

## METHODOLOGY FOR DETERMINING MOST SUITABLE COMPACTION TEMPERATURES FOR HOT MIX ASPHALT

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*Using an in-correct compaction temperature of hot-mix asphalt has caused significant problems not only in practice but also in the determination of optimum asphalt content in the design of mix. Asphalt mixture usually loses their temperature during transportation and when laying down.*

*The main objective of this research is to determine the most suitable value of compaction temperature of asphalt pavement that would be used in both laboratory investigations and in field technique*

*Laboratory measurements have been done to find out the effect of various compaction temperatures on the values of the optimum bitumen content and the volumetric properties and Marshall properties of asphalt mixtures. Field measurements were also done to determine the effect of different temperatures of asphalt pavement during laying-down and compaction process on the relative compaction of asphalt mixtures and on the pavement macrotexture. In addition the rate of heat loss of asphalt mixture during transporting it from mixing plant to was determined in both summer and winter seasons.*

*The main conclusion of this investigation is that pavement compaction temperature has a significant effect on the optimum bitumen content (OBC) of asphalt mixtures. Also it has remarkable effect on the values of volumetric properties of hot mix asphalt and Marshall indicators. Field investigations reveal that the Relative Compaction (RC) of the asphalt pavement layer is significantly affected by the temperature of asphalt mixture during compaction and is acceptable up to 110°C. Also, asphalt pavement macrotexture is deeply affected by the value of compacted temperature. A model was developed to relate compaction temperature to the depth of surface texture of asphalt pavement surface. The field results confirmed to a large extent the Laboratory results.*

**KEYWORDS:** Hot-Mix Asphalt, Volumetric Properties, Compaction Temperature, Relative Compaction.

### 1 – INTRODUCTION

Hot-mix asphalt (HMA) mixing and compaction temperature are important to the performance of HMA pavements. Appropriate mixing and compaction temperature are an aid in achieving complete aggregate coating and adequate field density [1].

Compaction is an essential factor in the design and subsequent production of asphalt mixtures. The available compaction temperature for Asphalt is one of the major controlling elements in this process. The compaction temperature influences workability of the asphalt mixtures.

Compaction below the standard compaction temperature may bring reverse effect on HMA properties. Moisture damage of HMA with low temperature referred as stripping and this problem become prevalent in recent years [2]. This weakens the subgrade, causing the pavement to settle and the surface to crack. Air entering the surfacing mix oxidizes the asphalt cement causing the surface to weaken and crack extensively.

Compaction temperature of asphalt mix is very important. One must be aware of how long it takes to cool from lay down to preserve a minimum compaction temperature. However, further attempts to compact the asphalt mixture normally in low temperature will not be effective. Further compaction may fracture the aggregate in the mix, decreases pavement density and frustrating the purpose of compacting. It's recommended that a compaction temperature between 135 and 150°C. Use of a 150°C compaction temperature can result in design binder contents that are as much as 0.5% lower than if compacted at 135°C [3].

If asphalt mixtures cooler than desirable temperature, a variation in mix temperature (temperature differentials) can cause poor mix compaction leads to non-uniform densities [4]. This decrease in density leads to a loss of fatigue life and serviceability of the pavement.

The decrease in achievable density has been directly linked to compaction temperatures. Laboratory study showed that an increase in air void content and a decrease in stability with lower compaction temperatures. Compared to a sample compacted at (135 °C), a sample compacted at a temperature of (93 °C) contained more than double the percent air voids and at (65 °C), the air void content quadrupled. Stabilities performed on these samples typically show a decrease in stability with decreasing compaction temperature and the resulting increase in air voids [5-9].

Large numbers of asphalt concrete paving projects have experienced a cyclic occurrence of low-density pavement areas [10]. The "cyclic segregation", is prematurely failed by fatigue cracking, raveling, or both. The "cyclic segregation" phenomenon in asphalt pavements has been studied [11, 12]. They related the problem to a differential in temperature of the hot mix asphalt (HMA) mass in the trucks developed in transport from the HMA manufacturing facility to the job site.

One of the major problems of insufficient compaction temperature is the non-uniformity of the existing pavement surface texture. This cause transverse variation in the surface texture of asphalt pavement through wheel paths and outside/between the wheel paths. Longitudinal variation occurs as the surface condition varies along the road from areas where the underlying surface is oxidized to other areas where the surface may be raveling and non uniform in surface texture [13]. Pavement macrotecture, or more specifically changes in macrotecture has been used to identify pavement segregation [14, 15]. Segregation refers to separation of the coarse and fine fractions of aggregate in the paving mixture. Coarse areas tend to have lower asphalt content, lower density and higher permeability. These areas tend to fail prematurely.

In this study the effect of different compaction temperature on the value of optimum bitumen content were investigated. Also the effect of eight-compaction

different temperature on the mechanical and volumetric properties of asphalt mixture is studied. Valuable recommendation for the acceptable pavement compaction temperature has been deduced. Field measurements for deduce the optimum time that be allowed for transporting the asphalt mixture from the mixing plant to the paving site has been found in both hot and cold weather. The Relative Compaction (RC) of asphalt pavement layer and asphalt surface texture depth (STD) were found as a function of compaction temperature.

This study was performed to assist asphalt mixture technologists in choosing an appropriate compaction temperature for asphalt pavement. This temperature is very important because it has significant effect on the value of optimum bitumen content, Marshall Properties, volumetric properties, Relative compaction of asphalt pavement layer, and on the depth of surface texture of asphalt pavement.

## **2- STUDY OBJECTIVES**

The aim of this research is to determine the suitable compaction temperature for HMA. More specifically, the work is intended to achieve the following objectives:

1. To determine the Effect of Laboratory Compaction Temperature (LCT) on the Optimum Bitumen Content. This is supposed to lead to a better control during the laboratory the compaction process.
2. To determine the field acceptable compaction temperature (ACT) to achieve allowable Relative Compaction (RC) of asphalt pavement layer. This is supposed to lead to a better control during compaction process.
3. To investigate the rate of heat losses related to the transportation time from the mixing plant to the asphalt lay-down location. This is supposed to lead to determine a better knowledge about the acceptable distance between the mixing plant and the paving site.
4. To investigate the effect of compaction temperature value on the value of surface texture depth (STD) of asphalt pavement to prevent raveling.
5. To propose recommendation to be used in the local industry of asphalt pavement related directly to the asphalt compaction procedures.

