA slab specimen. The wind speed value used is 7 meter/sec. This effect

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was simulated by a fan located 1.5m horizontally from the slab specimen surface.

### 4- **The solar radiation:**

Similar to wind speed parameter, two cases are considered; the existing and none existing of solar radiation.

### 5- **Layer confinement:**

This parameter is considered by measuring the temperature both at middle and corner slab positions. The difference of measurements reflects the influence of layer confinement on cooling time of HMA. However, other main parameters are being constant during the whole testing program. These parameters are:

#### 1- **Aggregate type, filler content, bitumen viscosity and content.**

These parameters remained constant because only one type of bitumen is available in Gaza Strip. This led not to consider the aggregate type, filler content, bitumen viscosity and content as a variable parameter in the testing program. To guarantee the consistency of this parameter, one typical mix is considered which is binder  $\frac{3}{4}$ " class, as shown in Figure 1.

#### 2- **Number of passes and compactor type.**

Thirty five (35) passes are considered for all cooling time temperature tests. Moreover, one constant manually operated steel wheel roller is considered in the tests. In addition, the manual compaction process is performed by the same person with an approximate constant effort in all tests.

#### 3- **Underlying surface temperature:**

Constant underlying surface temperature is adopted in the tests which is 100 °C. This factor is not considered in the study as the test model (by its dimensions) guarantees one direction heat transfer from hot to cold surface; i.e. from downward to upward.

#### 4- **Air temperature:**

This parameter remained constant to large extent in all laboratory tests. All these tests, except that for investigating the solar radiation effect, are done with air temperature range from 26.5 to 28 °C. The air temperature value was about 34 °C in case of solar radiation measurements, similar to that in the field measurements tests.

#### 5- **Atmosphere and humidity:**

These parameters are of less and they were neglected in the experimental program.

## 2.6 Criteria of laboratory results analysis

Forty eight laboratory tests are performed to investigate the effects of the slab thickness, mixing temperature, wind speed and solar radiation on the TOT and TAC values of binder layer. These tests are arranged in a matrix presented above in Table (1). Figure (4) presents the definitions of the essential analysis element used for results analysis in this research. These criteria are:

- The Traffic Opening Time (TOT). It is the time from laying asphalt to the point where the paved road is opened for traffic flow. This time is estimated at temperature less than the surface temperature of 40 °C at which the reduction rate becomes constant [6]. This limit is suitable for local environmental conditions.
- The Time Available for Compaction (TAC) at each test case. TAC is the time from laying to that at which the mixture temperature is 85 °C [2] or 90 °C [7]. This temperature is called End Compaction Temperature ( $T_E$ ). The  $T_E$  values, measured at the middle of the slab, used in this research is 85 °C.
- The heat losses of the slabs at various recording positions in case of 4, 6 and 8cm slab specimens. This is calculated as follows:

$$\text{Heat loss} = (T_o - T^*) / T_o (\%)$$

Where;

$T_o$  is the mixing temperature (Figure 4)

$T^*$  is the temperature where the cooling time rate curve start to be flatter.

This temperature is estimated at different cooling time values based on the applied parameters. At normal parameter (no wind or solar radiation effects),  $T^*$  is determined at 50 min. from slab laying. For wind effect case,  $T^*$  is determined at 30 min. While for solar radiation effect,  $T^*$  is determined at 100 min.

Figures (5 - 20) show the test results in the case of applying different mixing temperatures, wind and solar radiation effects on TOT and TAC at various recording position in case of 4, 6 and 8cm slab specimens.

Different values of the TOT and TAC are noted based on the applied parameters and test conditions. The TOT and TAC values at various mixing temperatures and influencing parameters as resulted from laboratory tests are presented in Tables (5) and (6) respectively. Figures (21) and (22) show respectively the change in the TOT and TAC for 6cm slab specimens, as example, at various mixing temperatures.

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### 3. Field Study

The field study covered the collection of data for the cooling time of the HMA binder layers. It aimed at providing data for verification of the laboratory test results. A test program was designed in order to provide the necessary data. It involved measuring layer temperature in ongoing paving projects. The testing field sites were selected with properties similar to large extent to the laboratory tests. These properties included:

- Aggregates type, gradation limits and mixture specification
- Bitumen type and content
- Range of mixing layer temperature and thickness.

The temperatures were measured at two different positions over a period of time as the layer cools. These positions were located at:

- 1- the middle of the slab, at depth equal half of layer thickness.
- 2- the slab surface.

Twelve field testing measurements were conducted from six sites with three mixing temperatures (145 °C, 150 °C, 165 °C). These sites were selected from two projects in Gaza City during the summer of 2004 in a two weeks period. The temperatures data were obtained using the same temperature thermocouple used in the laboratory tests. The recording started immediately after HMA laying. The sites conditions and HMA layer characteristic are summarized in the Table (8). Figures (23, 24) show samples of field records. The results for site 1 are used as a verification tool for the laboratory test results as shown in Figures (25, 26).

Similar to the analysis performed to the laboratory results, it can be said that an acceptable agreement is noted between the field and laboratory tests results regarding the analysis criteria. This is clearer in the case of mid layer recording.

### 4. Conclusions

- 1- The HMA slab specimen's compaction method, reconstructed in the Islamic University of Gaza (IUG), has proven to be a simple and reliable device to investigate the changing of cooling time of HMA binder layer in different range of weather conditions.
- 2- The ranges of TOT for HMA determined by the laboratory test program are according to the followings:
  - 110 to 270 minutes in case of no wind or solar radiation effect (for locally common used thickness of 4 , 6 and 8 cm at mixing temperature values of 130 °C, 145 °C and 160 °C )

- 100 to 140 minutes in case of wind effects (for 4 and 6 cm thickness at mixing temperature values of 130 °C, 145 °C and 160°C)
  - 180 to 250 minutes in case of solar radiation effects (for 6 cm thickness at mixing temperature values of 130 °C, 145 °C and 160 °C)
- 3- The ranges of the TAC at End Compaction Temperature (85 °C ) for HMA are according to the followings:
- 10 to 52 minutes in case of no wind or solar radiation effect. This is applicable at mixing temperatures of 130 °C to 160 °C according to slab thickness.
  - 5 to 40 minutes in case of wind effects (for 4 and 6 cm thickness). This is applicable at mixing temperatures of 130 °C to 160 °C in case of 6 cm slab thickness.
  - 40 to 50 minutes in case of solar radiation effects (for 6 cm thickness). This is applicable at mixing temperatures of 130 °C to 160 °C in case of 6 cm slab thickness. This agrees with the average value reached in the field study which is 55 minutes.
- 4- The heat losses range from 31 – 54 % of the HMA mixing temperature in case of mid slab record. For corner record, it decreases by 46 – 65 % of its mixing temperature. While at the HMA surface measurements, temperature decreases in a dramatic way in all testing cases (4, 6 and 8cm slab specimens). The heat losses for surface measurements range from 61 – 75 % of its mixing temperature.

