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Rutting Study in Saudi Arabia

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ABSTRACT. Newly constructed asphalt pavements of several of Saudi Arabian highways have been experiencing premature rutting. Various parameters are thought to be contributing to the problem, from which are, asphalt mix and environment.The aim of this paper is to present the findings of a research plan carried out to identify the factors which contribute to rutting in Saudi Arabia. In this research deterministic evaluation of causes of premature rutting was conducted and reported. Comparative evaluation and identification of diagnostic characteristics of rutting potential of asphalt mix were performed.

KEY WORDS. Asphalt mixes, Deformation, Field testing, Laboratory testing, Project design, Rutting, Permanent, Saudi Arabia.

1. Introduction

Rutting, the surface manifestation of the accumulation of the permanent deformation of pavement layers, is considered the predominant type of asphalt pavement failure in Saudi Arabia[1]. Newly constructed highways are experiencing unanticipated high degree of rutting within a short period from opening to traffic. This deformation is associated with the fast development in the infrastructure of the country. As a result of this rapid development, traffic of heavy trucks with uncontrolled axle load and high tire pressure were increased considerably. This problem has also been reported in various regions in the United States, Europe and Middle east[1-5]. In 1986 the ministry of communications (MOC), Saudi Arabia, performed a nation wide conditioning survey to set maintenance priorities. The rutting developed then affected more than eight major highways for a length extended more than 400 kilometers[1]. These highways, truck routes between major cities, were subjected to extensive evaluations to determine the most probable causes of the premature rutting, and to recommend solutions. The distress these highways experienced limited the use of the facility and caused safety hazard. Since then, the excessive premature deformation started to be wide spread all over the major highways in the Kingdom, thus MOC decided to embark on a nation wide applied research to study the problem. This effort resulted in the establishment of a research group from three universities in the kingdom and MOC. The group in a National Research Project (NRP) developed a research plan as indicated in Fig. 1. This paper discusses the findings of the first phase of the project which includes field and laboratory investigations in order to analyze the rutted and non-rutted road sections to identify the factors which may have contributed to the rutting of flexible pavements in Saudi Arabia.

2. Objectives

The National Research Project to Evaluate the Permanent Deformation of Asphalt Concrete Pavement in Saudi Arabia was set forth to identify the factors which may relate to rutting in order to reach a solution for the rutting problem. The factors identified would suggest modification to the MOC specification. Such modification is expected to minimize rutting and thus saving of capitals.

3. Project Design

The main causes of rutting in the asphalt pavements are attributed (in addition to other factors) to a complex relation between the constituent of the bitumen mix and environment. The stiffness modules of the bitumen mix is affected by the competent of such mix. Aggregate angularity[3], asphalt content and asphalt type, binder viscosity[6,7], filler type and filler content[6], are some of the materials' factors that contribute to such a problem. Traffic, and temperature would assist developing the premature deformation in the asphalt layers.

In order to achieve the objective set forth, the material that is prone to rutting was evaluated with thorough field and laboratory investigations to come up with the possible factors which have contributed to the rutting problem. To reach conclusions about these factors, a set of hypothesis was established. To verify these hypothesis, the following approach was adopted:

3.1 Data Collection

Viewpoints about rutting were solicited through literature and experts involved in pavement design and performance. Responses were reported elsewhere[4]. Construction data from MOC files were reviewed. This included monthly construction reports, technical reports, mix design reports, handing over reports, and investigation reports. All data collected in this study for asphalt concrete mixes and subbase soil were tabulated and statistically analyzed. The analysis was done by comparing parameters obtained from these reports to find any differences between rutted and non-rutted sections. The Statistical Analysis System (SAS) Forward Stepwise Discriminate analysis