## **3- EXPERIMENTAL PROGRAM**

### **3.1 Material Characterization**

The asphalt mixes investigated in this study, consisted of crushed lime stone with angular particles and rough surface texture (Bulk Specific Gravity of 2.75) as a coarse aggregate, siliceous sand (Bulk Specific Gravity of 2.67) was as a fine aggregate, and limestone dust (Bulk Specific Gravity of 2.60) as a mineral filler. Asphalt Cement AC 60/70 penetration grade from Suez Refineries was used as a binder. The average penetration value at 25 °C was 64. The flash point was 268 °C and the Bulk Specific Gravity was found 1.03. The Ring and Ball softening Point was (50.8 °C) the asphaltic mixtures which designed in the laboratory were the same used in the field.

### 3.2 Gradation of Asphalt Aggregate Mix.

Asphalt concrete mixes tested in this study are composed of 53 % coarse aggregate, 41 % fine aggregate, 6 % mineral filler [16]. This gradation of aggregate mix, incorporate in all asphalt concrete specimens, conforms to the mid point of the standard 4-c aggregate gradation specified in the Egyptian slandered specifications [17]. Five different value of asphalt content (4.0%, 4.5%, 5.0%, 5.5%, and 6.0%) were used to for Marshall Test specimens. The aggregate gradation is presented in **Table (1)**.

The Marshall Stability test (ASTM Designation: D 1559-82), which is one of the most common tests used in highway engineering was used in this study for both mix design and evaluation. Although Marshall Method is essentially empirical, it is useful in comparing mixtures under specific conditions. Therefore it was selected within this research to study the effect of different compaction temperatures on Marshall Properties of asphalt mixture at the same value of bitumen content.

Field measurements to find the effect of compaction temperature of asphalt mixture on the relative compaction of pavement layer were done. Asphalt surface texture depths related to compaction temperature values were also found. To find the suitable time allowable for transporting the asphalt mixtures from the production plant to the paving site, the rate of reduction of asphalt temperature considering time was established both in summer and in winter.

**Table (1):** Selected aggregate gradation (dense gradation 4c)

Sieve	% Passing	
	Utilized Gradation	Spec. Gradation Limits
1	100	100
¾	95	80 - 100
3/8	71.6	60 – 80
3/16	55	48 – 65
No. 10	45.24	35 – 50
No. 30	25.5	19 – 30
50	16.8	13 – 23
100	9	7 – 15
200	4.77	3 – 8

### 3.3 Asphalt Mix Design at Different Compaction Temperature

Marshall Mix Design, which is one of the most common tools, is used in highway engineering for both mix design and evaluation. Although Marshall Method is essentially empirical, it is useful in comparing mixtures under specific conditions. Therefore it was selected within this research to study the effect of different compaction temperatures on asphalt concrete mixtures properties. Optimum bitumen content (OBC) for three variable compaction temperatures (140, 110, and 90°C) was determined. Five different values of asphalt cements (4.0%, 4.5%, 5.0%, 5.5%, and 6.0%) were used.

Forty five samples have been used in this context, fifteen samples for each temperature were considered.

Bitumen content of 5 % (by weight of dry aggregate basis) that was found to be the optimum bitumen content at 140°C compaction temperature was determined for asphalt mixture. OBC (5%) was chosen for all mixtures so that the amount of binder would not confound the analysis of the test data.

Compactions of asphalt pavement mixture at eight different temperatures (140, 130, 120, 110, 100, 90, 80, and 70 OC) were considered. Twenty four samples have been tested, three samples for each temperature considered.

The following procedures are to be followed to ensure uniformity in preparation of the asphalt mix samples: Mixing:

1. Aggregates shall be heated for 24 hours minimum at a temperature of (110°C ± 5°C) prior to adding asphalt.
2. Mixing should be done at (140°C) using a "battered" mixing pan. The mixing pan should not be totally clean but should contain the residue from previous mixing that is left after scraping with a spoon and/or spatula.
3. The asphalt cement added should be the percentage specified and no allowance should be made for asphalt cement that is left sticking to the sides of the mixing pan.
4. All mixing is to be done by hand using a spoon and a spatula.
5. Mechanical compaction should be based on the equivalent blow count to each face that your laboratory correlates to 75 blows of the hand hammer at 140°C.

### 3.4 Sample Preparation

All examined asphalt concrete mixtures were prepared in accordance with the Standard 75-blow Marshall design method for designing hot asphalt concrete mixtures, designated as (ASTM Designation: D 1559-89) [18 ] using automatic compaction. To provide adequate data three samples were prepared from each mixture for each test. **Table (2)** presents the total number of tested samples.

### 3.5 Asphalt Mixture Properties Investigation

Marshall Properties at different compaction temperature have been found. The effects of compaction temperature of the following Marshall results of the hot mix asphalt (HMA) have been evaluated:

1. Effect of compaction temperature on asphalt mixture density.
2. Effect of compaction temperature on the Marshall Stability.
3. Effect of compaction temperature on flow value.
4. Effect of compaction temperature on the % VTM, and % VMA.
5. Effect of compaction temperature on Marshall Stiffness value.

**Table (2):** Number of prepared samples

Mix. Design Temperatures	Mix Properties Temperatures	Marshall Tested Samples
140	-	15
110	-	15
80	-	15
-	140	3
-	130	3
-	120	3
-	110	3
-	100	3
-	90	3
-	80	3
-	70	3
Total		69

## 4. FIELD MEASUREMENTS

### 4.1 Relative Compaction of Asphalt Pavement.

Asphalt compaction technique is different in laboratory than that in the field. So, field measurements have been done to find out the effect of various compaction temperatures on the relative compaction of the asphalt pavement. Studies have been done on koum El-arab road which was under construction in Tema District at Sohaj Governorate. The temperature of road base was about (20 °C). Air temperature was about (22 °C). surface layer was (5.0 cm).