## **5. Recommendations**

- 1- It is recommended to open the fresh asphalt paved road for traffic flow, according to Traffic Opening Time (TOT), after 270 minutes from start compaction.
- 2- It is recommended to end compaction in a time of 52 min. from laying asphalt layer. This time can reach 5 minutes in case of lower layer thickness and mixing temperature with existing of wind.
- 3- Shoulders and open joints, similar to HMA slab corner, should be paved quickly as cooling rate is higher at these positions. Heat loss can reach 65 % of mixing temperature.
- 4- Continue laboratory and field tests particularly for new influencing factors which may include: bitumen content, dense

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and light aggregate gradations. This requires more field verification works.

- 5- Develop mathematical model to be used for estimating the end compaction temperature and traffic opening time

## 6. References

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**Table (1): Test matrix for the laboratory tests program**

		Slab Thickness								
		4 cm			6 cm			8 cm		
		Recording positions								
		Mid slab	Corner	Surface	Mid slab	Corner	Surface	Mid slab	Corner	Surface
<b>Part 1: Tests for the slab thickness and initial temperature effect</b>										
Mixing temp. (°C)	130	√	√	√	√	√	√	√	√	√
	145	√	√	√	√	√	√	√	√	√
	160	√	√	√	√	√	√	√	√	√
<b>Part 2: Tests for the wind effect</b>										
Mixing temp. (°C)	130				√	√	√			
	145	√	√	√	√	√	√			
	160				√	√	√			
<b>Part 3: Tests for the solar radiation effect</b>										
Mixing temp. (°C)	130				√	√	√			
	145				√	√	√			
	160				√	√	√			

**Table (2): Physical properties for the aggregate components used in the HMA slab specimens**

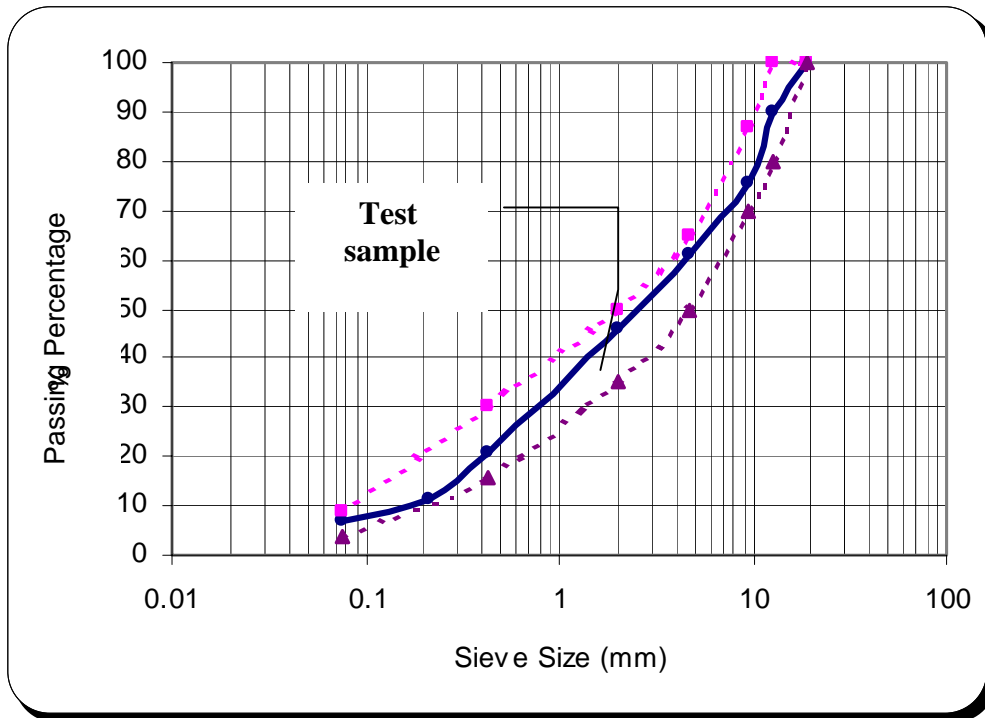
Description	Medium (I)	Medium (II)	Medium (III)	Fine	Sand	Filler
Specific Gravity (g/cm <sup>3</sup> )	2.67	2.67	2.69	2.69	2.6	--
Water absorption (%)	1.74	1.38	1.36	1.8	0.78	--
Atterberg limits	NP	NP	NP	NP	NP	NP
Los Angles (%)	24	23.5	25.5	--	---	--

NP: Non plastic material

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**Table (3): The test results carried out on the bitumen used in the laboratory tests**

Test	Test Standard	Result	Specification requirements
Penetration @25 °C, 100gm, 5sec. (1/10 mm)	ASTM D-5	69	60-70
Softening point by Ring and Ball method (°C)	ASTM D-36	53	45-55
Ductility @25 °C, (cm)	ASTM D-113	100	Min. 90
Density $d_{25}$ (g/cm <sup>3</sup> )	ASTM D-70	1.0295	-



**Figure (1): Gradation curve for the aggregates used in all laboratory tests  
(Limits are for the MOHW)**

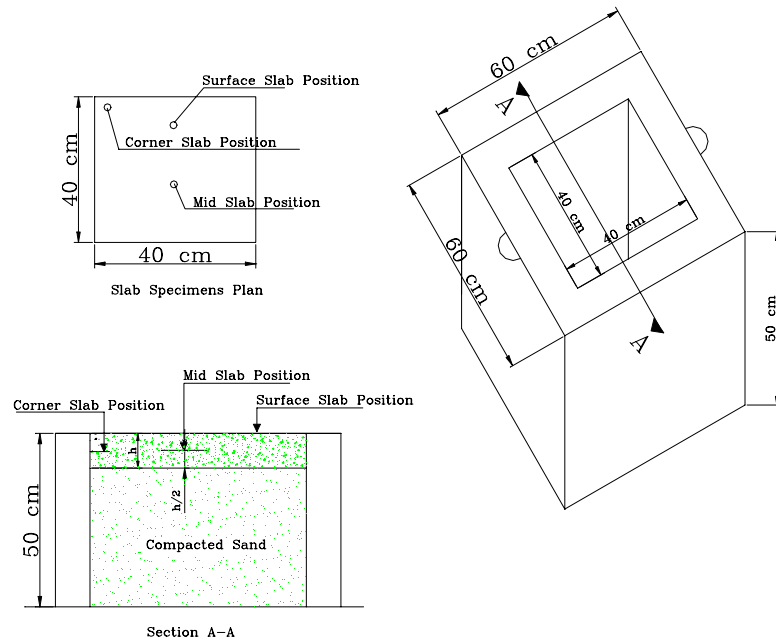


Figure (2): Slab steel mold for laboratory cooling time-temperature measurements test