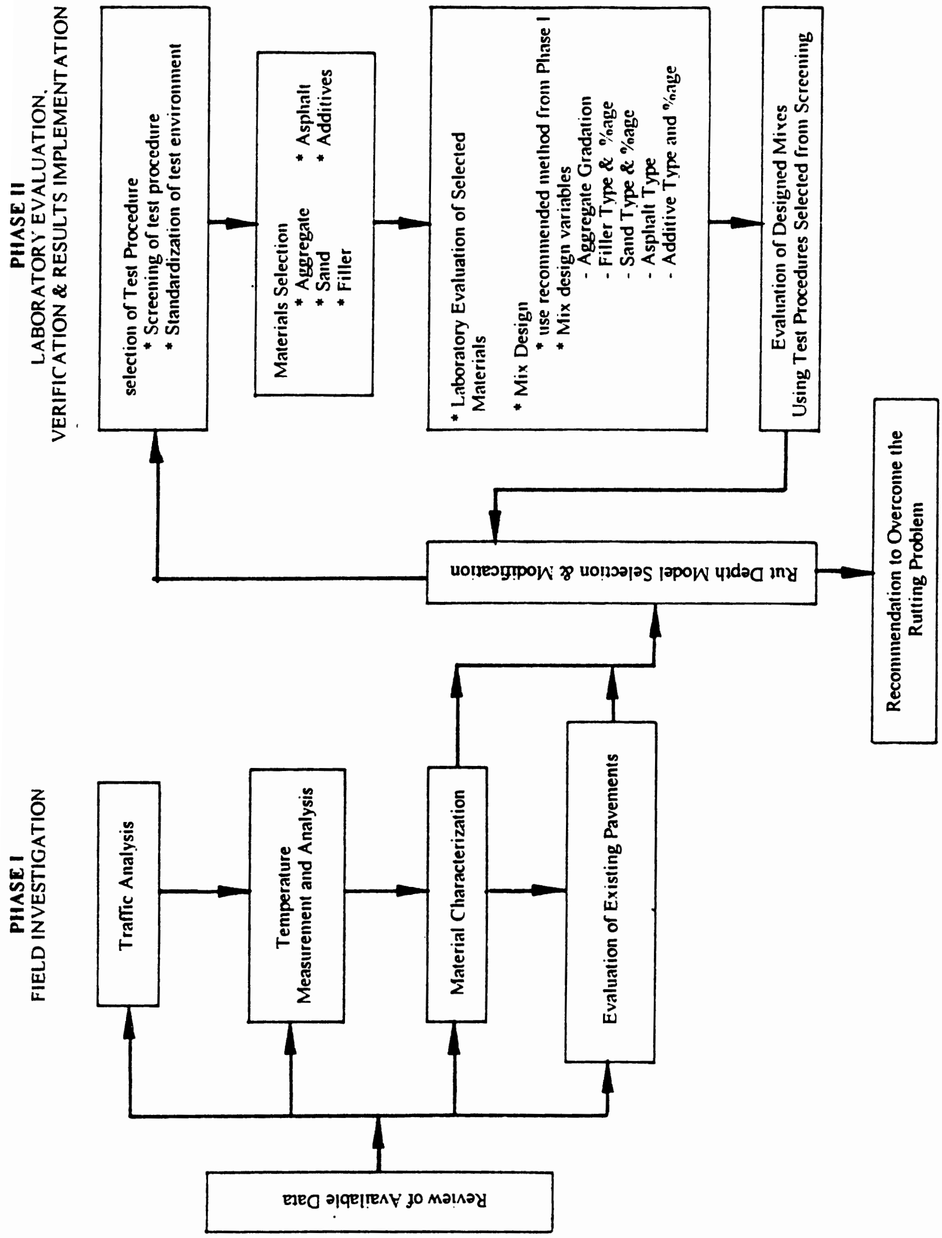

FIG. 1. Research plan.

was used. The procedure selects a subset of qualitative variables, considered in the analysis which produces a good discrimination model between the two groups, rutted and non-rutted. Table 1 shows a summary of the statistical analysis for the data collected from the rutted and non-rutted sections. From this analysis it is difficult to pinpoint the parameter(s) that may have contributed to rutting problem in the kingdom. However, there were some statistical significant differences, using the two sample T-test, in some parameters as indicated in Table 1.

TABLE 1. Number of combinations having $uN = uR$ or $uN \neq uR$ for different analysis parameters obtained from data collected from MOC files.*

Parameters	BWC		BBC		Sig. total	Difference percent
	$uN = uR$**	$uN \neq uR$	$uN = uR$	$uN \neq uR$		
Asphalt content	3	1	4	1	2	22
Surface area	4	–	3	2	2	22
Film thickness	3	1	5	–	1	11
Filler / asphalt	3	1	2	3	4	44
Hump value	3	1	3	2	3	33

*Statistical analysis were done by the two sample T-test
** uN = mean value obtained for non rutted sections
uR = mean value obtained for rutted sections

3.2 Test Section Selection

Test sections of one kilometer in length were selected covering most regions of the Kingdom of Saudi Arabia (Fig. 2). These sections were selected, based on intensive field visits, so as to accommodate a number of external and internal factors which affect pavement performance, such as: 1) traffic volume, 2) materials, 3) pavement structure, 4) quality control, and 5) performance. A test section may satisfy one or more of these factors. The characteristics of the sections selected are present in Table 2. It should be noted that rutted sections are limited to pavement with rutting depth equal or greater than 10mm.