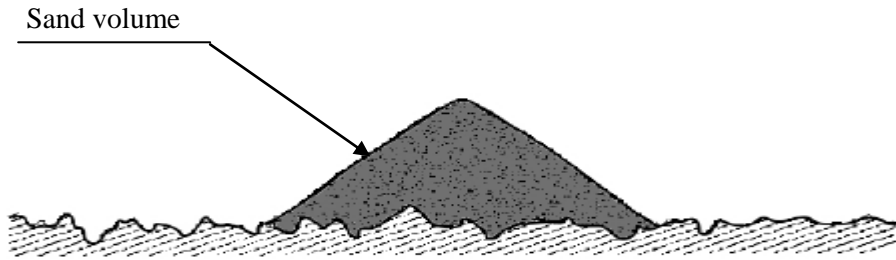
Pavement surface has been divided into four sectors; each sector has length (10.0 m), width (3.0 m). Asphalt pavement mixture for each sector has been laid and compacted at different temperatures, these were (130, 110, 90 and 70°C). The roller speed and number of passes are the same over the pavement layer. Three cores have been excavated from each sector of the four sectors under investigation. Bulk density, and volumetric properties has been investigated for each sample and its average values have been calculated. Then, the relative compaction has been calculated.

### 4.2 Surface Texture Measurement of Asphalt Pavement.

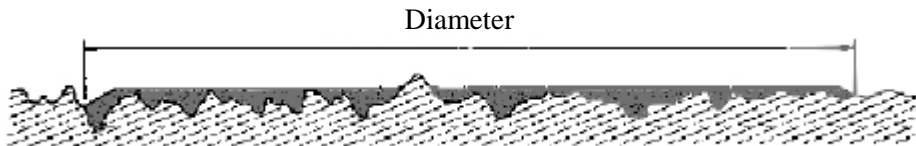
One of the major problems of insufficient compaction temperature is the non-uniformity of the existing pavement surface texture. Surface texture refers to the macrotexture of the pavement surface [19, 20]. Characterization of the pavement's surface texture is a critical step in the pavement surface evaluation.

In this research, the surface texture depth of pavement surfaces is determined by the sand patch technique. Considering the four sectors that compacted in the field at different compaction temperature, the macrotexture of each sector has its own characteristics.

Firstly, the surface of the sample site must be dried and cleaned. Known volume of sand (particle size of 300 μm to 600 μm) is spread by revolving a straightedge until the sand is level with the tops of the cover aggregate. The volume of sand used for the texture determination shall be such that the sand patch has a minimum diameter of 170 mm. The volume of material that fills the surface voids determines the surface texture. In this research 45 ml of sand is used **Figs (1 and 2)**.



**Fig. (1):** Measured volume of sand on pavement surface



**Fig. (2):** Sand spread to form circular patch on pavement surface.

The average surface texture depth is calculated by dividing the volume of sand by the area of the sand patch the mean surface texture depth (STD) using the following equation [20].

$$STD = \frac{4V \times 1000}{\pi D^2} \tag{1}$$

Where:

STD = surface texture depth in mm.

V = volume of sand in patch in cm<sup>3</sup>

D = average diameter of sand patch in mm

### 4.3 Rate of Heat Loss of Asphalt Mixture.

To determine the permissible time required for transporting and laying-down of asphalt mixtures from mixing plant to the paver machine, the rate of heat losses in the temperature with time have been studied. The temperature of asphalt pavement just after mixing was measured as (160°C). Then the temperature was measured every five minutes within two hours. Three thermometers were immersed inside the asphalt mixture to about (15 cm) at different distances of the asphalt surface on the truck, the average value were calculated. This has been done twice, one in summer in (July), the air

temperature was (40°C). The other was in winter in (January), the air temperature was about (22°C). No wind was recorded during those measurements.

## 5. RESULTS AND DISCUSSION

### 5.1- Laboratory Investigations Results

#### 5.1-1 Effect of Compaction Temperature on the Value Optimum Bitumen Content

The Values of Optimum Bitumen Content of asphalt mixtures at (140,110, and 80°C) compaction temperatures have been determined. Three asphalt mixtures have been compacted within the three different temperatures at different values of bitumen content, these were (4, 4.5, 5.0, 5.5, and 6%).

**Table (3)** shows the values of density, stability, flow value, % of voids of mineral aggregate (%VMA) and % of voids of total mixture (%VTM) corresponding the optimum asphalt content for the three-compaction temperature values determined in this study. It's investigated that the percentage of bitumen content is significantly affected with the values of compaction temperature. Where its value increases with about 10 % for 80°C compaction temperature than that which compacted at 140°C while bulk density and Marshall stability decrease with about 40%. At compaction temperature 110°C the percentage of increase in bitumen content is only about 2% and bulk density and Marshall stability decrease with about 10% only than that compacted at 140 °C. This attributed to that the bitumen viscosity is considerably increases as its temperature decreases which have direct effect on the workability of the asphalt mixture. The above discussion reveals that the minimum laboratory compaction temperature for Marshal Mix design would not less than 110°C.

**Table (3):** Values of optimum bitumen content (OBC) of asphalt mixtures compacted at different temperatures.

Compacted temperature	Density (gm/cm <sup>3</sup> )	Max. stability (Newton)	% of VTM	% of VMA	Flow (mm.)	OBC
140 °C	2.42	6700	3.5	12.8	3.2	5.0
110 °C	2.41	6010	3.7	13.5	3.4	5.1
80 °C	2.35	4030	6	16.8	4	5.5

#### 5.1.2 Effect of Compaction Temperature on Volumetric Properties of Asphalt Pavement Mixtures

**Figure (3)** shows relationship between different compaction temperatures in (°C) versus % VTM & % VMA and percentage of voids filled with bitumen (%VFB). It is clear that as the compaction temperature increase from (70°C to 110°C), both the (% VTM) and (% VMA) sharply decrease. The value of (% VTM) was (6.8%) at (70°C) and reduced to (3.9%) at (110°C), while these values slightly decrease as the compaction temperature increases than (110°C), its value is (3.5%) at (140°C).