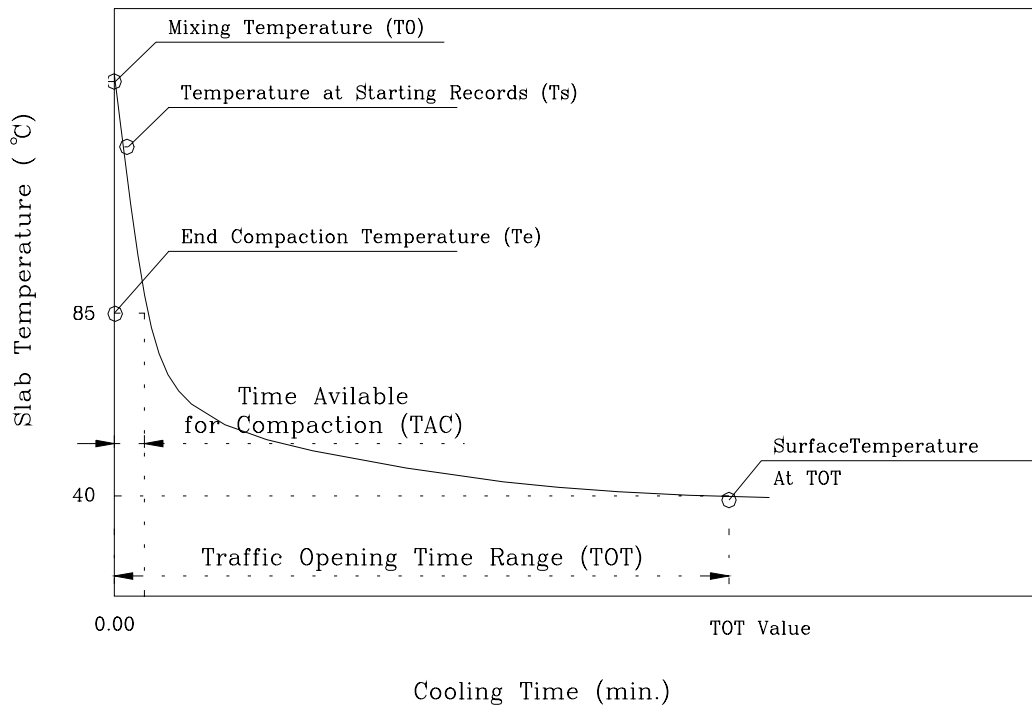


Figure (3): Photo of the used slab steel mold

Table (4): Percent air voids at steel wheel roller HMA slab compaction

No. of passes	25	30	35
Air voids (%)	24.4	22.1	20.2

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**Figure (4): Definition of main analysis elements**

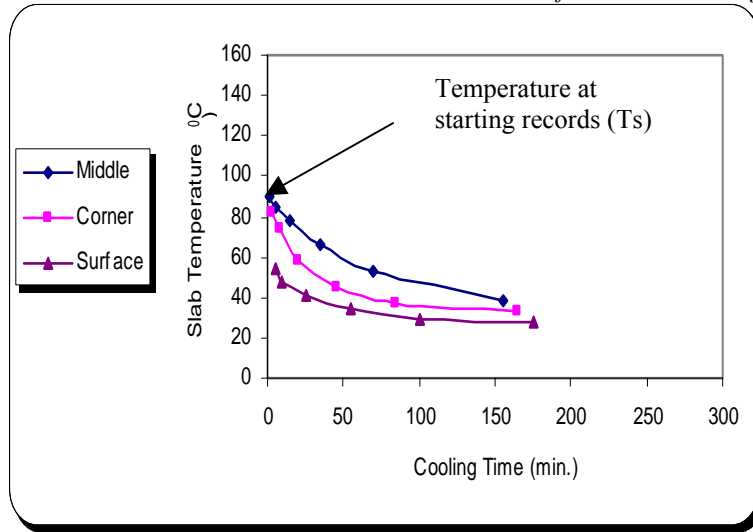


Figure (5): Cooling time versus temperature for  $h=4$  cm,  $T_0=130$  °C.

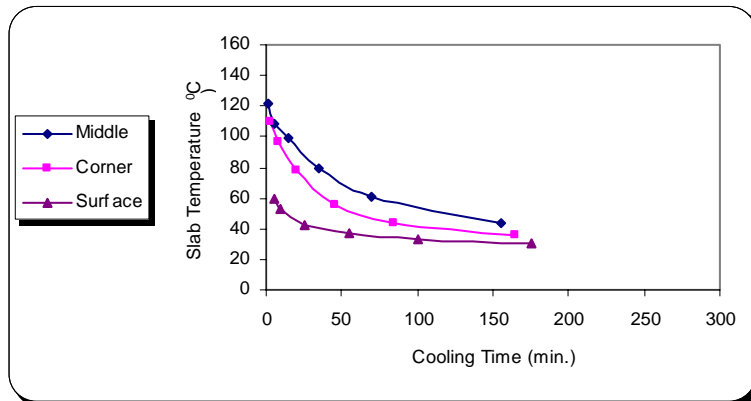


Figure (6): Cooling time versus temperature for  $h=4$ cm,  $T_0=145$  °C.