3.3 Field Sample Collection

Samples were collected from both rutted and non-rutted sections as indicated in Fig. 3. This task was aimed to obtain field samples for laboratory testing. Cores were extracted, slabs were cut, subbase soil was removed and sent to different laboratories. Each laboratory was specialized in one test category as shown in Fig. 4. Full depth full lane width saw cut trenches and continuous coring obtained from rutted sections were performed to view the extent and severity of rutting.

3.4 Traffic

Traffic load is one of the most important factors affecting pavement deformation. Thus, the total equivalent of standard axle load was estimated for each selected section with the help of computerized traffic counters and vehicles classifiers. Gross weight, axle load, and tire pressure of commercial vehicles were measured utilizing existing weight stations. The general observations were as follow:

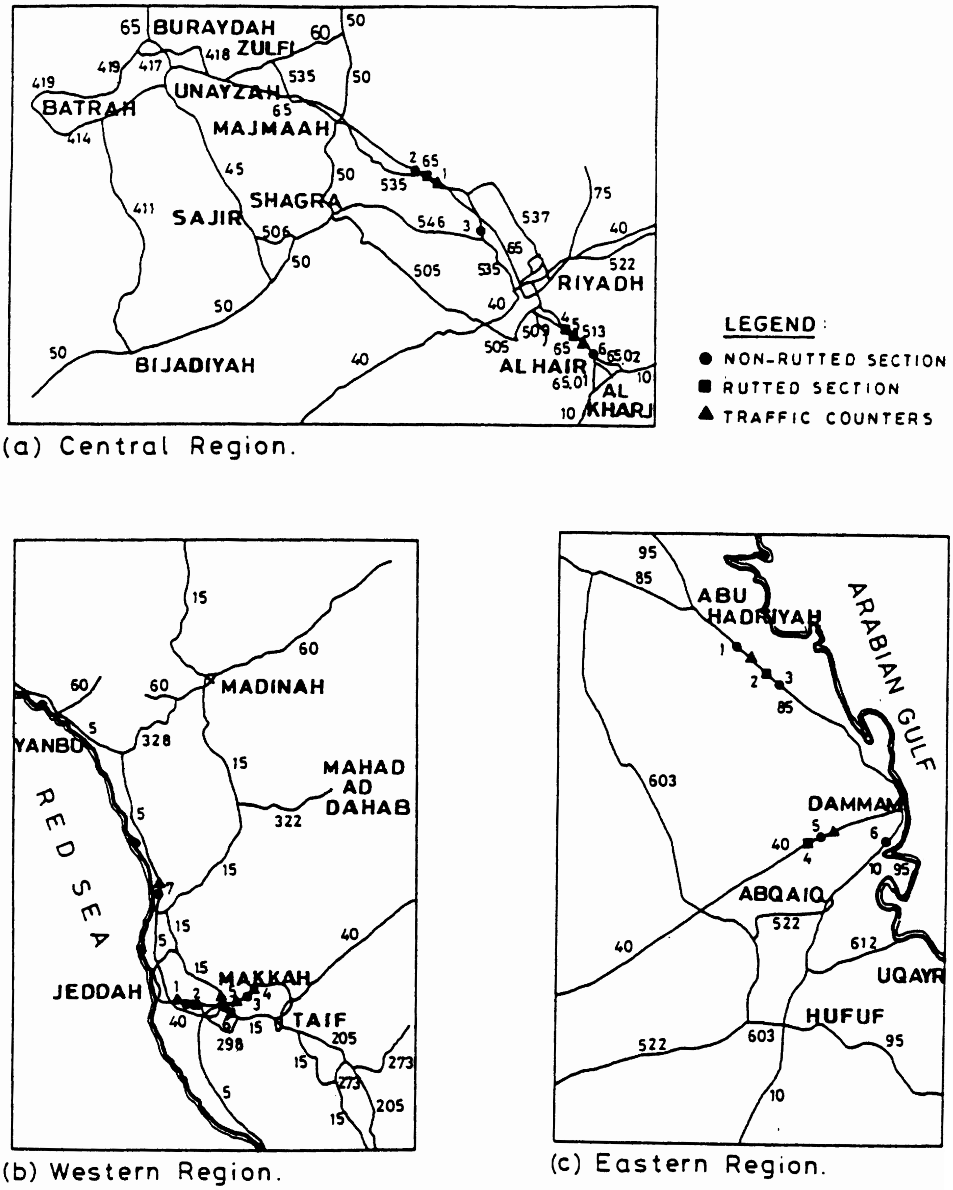

FIG. 2. Location of test sections

1. Heavy trucks make up more than 25% of the total traffic over all test sections.
2. Of these 20% exceeded the MOC weight regulation limit.
3. About 60% of the trucks use the road between 9:00 am to 4:00 pm.
4. All trucks use the slow lane, except in overtaking.
5. Air pressure in more than 95% of the tested tires exceeded the recommended 70 psi (483 kPa), and more than 90% of the tested tires exceeded 90 psi (621 kPa).
6. Trucks with 170 psi (1172 kPa) tire pressure were noted.