The value of % VMA was (18.3%) at (70°C), and decreased to (15.4%) at (110°C). As the compaction temperature increase, that value slightly decreases. Its value is (14.8%) at (140°C). One can conclude that the change in both % of VTM and % VMA are significantly affected at compaction temperature less than (110°C). This may be attributed to that the asphalt spacemen is difficult to compact as the temperature decrease because the bitumen viscosity is significantly increases. The value of voids filled with bitumen (% VFB) is not significantly affected with compaction temperature value.

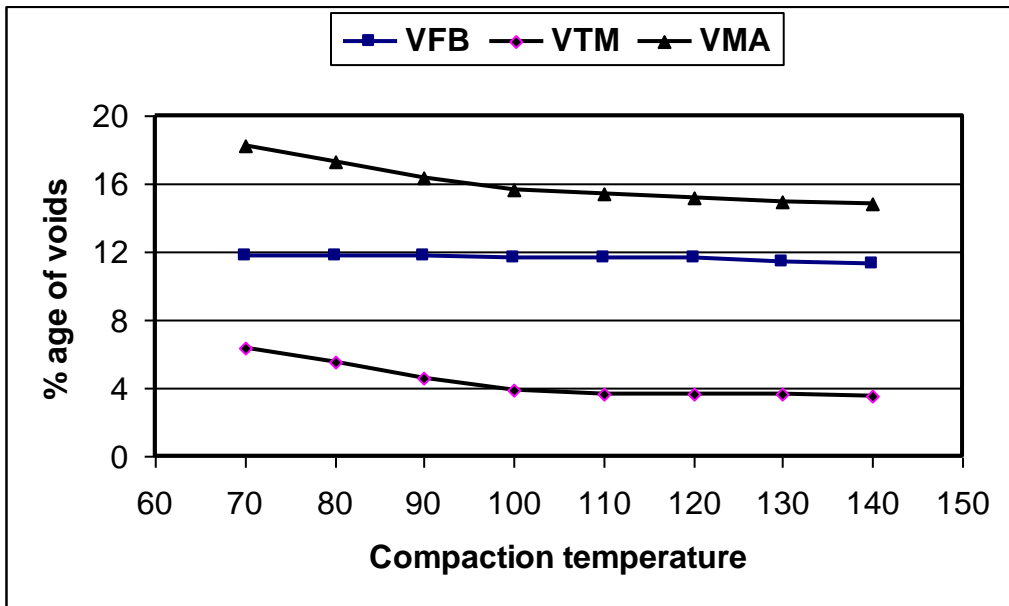


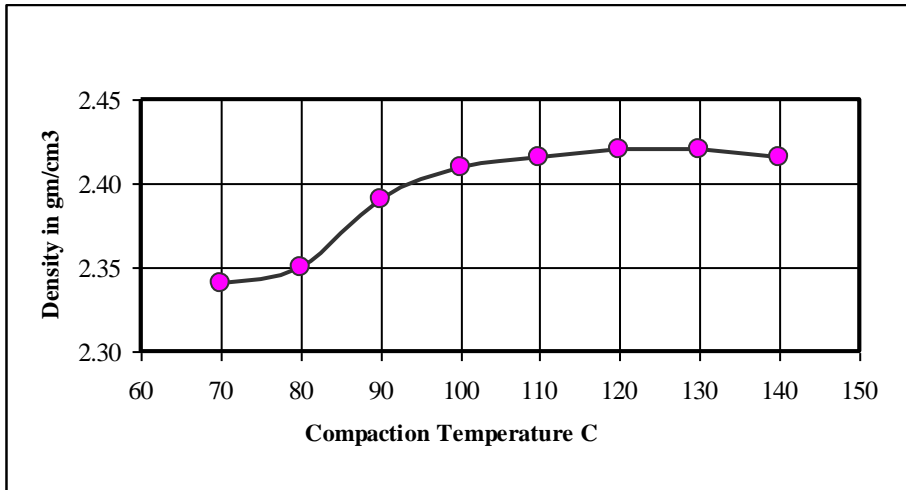
Fig. (3): Percentage of voids in asphalt mix. & compaction temperature in (°C)

5.1-3 Effect of Compaction Temperature on Asphalt Mixture Density

Relationship between compaction temperature in (°C) and Density in (gm/cm<sup>3</sup>) has been plotted in **figure (4)**. It is found that when compaction temperature decreases from (140 to 100 °C) the density values remains constant. This reflects that the asphalt mixture is more workable due to low viscosity of bitumen which lubricated aggregate particle well at that range of temperature. At compaction temperature from (100 to 80°C) the density decreases. This is because the bitumen viscosity may increase sharply which cause sharply decrease in density with the same trend. As the compaction temperature decreases from (80 °C), the bitumen viscosity is so high that the asphalt mixture is not workable so, the density is slowly decrease in this zoon.

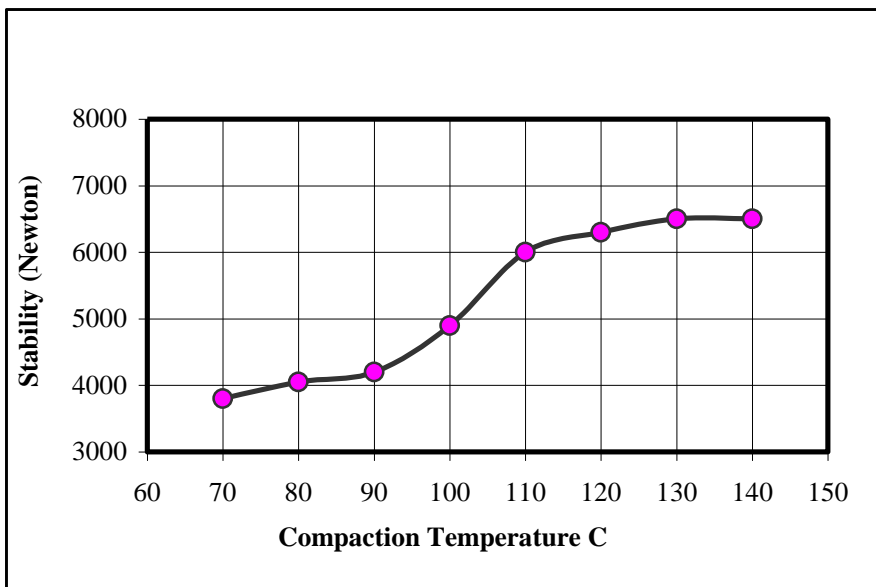
5.1-3 Effect of Compaction Temperature on Marshall Stability

Marshall stability ( $S_m$ ) is an indicator of the resistance against the deformation of the asphalt concrete;  $S_m$  values are calculated to evaluate the resistance of the deformation of the tested specimens. A higher value of  $S_m$  indicates a stiffer mixture and, hence, indicates that the mixture is likely more resistant to rutting and shoving.