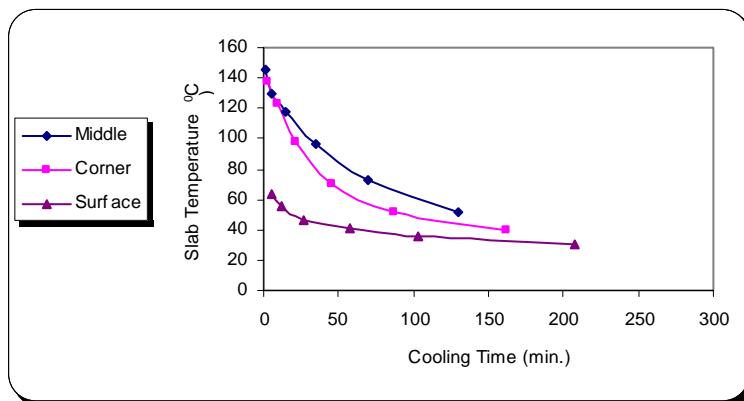
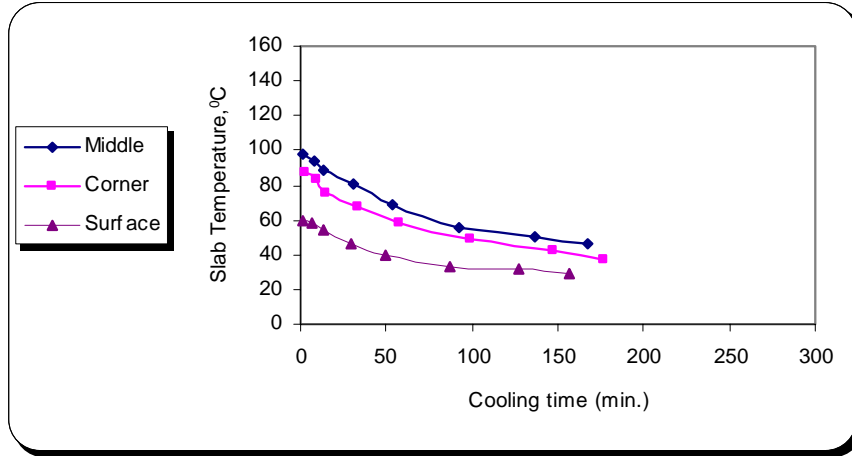
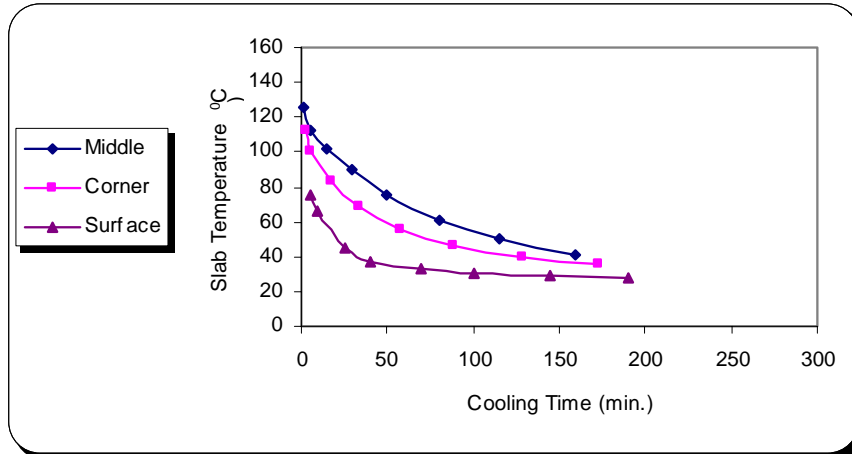


Figure (7): Cooling time versus temperature for  $h=4$ cm,  $T_0=160$  °C.

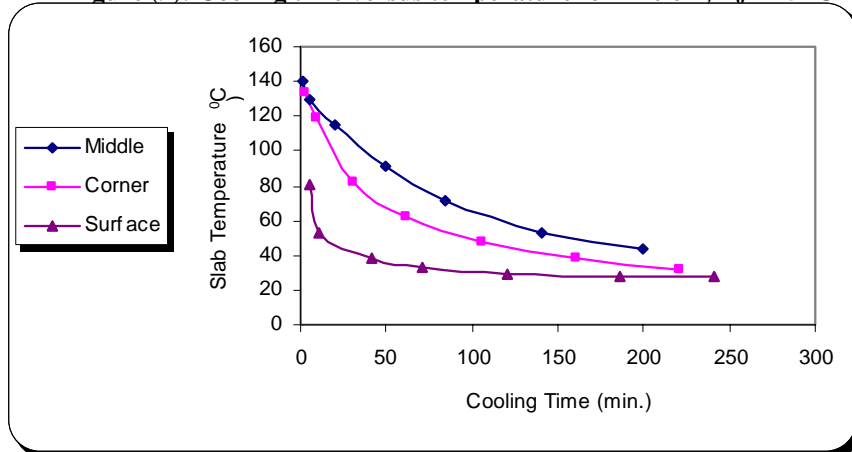
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**Figure (8): Cooling time versus temperature for h= 6cm,  $T_0=130$  °C**