TABLE 2. Test section characteristics.

Region	Section[2]	MOC Rod No.	Thickness, mm				Rut depth[1], mm		
			BWC	BBC	ASB	Total	Range	Mean	St Dev
Eastern									
	E1N	85	50	130	300	480			
	E2R	85	50	130	300	480	30 - 63	43.6	0.815
	E3N	85	50	130	300	480			
	E4R	40	50	190	300	540	15 - 37	24.6	0.492
	E5N	40	50	190	300	540			
	E6N	Aramco	50	190	300	540			
Central									
	C1R	65	50	200	300	550	15 - 55	33.0	0.661
	C2N	65	50	200	300	550			
	C3N	535	50	200	300	550			
	C4R	65	50	200	300	550	15 - 70	29.3	0.737
	C5N	65	50	200	300	550			
	C6N	513	50	100	300	450			
Western									
	W1N	290	50	150	300	500			
	W2R	290	50	150	300	500	15 - 40	32.6	0.700
	W3N	40	50	150	300	500			
	W4R	40	50	150	300	500	15 - 38	27.6	0.550
	W5N	15	50	150	300	500			
	W6R	15	50	150	300	500	15 - 42	34.0	0.692
	W7N	5	50	130	300	480			

1. Non rutting rut depth is equal or less than 10 mm.
2. E = Eastern, C = Central, W = Western, N = Non rutted, R = Rutted.

As it could be observed, sever concentrated loading conditions are contributing to the rutting condition that the Saudi highway are experiencing.

3.5 Temperature

The asphalt concrete pavement function and performance are temperature dependent. Although asphalt concrete is considered viscoelastic material, at high temperature level, it will behave as a viscous material. Hot environment would enhance distortion of the asphalt layers thus causing layer deformation under loading condition. Therefore, a thorough documented seasonal temperature variations of selected area was performed. Thermocouples temperature sensors were located at various selected depths of the asphalt layer, (surface, 2, 4, 8, 16cm and bottom of the layer). Air temperature was also measured at a height of 1.5 m above the pavement surface. This data established the actual local effect of temperature on the permanent deformation of the asphalt layers. Measurements were collected 24 hours a day, for two years period. Figure 5 shows the temperature gradients along the depth of the pavement, while Fig. 6 shows the average pavement temperature for 48 hours during the hottest month of the year 1990 for a 20cm full depth asphalt layer. The following general observations were concluded:

1. Roads in Saudi Arabia are exposed to extremely high temperature (> 55°C) for a period more than 12% of the year.
2. Pavement temperature reaches 70°C (158°F) with air temperature approaching 50°C (122°F) in the summer months.
3. Highest temperature occurred in the middle of the 5 cm wearing course layer.

Thus, the extreme high temperature is considered to be also contributing to the rutting phenomena that the Saudi highway are experiencing.

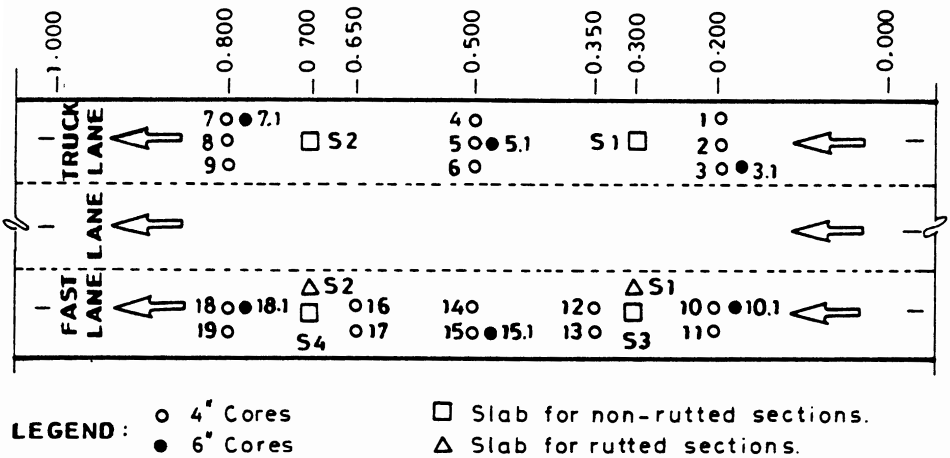

FIG. 3. Test section and field sample collection plan.