**Fig. (4):** Relation between compaction temperature in  $^{\circ}\text{C}$  and density in  $\text{gm}/\text{cm}^3$

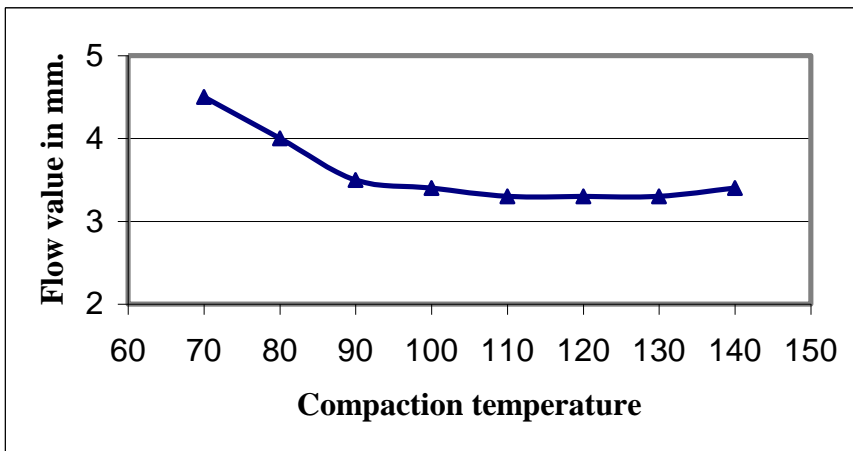
Marshall stability value in (Newton) is studied as function of compaction temperature in ( $^{\circ}\text{C}$ ) that relation has been plotted as shown in **figure (5)**. It shows that as the compaction temperature decrease from (140 to 110  $^{\circ}\text{C}$ ) stability values slightly decrease, and as the compaction temperature decreases from (110 to 70  $^{\circ}\text{C}$ ) the stability values sharply decrease. Where, the value of Marshall stability at compaction temperature (140 $^{\circ}\text{C}$ ) is about 10% higher than if compacted at (110 $^{\circ}\text{C}$ ), and 40% if compacted at (90 $^{\circ}\text{C}$ ) while it increases to (55%) if compacted at (70  $^{\circ}\text{C}$ ). This is because at high temperature the bitumen viscosity is so low that cause good lubrication of aggregate particle and this cause better interlock between particles during compaction.



**Fig. (5):** Relation between compaction temperature & stability

**5.1-4 Effect of Compaction Temperature on Flow Value**

To find out the effect of different compaction temperature on the Marshal Flow values in mm. **figure (6)** has been plotted. It is shown that the flow value is about the same for temperature rages between (140 to 100°C), then as the compaction temperature decrease, the flow values increase. This is attributed to that, at low temperature the percentage of voids of total mixture is high than that at higher temperature. This causes air space for the aggregate particle to deform and this increases flow value.



**Fig. (6):** Flow values in (mm) versus compaction temperature in °c

**5.1.5 Effect of Compaction Temperature on Marshall Stiffness Value**

Marshal stiffness values ( $S_M$ ) have been calculated using the following expression [21]:

$$S_M = \frac{M_S}{M_F \times S_H} \dots\dots\dots (2)$$

Where:

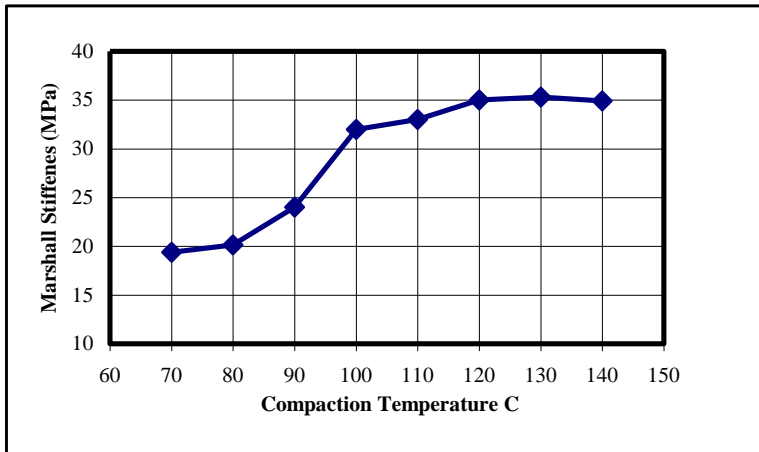
$S_M$  = Marshal stiffness.

$M_S$  = Marshal Stability.

$M_F$  = Marshal Flow.

$S_H$  = Spacemen height.

Values of Marshall stiffness versus different compaction temperatures are shown in **Figure (7)**. It is clear that the Marshall stiffness value is slightly decreased as the compaction temperature decrease for temperature ranges from 140 to 100°C. As the compaction temperature decrease in from 100 to 70°C the Marshall stiffness values sharply decrease. This is attributed to that at high compaction temperature the bitumen viscosity is low and the asphalt mixture is workable and compacted well.

