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Experimental Characterization of Design Performance of Sand-Grained Asphalt Concrete for Worn Pavement

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Abstract

Most of the roads in Algeria are flexible pavements, the main component of which is asphalt concrete. Asphalt concrete aggregates made from crushed stone are now expensive and unavailable near roads, favoring the use of local materials such as dune sand, which is abundant in southern Algeria. The aim of this work is to study the rheological behavior of asphalt concrete, which is partially made of dune sand, as an alternative to crushed sand currently used. The effect of dune dosage on the rheological properties of concrete, in particular its compaction and rutting resistance, was determined using several formulations. To this end, various asphalt mixtures were tested on different dune sand grains using the Super pave rotary shear compaction (GSC) test by means of a rotary shear press to quantify their effect on compaction. These same asphalt mixtures were used to manufacture inserts for rutting tests. According to the results obtained, very acceptable values of resistance to rutting were achieved with 05 to 15% of dune sands compared to the reference concrete.

1. Introduction

Asphalt concrete is one of the widely used materials for paving roads and airports [1, 11, and 32]. In fact, approximately 95% of sidewalks worldwide are made of asphalt [2, 3]. Asphalt concrete (HMA) is used as a surface course in road pavement construction to distribute stresses caused by vehicle loads and to protect the underlying course from water penetration. The properties of the starting material play an important role and must comply with road construction codes [4]. These two tasks are effectively performed during the service life of the pavement; in order to protect the various layers and distribute the load, the concrete elements must withstand various degradations caused by permanent deformation caused by climatic conditions and traffic restrictions. According to the literature, damage affecting the surface layer of a flexible floor can be divided into four main families; deformation, cracks, fissures, and raised asphalt. [5].

Among the aforementioned degradations, the rutting of bituminous layers is one of the main modes of pavement degradation [6, 7, 8, and 9] and the most frequent in roads with high traffic [2, 11, 12, and 13].This type of deterioration affects the durability of the pavement and poses a potential risk to users in the short and medium term. Since the early 1980s, asphalt rutting has become a worldwide problem due to increases in road traffic, heavy vehicle traffic, axle loads, and tire pressure [14, 15]. Rutting's are all permanent deformations of the transverse section of a road that occur under the influence of traffic [6, 16]. These deformations are amplified in dense and canalized traffic, such as B. yards, intersections, bus stops, parking lots, etc. [17]. In the laboratory, permanent deformation caused by rutting of asphalt materials is assessed by the depth of ruts formed after repeated passage through rolling loads at a constant temperature. The causes of wheel rutting are varied and often interact with each other several studies have shown that the main cause of rutting is the accumulation of permanent deformations, particularly under the effect of high temperatures [18].

However, during hot periods, the rutting is all the more important as the traffic is channeled and at low speed. This phenomenon appears clearly in the acceleration or deceleration zones.

In addition, Haddadi and Meunier [19, 20] have linked rutting to the low stability of the wearing course [18] or to an under-dimensioning of the surface layers, while Corte and di Benedetto, 2004 have associated the phenomenon of rutting to the lack stiffness of the filler associated with the base binder.

According to [20], types of rutting can come from an under-dimensioning of the structure, or from a phenomenon of fatigue altering the initial mechanical properties of the pavement, as there are other indirect reasons linked to the implementation defects and the quality of the materials used [21].

To overcome rutting, it is important to ensure optimum performance in terms of resistance and compaction of the surface layer, which has been the main goal in recent years to improve the rheological behavior of the surface layer [21]. The rate of compaction, as assessed by rotating shear press (SGC) tests, during the formation of the surface layer greatly helps to counteract the risk of subsidence and other deformations. In fact, the PCG test, which evaluates the compact ability of asphalt mixtures under several cycles, also allows a practical and rapid prediction of the void fraction in the field. This study evaluates the rheological properties associated with PCG compaction tests, especially the rutting behavior of a new concrete partially composed of dune sand instead of ordinary crushed sand.

Results show that the partial use of dune sands in ordinary asphalt concretes leads to a significant decrease in the rutting depth rate compared to traditional asphalt concretes.

Fig. 1 *Rutting phenomenon occurrence in asphalt pavement*

1.1 Overview of the Rutting Phenomena

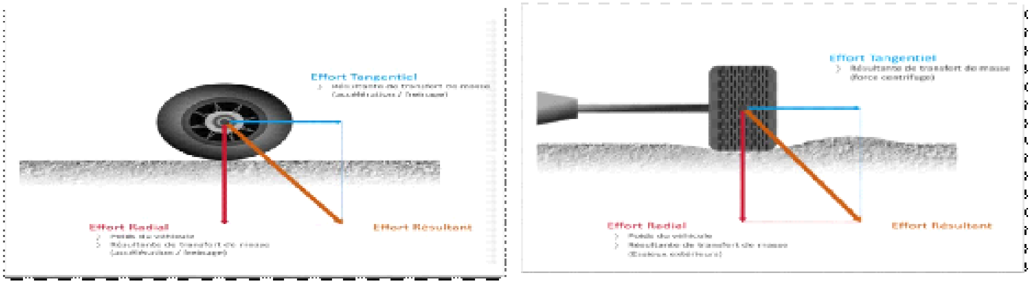
Problems of rutting the surface layers are the result of the accumulation of permanent deformations under the effect of high temperatures [21,23,24].For this, the chosen bituminous asphalt must be flexible enough at low working temperature to prevent cracking and be sufficiently rigid at high working temperature to prevent rutting [25].