3.6 Material Characterization

Material variables were compared between rutted and non-rutted pavement sections. This was accomplished by choosing pavement sections having the same characteristics, such as loading condition (traffic), contractor (quality control), within the same area (same environment effect) and having the same structural design (thickness). The analysis revealed the properties of materials which favor permanent deformation under the prevailing conditions. The properties of mixes (would be discussed in the following subsections) that did not develop rutting indicate the range of the property value where the mix is less susceptible to permanent deformation.

Due to material shoving in the slow lane of rutted sections, the comparison of the material characterization was based on the fast lane of rutted sections and the fast lane of non-rutted sections. The fast lane and slow lane material characterization were also compared for the non-rutted sections. The sampled materials were tested according to tests indicated in Fig. 4. Twenty five cores, four slabs and four subbase soil samples were collected from each non-rutted road section (Fig. 3). In the rutted sections no slabs were cut in the slow lane due to the material shoving, leaving only twenty two cores, two slabs and two subbase soil samples for each section. Cores were separated into designated layers and tested as indicated in Fig. 4a and 4b.

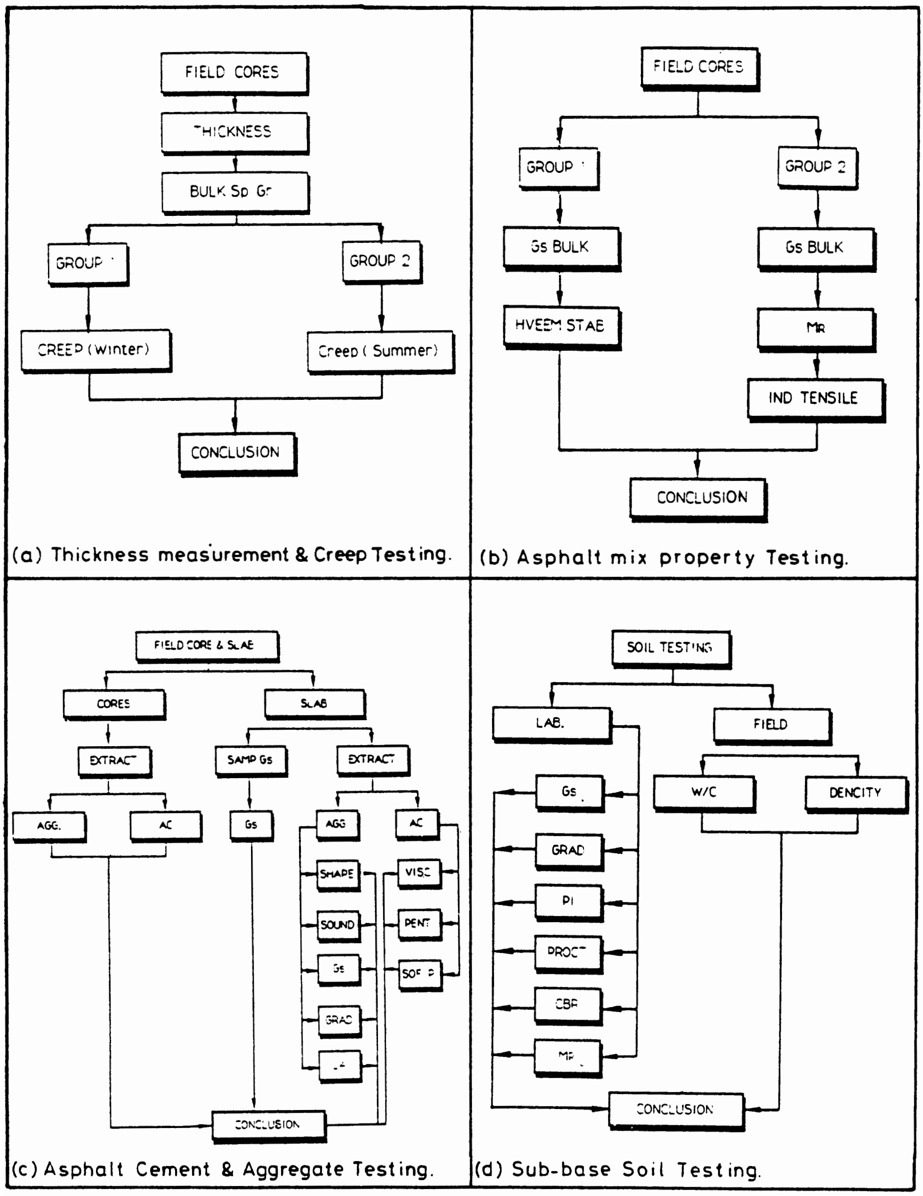

FIG. 4. Testing field samples at the project laboratories.