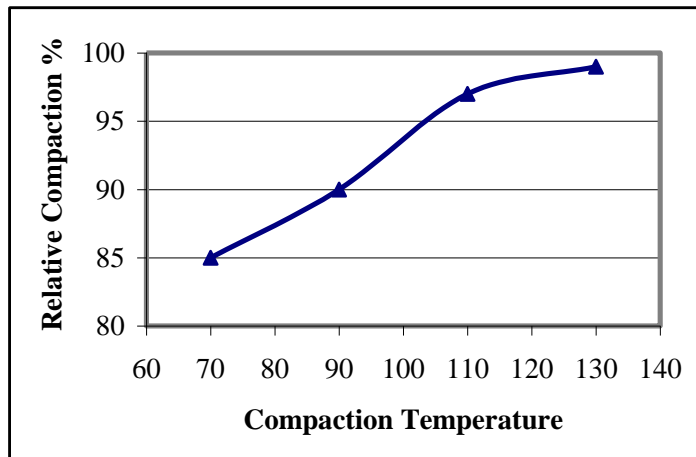


**Fig. (7):** Relation between Marshall stiffness and different compaction temperatures.

## 5.2- Field Measurements.

### 5.2-1 Effect of Compaction Temperature for Asphalt Mixture on the Relative Compaction of Asphalt Pavement Surface Layer.

Relationship between compaction temperature of asphalt mixtures in °C and relative compaction (RC) of asphalt pavement mat has been found. **Figure (8)**, shows that as the compaction temperature decrease the RC of the asphalt mixture decreases. Slight reduction in RC was noticed when the compaction temperature ranged between (130°C to 110°C). While as the compaction temperature decreases, ranges between (110 to 70°C) the RC is sharply decreases. This is may be due to the high workability of the asphalt concrete mixture at temperature more than 110°C, which significantly decreases as the temperature decrease due to the relative increase in the binder viscosity. Also, aggregate segregation during laying-down of asphalt mixture may be occurred at low temperature.



**Fig. (8):** Relation between relative compaction of asphalt pavement and compaction temperature in °C

**5.2-2 Measurement of Macrotexture Asphalt Pavement Surface**

A known volume of sand was spread evenly over the pavement surface to form a circle, thus filling the surface voids with sand. Three portions on each studied sector were selected and tested and the value of the mean surface texture depth (STD) has been calculated. The diameter of the circle was measured at four locations at approximately equally spaced distances around the sand patch to the nearest 1.0 mm and the value averaged [20].

$$\text{Surface Texture Depth} = \frac{57300}{d^2} \quad (\text{d in mm}) \quad \dots\dots\dots (3)$$

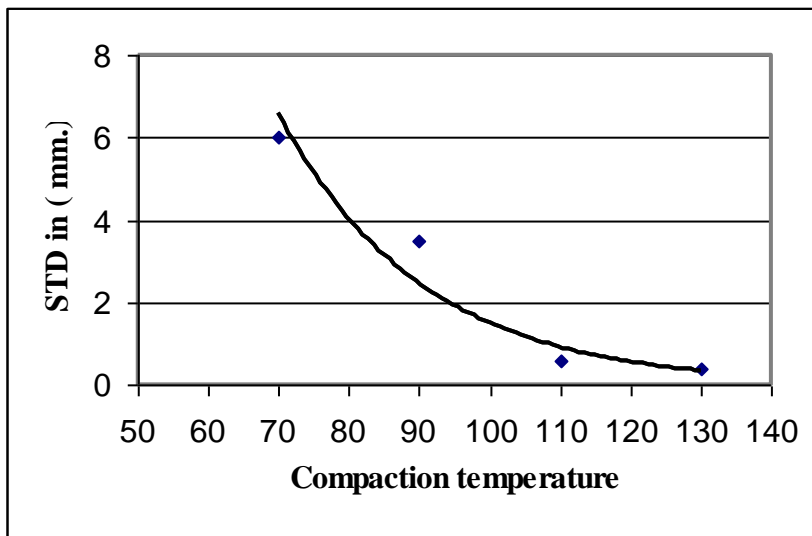
Where: d = patch diameter

The mean surface texture depths (STD) at different compaction temperature have shown in **table (4)**. The relationship between compaction temperature and mean surface texture depth (MSTD) are plotted in **figure (9)**. It's found that the texture depth is strongly affected with compaction temperature. This is attributed to the segregation of aggregate that may be occurred at low temperature of asphalt pavement mixture.

**Table (4):** Values of average texture depths versus compaction temperature

Comp. Temp.	Texture Depth mm.			STD* mm.
	Patch 1	Patch 2	Patch 3	
70	5.5	6.3	6.1	6
90	3.0	3.8	3.6	3.5
110	0.4	1.0	0.5	0.6
130	0.2	0.5	0.45	0.4

\* STD = surface texture depth (mm),



**Fig. (9):** Relationship between compaction temperatures and surface texture depths.

Relationship was developed between compaction temperature and the STD Exponential model give the highest correlation factor, where

$$STD = 210.23 e^{-0.0494 C_t} \dots\dots\dots (4)$$

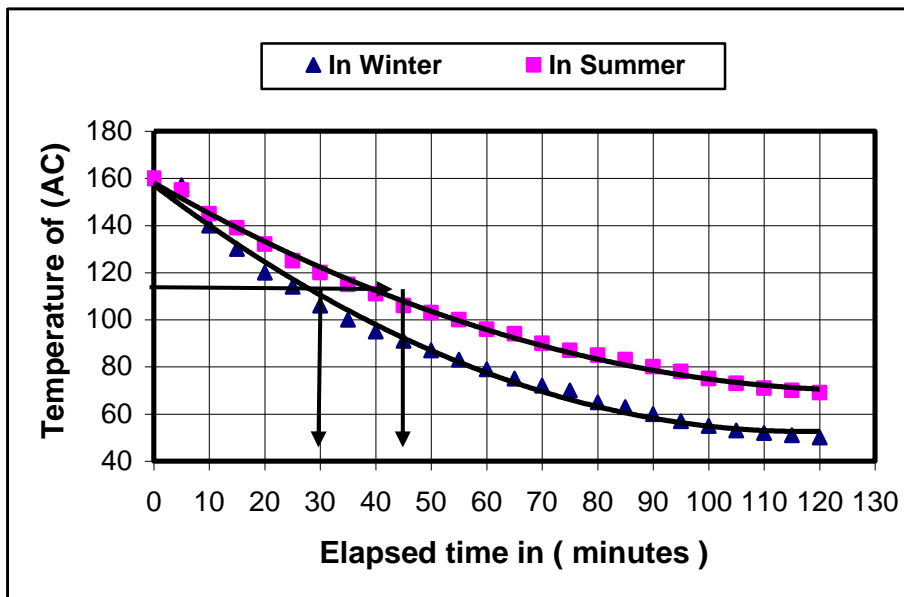
$$R^2 = 0.94$$

Where:

- STD = Surface texture depth (mm),
- C<sub>t</sub> = Compaction Temperature in °C.