**Figure (9): Cooling time versus temperature for h=6 cm,  $T_0=145$  °C**



**Figure (10): Cooling time versus temperature for h= 6cm,  $T_0=160$  °C**

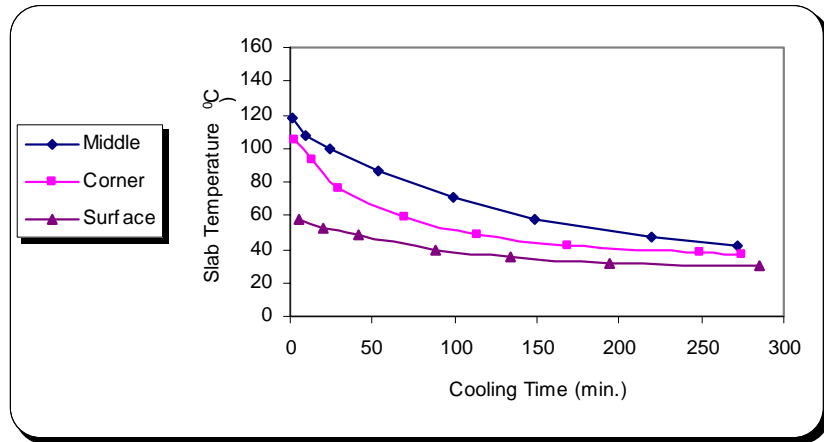


Figure (11): Cooling time versus temperature for h= 8 cm, T<sub>0</sub>=130 °C

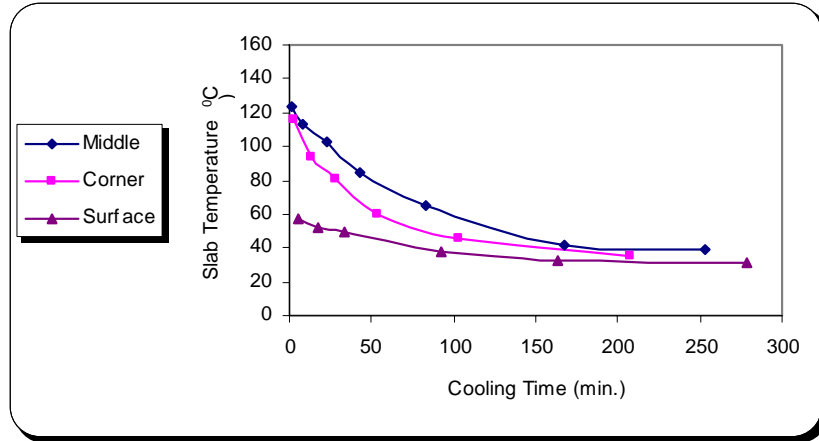


Figure (12): Cooling time versus temperature for h=8 cm, T<sub>0</sub>=145 °C

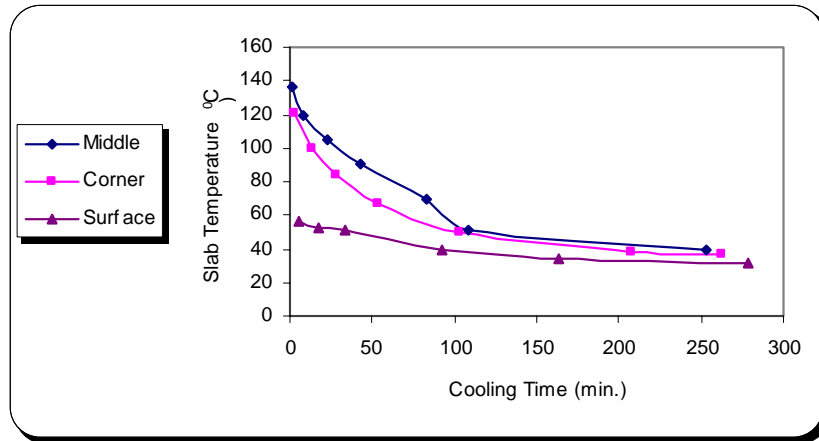
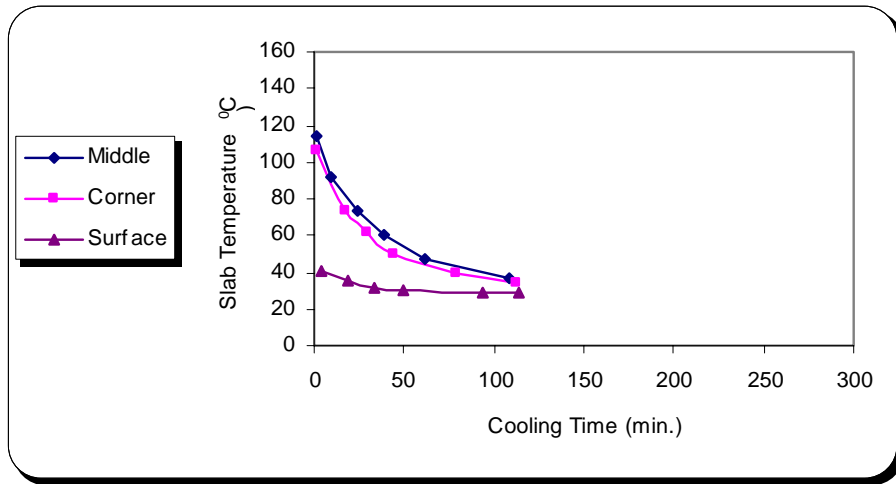
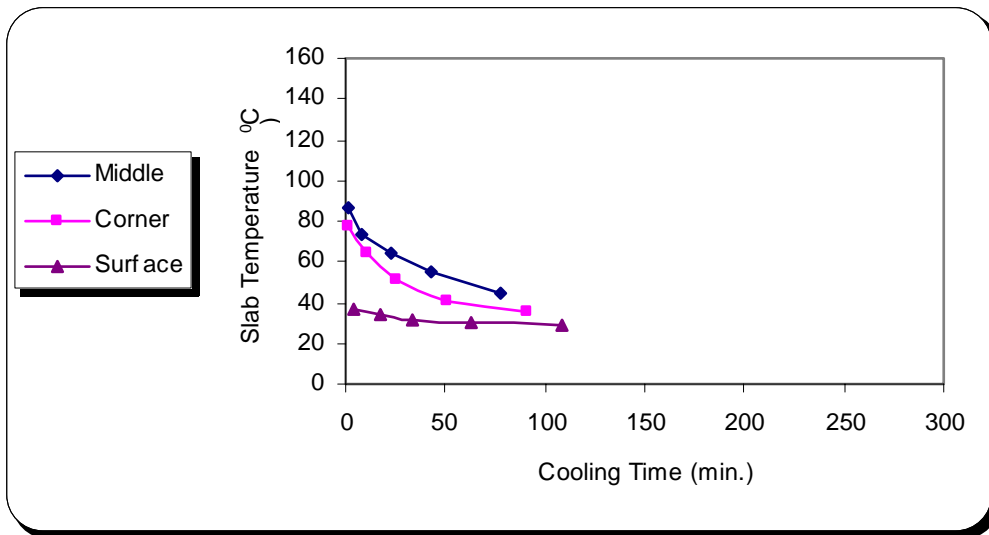


Figure (13): Cooling time versus temperature for h=8 cm, T<sub>0</sub>=160 °C

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**Figure (14): Cooling time versus temperature for  $h=4$  cm,  $T_0=145$  °C, wind speed =7 m/sec.**