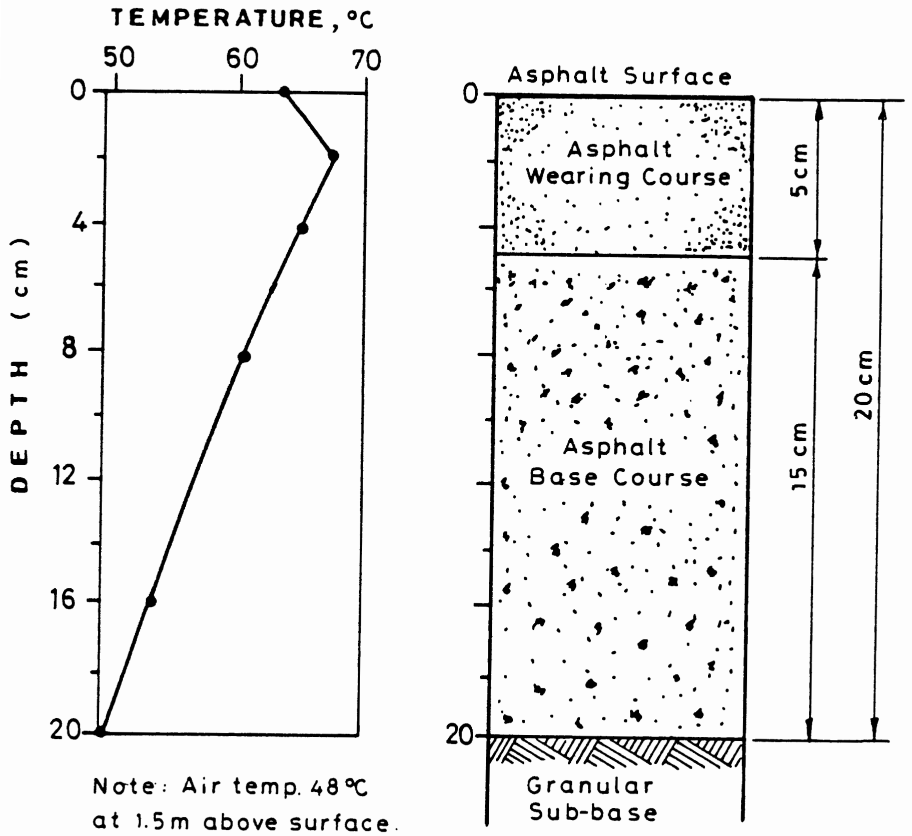

FIG. 5. Temperature gradient in asphalt pavement layer at Riyadh site.

3.6.1 Asphalt Cement Characteristics

Asphalt cement extracted from cores was subjected to the tests indicated in Table 3. The comparison was based on the fast lane of rutted sections and the fast lane of the nun-rutted sections. The rutted section gave relatively higher penetration, lower softening point and lower viscosity. No statistically significant differences were reported when comparing fast lane and slow lane within the same section (rutted or non-rutted). This indicates that material characteristics of the fast lane and the slow lane of the same section are similar. Thus, the asphalt cement properties are contributing to the rutting phenomenon as revealed by the analysis shown in Table 3.

3.6.2 Aggregate Characteristics

Aggregate extracted from the cores and slabs (Fig. 4c) was tested for gradation analysis, surface area, hump value, and percent passing No. 200. No statistical significant deference was observed between rutted and non-rutted sections for both bitumen wearing course (BWC) and bitumen base course (BBC).