**5.2-3 Effect of Transportation and Laying-down Duration of Asphalt Mixture on its Temperature Depression.**

The relation between dissipating temperature of asphalt mixture versus elapsed time during transporting from mixing plant to laying-down sit is shown in **figure (10)**. As it is expected, the asphalt temperature decreases with time. The rate of reduction in temperature is higher in winter compared with that in summer. Considering the minimum allowable compaction temperature 110°C, it can be recommended that the allowable time of transporting and laying time of asphalt mixtures should not be more than 45 minutes in summer and 30 minutes in winter.



**Fig.(10):** Losses of asphalt mixture temperature in (°c) & elapsed time.

To estimate the time that must be considered to get the required temperature of asphalt pavement mixture during transportation and laying-time, the relationship between drop in temperature in degrees centigrade and time in minutes of the asphalt pavement mixture is presented in **figure (11)**. It is found that the rate of heat dissipating in winter is significantly higher than that in summer. This must be considered in project pavement management construction and planning.

The following equations were found to deduce required time for permissible heat dissipation of asphalt pavement:

Within summer season:-

$$T = 1E-04 C_t^3 - 0.0022 C_t^2 + 0.6722 C_t + 0.6193 \dots\dots\dots ( 5 ) \quad R^2 = 0.99$$

Within winter season:-

$$T = 8E-05 C_t^3 - 0.0042 C_t^2 + 0.5355 C_t + 1.2256 \dots\dots\dots( 6 ) \quad R^2 = 0.99$$

Where:

T = elapsed time in minutes

C<sub>t</sub> = heat dissipation in °C

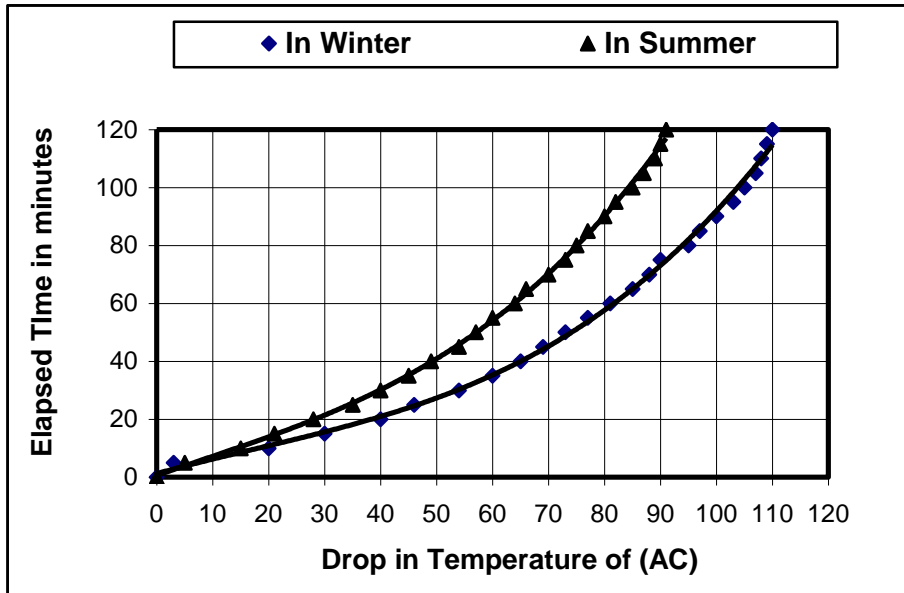


Fig.(11): Relation between drop in temperature of (ac) and elapsed time.

## 6- CONCLUSIONS AND RECOMMENDATIONS

The effect of compaction temperature of asphalt mixtures on the value of optimum bitumen content (OBC) has been found. Also, the effect of compaction temperatures on the volumetric properties and overall Marshall Properties of hot mix asphalt which operated at the controlled asphalt pavement mixture are determined. Field measurements to find out the effect temperature of asphalt pavement mixtures during laying-down and compaction process on the values of relative compaction and macrotexture of asphalt pavement surface layer are determined. Finally, the rate of the heat dissipation of the asphalt pavement mixture during transporting from mixing plant to laying-down sit at winter and summer seasons is presented.

The final conclusions can be summarized as follows;

- 1- The value of OBC determined by Marshall method is significantly affected by laboratory compaction temperature of asphalt mixtures. It is found that at compaction temperature (80°C) OBC is higher with about 10 % than that which compacted at (140°C), while asphalt mixture compacted at (110°C), is higher with about 2% only.

- 2- The % VTM at compaction temperature (140 to 100°C) increased from (3.5 % to 4 %), while at compaction temperature (70 °C), it reaches 6.4%.
- 3- The value % VMA at compaction temperature (140 to 110°C) increased from (14.8 % to (15.7 %), while at compaction temperature (70 °C) it reaches (18.3 %).
- 4- Marshall stability value at compaction temperature (140°C) is about 10% higher than that which compacted at (110°C), and higher with about 40% if compacted at (90°C), While it reaches about (55%) higher than that compacted at (70 °C).
- 5- Marshall Stiffens value is significantly affected by the temperature of compaction less than 100 °C; while the compaction temperature ranged from 140 to 100 °C the change in stiffens value is not significance.
- 6- The effect of asphalt mixture temperature during laying-down and compaction on the relative compaction (RC) for asphalt pavement surface layer revealed that 100 °C is the minimum allowable compaction temperature to get RC more than 97%.
- 7- Field measurements of the surface texture for asphalt mixture which laid-down and compacted at different temperature conclude that the macrotexure of asphalt pavement layer is significantly affected by compaction temperature. This is attributed to the segregation of aggregate that may be occurred at low temperature of asphalt pavement mixture during laying-down and compaction process.
- 8- It would be strongly recommend that the minimum allowable temperature for compaction must not less than (110 °C), this must be done in laboratory for determining the optimum bitumen content and on the field for getting asphalt pavement layer with good surface texture and acceptable relative compaction.
- 9-The elapsed time for transporting and laying-down of asphalt mixtures from mix station to the lay-dawn location should not be more than (45 minutes) in summer and (30 minutes) in winter.