**Figure (15): Cooling time versus temperature for  $h=6$  cm,  $T_0=130$  °C, wind speed =7m/sec.**

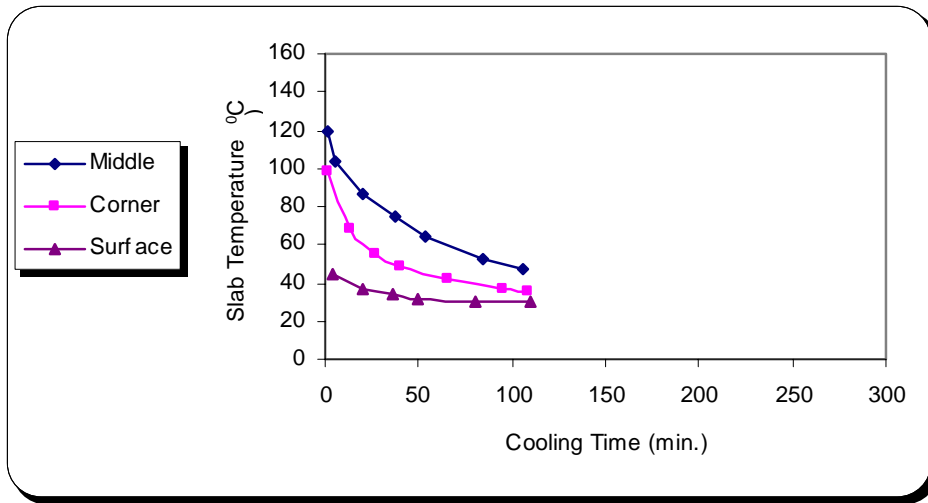


Figure (16): Cooling time versus temperature for  $h=6$  cm,  $T_0=145$  °C, wind speed =7m/sec.

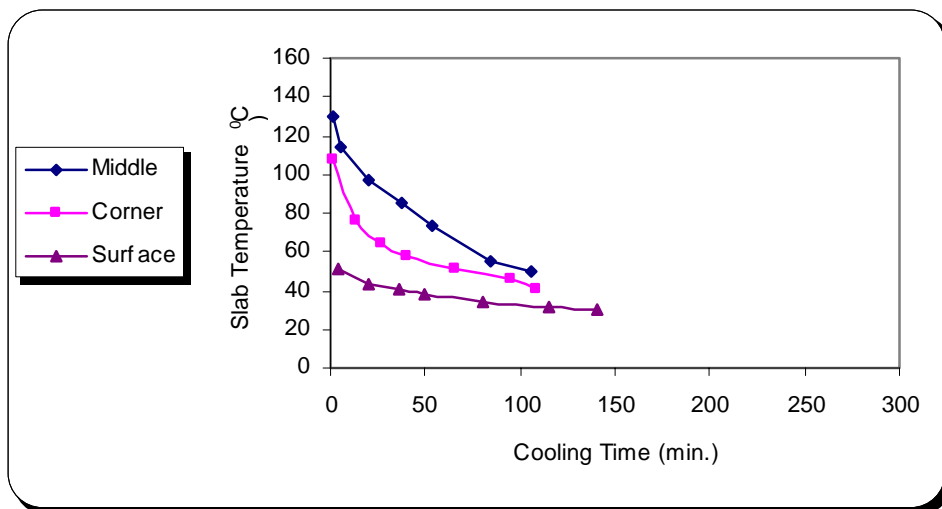
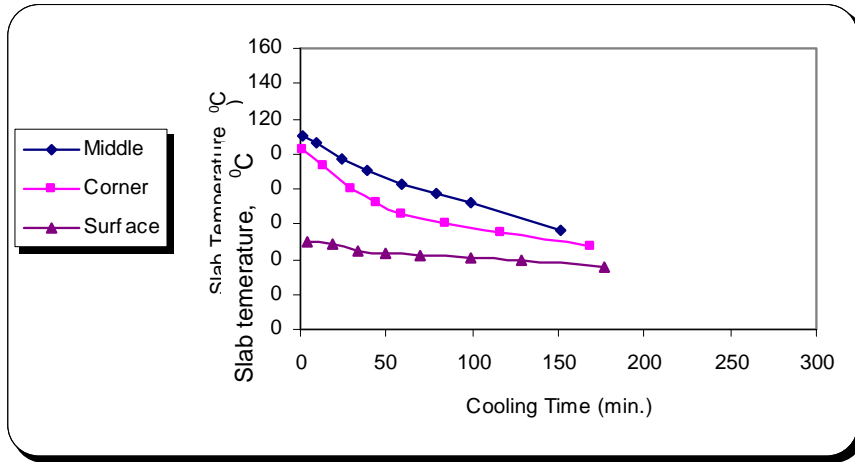
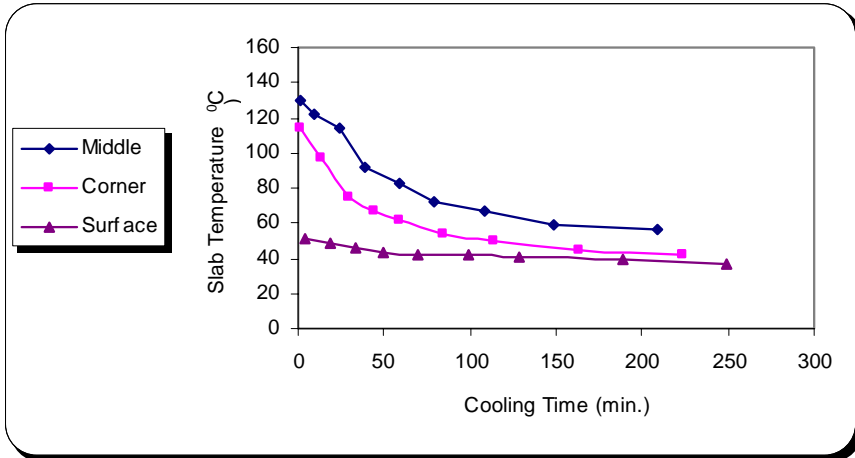


Figure (17): Cooling time versus temperature for  $h=6$  cm,  $T_0=160$  °C, wind speed =7m/sec.