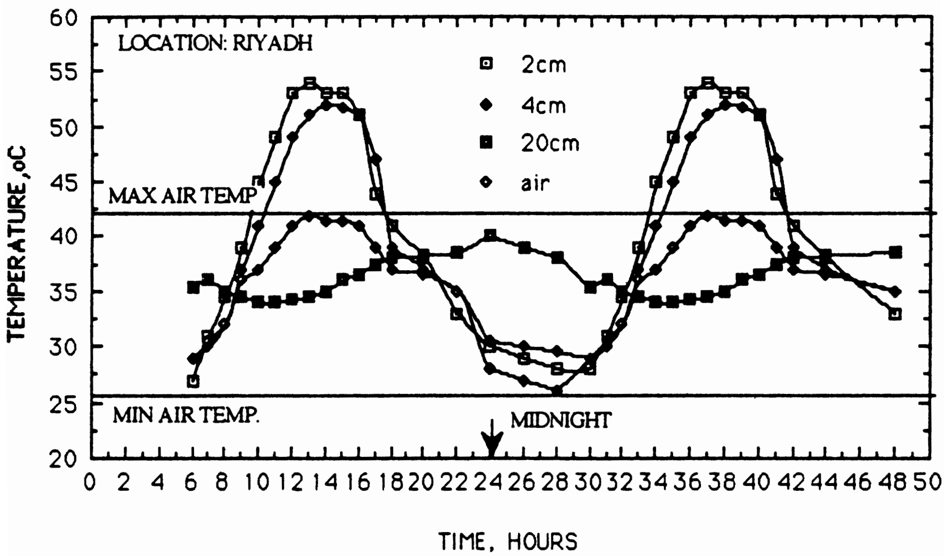

FIG. 6. Typical average pavement temperature in a typical summer month.

TABLE 3. Material characteristics for the fast lanes of rutted and non-rutted sections.

Variable	Mean		P-Value*
	N rutted	Rutted	
Asphalt cement			
PEN25,0.1 mm	21.01	27.03	0.022
SOFTP, °C	67.25	62.52	0.011
KINVS,C Stokees	1724.44	1339.58	0.034
ABSVS, Poises	81295.55	35645.50	0.011
Bitumen wearing course			
AC, %	4.615	4.989	0.190
GMB	2.387	2.427	0.027
GMM	2.518	2.513	0.915
AV, %	4.838	3.457	0.000
GSB	2.609	2.590	0.717
VMA, %	12.717	10.974	0.000
VFB, %	59.942	69.573	0.000
Bitumen base course			
AC, %	4.194	4.245	0.831
GMB	2.334	2.392	0.007
GMM	2.496	2.504	0.038
AV, %	4.447	3.484	0.000
GSB	2.543	2.569	0.609
VMA, %	12.063	11.636	0.454
VFB, %	48.553	64.780	0.000

*If the P-value is less than a specific alpha (say 0.05) we declare that the two means are significantly different.

3.6.3 Asphalt Mixes Characteristics

Asphalt cores obtained from the study sections for both the BWC and BBC were tested for the bulk specific gravity (GMB), the maximum theoretical specific gravity (GMM), asphalt content, extracted aggregate bulk specific gravity (GSB), percent air voids in mineral aggregate (%VMA), percent air voids (%AV), and percent air voids filled with asphalt (%VFB). All tests are in accordance with the Asphalt Institute Mix Design Manual[8]. The statistical comparison was made for the mix design parameters of fast lane for rutted and non-rutted sections. No samples could be analyzed from the slow lane of the rutted section due to material shoving. The following general observations were drawn (Table 3).

1. Bulk specific gravity values (GMB) for both BWC and BBC of rutted sections were significantly higher than that of the non-rutted sections.
2. In situ %VMA and %AV values for the BWC of rutted section were significantly lower than that of the non-rutted sections. For the BBC, %VMA showed no significant difference.This is due to the deformation in the upper portion of the asphalt layers.
3. Percent voids filled with bitumen (%VFB) of rutted sections were significantly higher, in both BWC and BBC, than that of the non-rutted sections.
4. Other mix design parameters (%AC, GMM, GSB) did not show any statistical significant differences.

Asphalt cement properties (penetration, softening point and viscosity) along with the mix properties (%AV, %VMA, and %VFB) played a significant role in accelerating the rutting phenomena in the Saudi highways.

As a result, statistical risk for rutting occurrence was established in the tested sections at the following values for both BWC and BBC:

Value	BWC	BBC
In Situ % AV	> 5%	> 5%
In Situ % VMA	> 13%	> 12.5%
In Situ % VFB	< 60%	< 50%

3.6.4 Subgrade Soil Characteristics

Many well known pavement design methods assume that pavement rutting is a subgrade problem, reflected on the pavement surface. Among these are the Asphalt Institute and AASHTO methods[9,10]. It was therefore imperative to investigate the subgrade characteristics of the study sections. Results, however, indicated that rutting observed in all sections was not initiated in the subgrade and reflected on to the surface. It is rather limited to the top 100 mm as it was observed from the full cut full width trenches and continuous coring.