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## منهاج لتحديد درجات الحرارة المثلى لدمك الخلطات الأسفلتية على الساخن

دمك الطبقات الأسفلتية في درجات حرارة غير مناسبة يؤثر سلبيًا ليس فقط على خواص وأداء سطح الرصف ولكن أيضًا على تحديد نسب الأسفلت المثلى وخواص الخلطات الأسفلتية عمليًا ، ويعتبر الدمك من أسهل الوسائل التي يمكن استخدامه لتحسين خواص الخلطات الأسفلتية، مما يساعد على الحد من معدلات الصيانة المستقبلية المحتملة فضلًا على أنه يزيد من العمر الافتراضي للطريق ويحسن من أدائه. وقد تم في هذا البحث إجراء دراسة عملية وميدانية لتحديد مدى تأثير خواص الخلطات الأسفلتية عند إجراء الدمك في درجات حرارة مختلفة ، ومدى تأثير ذلك على تحديد نسب البيتومين المثلى وعلى خواص الخلطات الأسفلتية عمليًا ، أيضًا تمت دراسة تأثير اختلاف درجات حرارة الخلطات الأسفلتية أثناء الدمك على نسب الدمك وعلى الخشونة الموضعية لسطح البلاطات الأسفلتية في الطبيعة ، وتم ذلك بالمنهاج التالي:-

**عمليًا :** تم دراسة مدى تأثير درجات حرارة الخلطات الأسفلتية عند الدمك على تحديد القيم المثلى للبيتومين حيث تم دمك الخلطات أسفلتية عند نسب بيتومين مختلفة في درجات حرارة مختلفة هي 140 ، 110 ، 90 درجة مئوية ، أيضًا تم دراسة مدى تأثير اختلاف درجات الحرارة الدمك على خواص الخلطات الأسفلتية ، حيث تم دمك خلطات أسفلتية متماثلة عند ثمانى درجات حرارة مختلفة 140،130،120،110،100،90،80،70 درجة مئوية.

**ميدانيًا :** تم فرش حصىرة من الأسفلت لها نفس خواص الخلطات الأسفلتية التي تم اختبارها عمليًا عند درجات حرارة مختلفة هي 130 ، 110 ، 80 درجة مئوية وذلك على مساحة 6×3 متر في ثلاثة مواقع متجاورة وتم دمك جميعها بمعدل ثابت ، ثم تم دراسة نسبة الدمك الحقلية ، وأيضًا تم تحديد درجة الخشونة الموضعية لسطح الأسفلت لكل موقع من هذه المواقع الثلاث ، حيث تم أخذ عينات غير مقلقة من الطبقة الأسفلتية باستعمال جهاز أخذ العينات ، وتم تحديد خواصها عمليًا لتحديد درجة الدمك الحقلية ، أيضًا تم تحديد قيم الخشونة الموضعية لسطح الأسفلت في الثلاث مواقع باستخدام طريقة رقعة الرمل (Patch Sand) ، أيضًا تم قياس معدل الفاقد مع الزمن في درجات حرارة الخلطات الأسفلتية أثناء نقلها من محطة الخلط وحتى فرشها وذلك في ظل الظروف السائدة ، حيث تم قياس هذا المعدل خلال فصل الصيف (شهر يوليو) وفي الشتاء (شهر يناير).

**وقد أظهرت الدراسة العملية:** أن النسب المثلى للبيتومين للخلطات الأسفلتية تتأثر بتأثر واضح بدرجة حرارة الدمك ، حيث أن نسبة البيتومين التصميمية عند درجة حرارة 90 درجة مئوية تزيد بمقدار 10% عنه في حالة الدمك عند 140 درجة مئوية بينما لا تتعدى 2% في حالة الدمك عند 110 درجة مئوية ، أيضًا تبين أن نسبة الفراغات في الخلطات (VTM % ، VMA %) لا تتأثر عند تغير درجة حرارة الدمك من 140 وحتى 110 درجة مئوية ، بينما تزيد زيادة ملحوظة عند الدمك عند درجة حرارة أقل من 110 درجة مئوية ، أيضًا تبين أن قيم الثبات وقيم جساتة مارشال لا تتأثر بتأثر ملحوظ عند الدمك حتى 100 درجة مئوية عنه عند الدمك عند 140 درجة مئوية ، بينما تقل بمعدل ملحوظ عند الدمك عند درجة حرارة أقل من 100 درجة مئوية.

**كما أظهرت الدراسة الميدانية:** أن نسبة الدمك الحقلية ( Relative Compaction ) تقل بشكل واضح في حالة الدمك عند درجة حرارة أقل من 110 درجة مئوية، أما الخشونة الموضعية بسطح الأسفلت تزيد زيادة ملحوظة في حال الدمك عند درجة حرارة أقل من 100 درجة مئوية، من سياق هذا البحث تم إستنباط أن درجات الحرارة المناسبة لدمك الخلطات الأسفلتية يجب أن لا تقل عن 110 درجة

مئوية ومن واقع القياسات الحقلية تبين وجود توافق بينها وبين النتائج المعملية بالنسبة لخواص الخلطات عند درجات حرارة الدمك المختلفة. أيضا ومن واقع ماتم التوصل إليه يمكن التوصية بأنه يجب أن لا يتعدى زمن نقل وفرش , الخلطات الأسفلتية عن 45 دقيقة في فصل الصيف ولا يتعدى 30 دقيقة في فصل الشتاء ، وبناءا عليه يمكن لمهندسى الطرق تحديد موقع محطة الخلط بالنسبة لموقع الإنشاء.