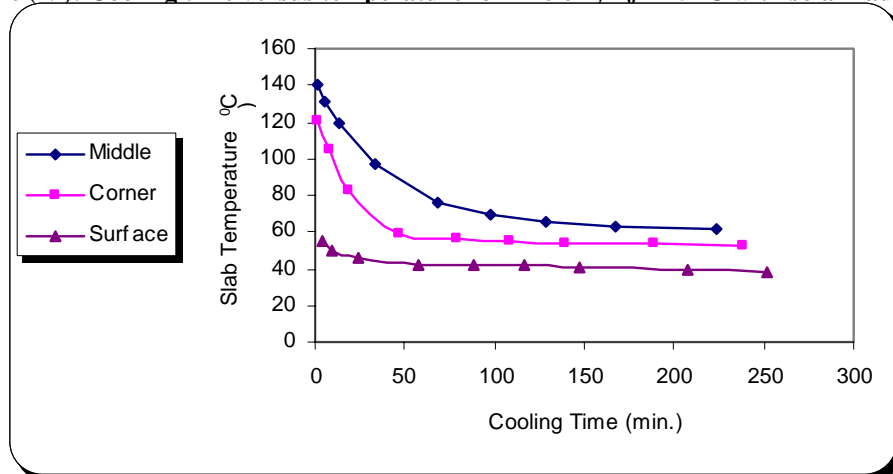
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**Figure (18): Cooling time versus temperature for  $h=6$  cm,  $T_0=130$  °C with solar radiation effect**



**Figure (19): Cooling time versus temperature for  $h=6$  cm,  $T_0=145$  °C with solar radiation effect**



**Table (5): TOT values, in minutes, at different temperature measurements cases**

**Table (5): TOT values, in minutes, at different temperature measurements cases**

		Mixing Temp. 130 °C			Mixing Temp. 145 °C			Mixing Temp. 160 °C		
		Normal	Wind effect	Solar effect	Normal	Wind effect	Solar radiation	Normal	Wind effect	Solar radiation
Slab Thick	4 cm	110			150	110		200		
	6 cm	150	100	180	180	120	240	230	140	250
	8 cm	180			270			270		

Normal: without the effect of wind or solar radiation

**Table (6): TAC values, in minutes, at different temperature measurements cases**

		Mixing Temp. 130 °C			Mixing Temp. 145 °C			Mixing Temp. 160 °C		
		Normal	Wind effect	Solar effect	Normal	Wind effect	Solar radiation	Normal	Wind effect	Solar radiation
Slab Thick	4 cm	10			48	15		48		
	6 cm	25	5	40	50	20	45	50	40	50
	8 cm	50			52			52		

Normal: without the effect of wind or solar radiation

**Table (7): Heat losses values at different temperature measurements cases**

Record Positions	Slab Thick.	Mixing Temp. 130 °C			Mixing Temp. 145 °C			Mixing Temp. 160 °C		
		Normal	Wind effect	Solar effect	Normal	Wind effect	Solar effect	Normal	Wind effect	Solar effect
Mid Corner Surface	4 cm	54%			50%	51%		43%		
		65%			62%	55%		56%		
		70%			72%	75%		75%		
Mid Corner Surface	6 cm	45%	54%	39%	45%	45%	52%	44%	43%	53%
		47%	61%	54%	60%	65%	65%	53%	62%	62%
		69%	73%	70%	74%	75%	72%	75%	75%	73%
Mid Corner Surface	8 cm	31%			45%			44%		
		46%			60%			56%		
		61%			72%			69%		

Normal: without the effect of wind or solar radiation

### TRAFFIC OPENING TIME AND TIME AVAILABLE...

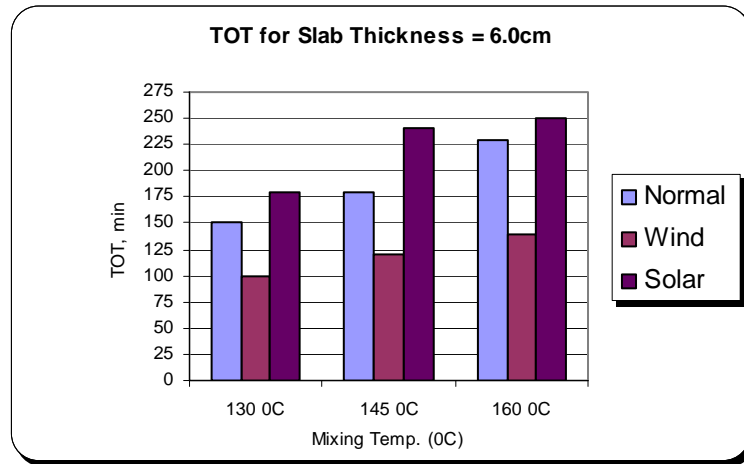


Figure (21): Traffic Opening Time (TOT) at different cases for h = 6.0 cm

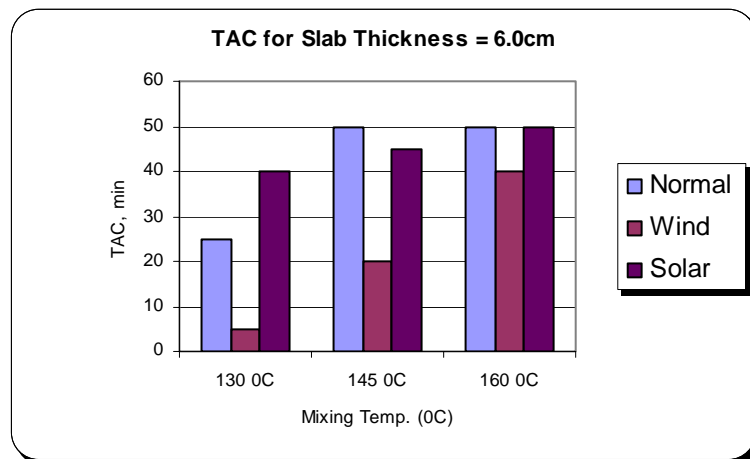
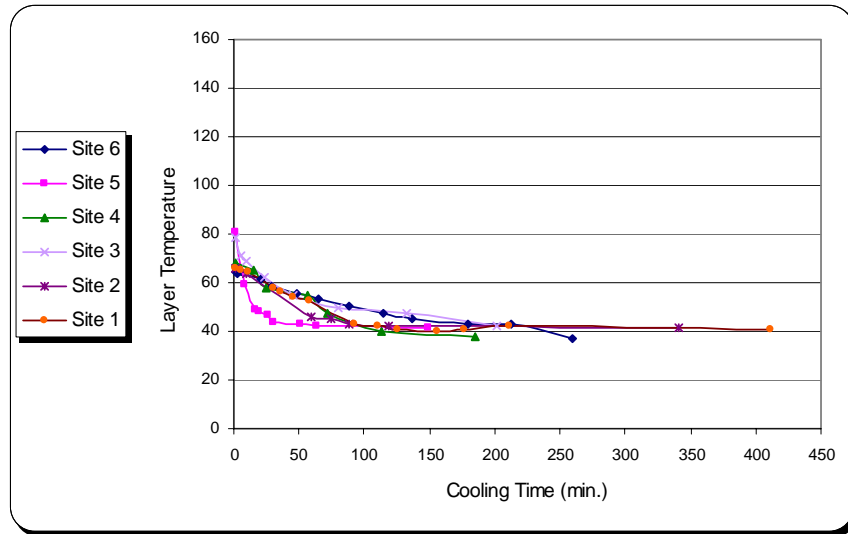