4. Conclusion

The statistical analysis of data collected from samples tested at the laboratories and field measurements revealed the following conclusions:

1. Asphalt cement properties (penetration, softening point and viscosity) along with the mix properties (%AV, %VMA, and %VFB) are contributing to the rutting problems on the Saudi Arabia highways.

2. The sever environment of heavy loaded trucks, high tire pressure, and high temperature played a significant role in accelerating the rutting phenomena in the Saudi highways.

3. Rutting in the Saudi highways is limited to the top 100 mm as observed from the full cut full width trenches and continuous coring.

4. The total rut depth for all rutted sections studied was 1.5 mm per one centimeter of asphalt layer thickness.

Acknowledgement

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References

[1] **Jimenez, R.A.,** *Pavement Rutting in Saudi Arabia.* Unpublished reported submitted to the Ministry of Communications, Saudi Arabia, Riyadh (1986).

[2] **Southgate, H.F.,** Effects of construction variability on dynamic modulus of asphaltic concrete, *Proceedings, Association of Asphalt Paving Technologists,* **51:** 484-493 (1982).

[3] **Kalcheff, I.V.** and **Tunnicliff, D.G.,** Effect of Crushed Stone Aggregate Size and Shape on Properties of Asphalt Concrete, *Proceedings, Association of Asphalt Paving Technologists,* **51:** 453-483 (1982).

[4] **Hamadani, S.K., Limbrick, A.J., Sterling, A.B.** and **Mesadary, M.S.,** Development of a deformation resistant wearing course for use in Kuwait high temperature, *Proc. of 10th. World Meeting of IRF* (1987).

[5] **Fatani, M.N., Abdul Wahab, H., Balghunaim, F., Bubshait, A.** and **Dhubaib, I.,** *Evaluation of Permanent Deformation of Asphalt Concrete Pavement in Saudi Arabia,* National Research Project, First Technical Progress Report, King Abdulaziz City for Science and Technology, Riyadh, pp. 6-51 (1988).

[6] **Kallas, B.F.** and **Shook, J.F.,** Factors influencing dynamic modulus of asphalt concrete, *Proceedings, Association of Asphalt Paving Technologists,* **38** (1969).

[7] **Ruth, B.E.** and **Olson, G.K.,** Creep effect on fatigue testing of asphalt concrete, *Proceedings, Association of Asphalt Paving Technologists,* **46:** 176-195 (1977).

[8] **The Asphalt Institute,** *Mix Design Methods for Asphalt Concrete and Other Hot Mix Types,* Manual Series Number 2. (MS-2), College Park, Maryland, pp. 17-25 (1984).

[9] **The Asphalt Institute,** *Thickness Design – Asphalt Pavements for Highways and Streets,* Manual Series Number 1. (MS-1), College Park, Maryland, p. 7 (1981).

[10] **American Association of State Highway and Transportation Officials,** *AASHTO Guide for design of Pavement Structures,* Washington, D.C., Vol. **1,** I-14 – I-16 (1986).

Nomenclature

AASHTO	American Association of State Highway Officials
ABSVS	absolute viscosity
AC	asphalt content
AV	air voids
ASB	aggregate sub base
BBC	bitumen base course
BWC	bitumen wearing course
°C	degree celcius
C	central region

E	eastern region
°F	degree fahrenheit
FWD	falling weight deflectometer
GMB	bulk specific gravity
GMM	maximum theoretical specific gravity
GSB	aggregate bulk specific gravity
KINVES	kinetic viscosity
kg/cm^2	kilogram per square centimeter
mm	millimeter
MOC	Ministry of Communications
N	non-rutted section
NRP	national research project
VMA%	percent air voids in mineral aggregate
VFB	voids filled with asphalt
PEN25	penetration at 25°C
psi	pound per square inch
R	rutted section
SOFTP	softening point
W	western region

دراســـة التخـــدد بالممــلكة العربيـــة السعوديـــة

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المستخلص . لقد عانى العديد من طرق الرصف الزفتي المنشأة حديثًا بالمملكة العربية السعودية من التخدد المبكر . يُعتقد أن عوامل عدة تسببت في حدوث هذه الظاهرة ، والتي منها : الخليط الزفتي والبيئة . إن الهدف من هذه الورقة هو عرض نتائج بحث تم عمله للتعرف على العوامل المسببة للتخدد في المملكة العربية السعودية . تم في هذا البحث تقويم تحديدي لأسباب التخدد المبكر ، وتقويم مُقارن وتشخيصي للتعرف على خصائص الخلطات الزفتية القابلة للتخدد .