Figure (22): Time Available for Compaction (TAC) at different cases for h = 6.0 cm

**Table (8): Field tests matrix and characteristics of HMA binder layer**

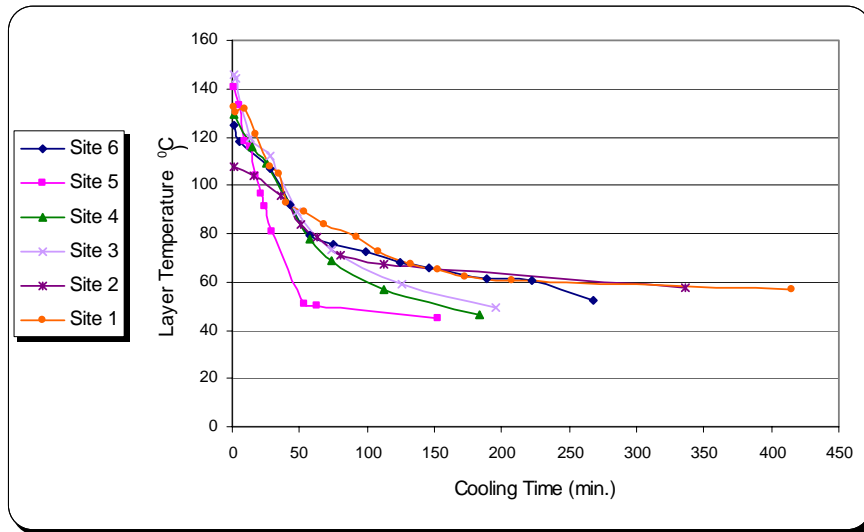
Project No.	Site No.	Layer characteristic			Environmental conditions		Measurements location	
		Thick. (cm)	Mixing temp. (°C)	Bitumen content (%)	Solar Radiation Effect*	Wind velocity Effect*	Mid layer	layer surface
1	1	6.0	165	5.3	√	X	√	√
	2	6.0	150	5.3	√	X	√	√
	3	6.0	150	5.3	√	X	√	√
	4	6.0	150	5.3	X	X	√	√
2	5	7.0	150	5.2	√	X	√	√
	6	7.0	145	5.2	√	X	√	√

\* (√) means the parameter effect exists, while (x) mean that parameter effect is not existing.

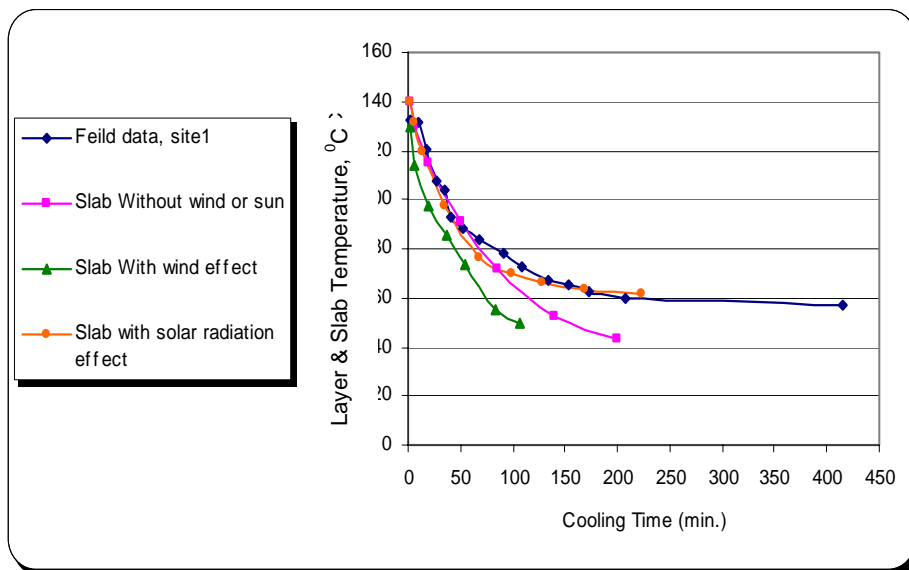


**Figure (23): Cooling time versus temperature at surface record for field results**

**TRAFFIC OPENING TIME AND TIME AVAILABLE...**



**Figure (24): Cooling time versus temperature at middle record for field results**



**Figure (25): Laboratory results verification using the field data from site 1, mid slab records**

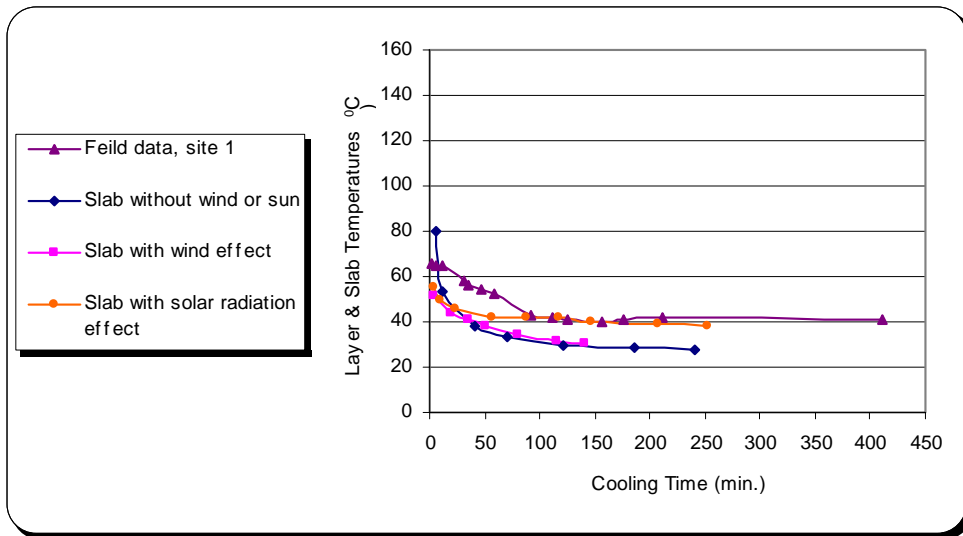


Figure (26): Laboratory results verification using the field data from site 1, surface records