The creation of ruts is often due to a lack of absorption of forces by the pavement, repeatedly subjected to high stresses, these applied forces are the result of the combination of two mechanical components that are often combined in potentially stressed areas;

Radial force: combination of weight and vertical acceleration-braking of the vehicle in question.

Tangential force: resulting from weight by acceleration and mass transfer on axles.

Figure 2 shows the mechanism of deformation of the pavement in both cases.



(a) **Radial effort diagram** (b) **Tensile effort diagram**

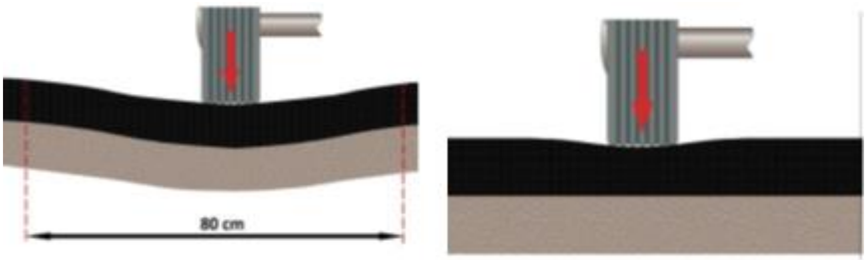
Fig. 2 *Pavement deformation due to rutting*

Depending on the radius of curvature of the deformation, two families of factors responsible for the creation rutting can be distinguished; these are summarized in Table. 1.

Table 1 *Main causes of rutting*

	plastic rutting (small radius rutting)	Structural rutting(large rayon rutting
Responsible factors	• High temperatures • Mixes that are too ductile • Significant tangential forces • Weak underlying design.	• Insufficient compaction • Poor drainage • Aging • Low structural capacity [26]

Depending on the importance of the stresses compared to the resistance of the pavement, two cases of settlements may appear. Figure 3 illustrates the settlement phenomenon in the two cases of rutting.



(a) Large radius rutting **(b) Small radius rutting**

Fig. 3 *Cases of settlement due to rutting (a) Structural, (b) Plastic [27]*

2. Material Used

The hydrocarbon binder used is a class 40/50 bitumen taken from the asphalt plant of the National Society of Public Works -SNTP- of Ain-Beida (Ouargla) which is produced by Total Company.The main bitumen'scharacteristics are listed in Table.2.

Table 2 *Main characteristics of bitumen used*

Test	Standard	Result	CTTPcriteria(*)
Penetration grade at 25°C	EN-1426	37.9	40 – 50
Softening Point, (°C)	EN-1427	50.5	52 – 57
Specific weight at 25°C	EN-1526	1.01	1,00 – 1,10
Flash Point	EN-12591	335	> 230
Penetration index Pfeiffer	-	-1.6	-
PI LCPC*	-	2.350	-

*CTTP: Public Works Technical Control Body, Algiers

The aggregates making up the mineral skeleton of the tested 0/14 bituminous concrete are: 0/3, 3/8 and 8/15, they are taken from the Ben-Brahim crushing station in Haoud El-Hamra (40 km from Ouargla). Dune sand is brought back from the Sidi-khouiled sandpit. Table 3 lists the main geotechnical characteristics of the aggregates used.

Table 3 *Physico-mechanical properties of aggregates used*

Test	Standard	DS*	0/3	3/8	8/15	Recommandation
SpecificGravity(g/cm^3)	-	1.42	1.43	1.36	1.42	-
Sand Equivalnt (%)	NF P 18-597	48.6	49.9	-	-	≥ 50
Flattening coefficient (%)	NF P 18-561	-	-	19	17	≤ 25
LA Abrasion (%)	NF P 18-573	-	-	-	22.4	≤ 25
Methylene Blue			0.64			
Micro-Deval (%)	NF P 18-572	-	-	-	19.4	≤ 20
Analyse chimique sommaire	Insolubles	86.38	32.51	17.59		-
	CaSO4	1.36	0.90	0.75		-
	Carbonates	4.51	56.0	77,03		-
	NaCl	0.10	0.07	0.09		-

*DS: Dune Sand

2.1 Mixture Formulation

For the purposes of the study, five (05) mixtures were prepared; E0 (control mixture), E1, E2, E3 and E4. The percentage composition of each mixture is described in table 4.

Table 4 *Composition of mixtures*

	E0 (réf.)	E1	E2	E3	E4
DS* (%)	00	05	15	15	15
Lime (%)	00	00	00	00	05
Filler (%)	00	00	00	05	00
Gravel 0/3	41	36	26	21	21
Gravel 3/8	25	25	25	25	25
Gravel 8/15	34	34	34	34	34

According to Table 4, Figure 4 plots the granulometric curves of each mixture as well as the reference zone for a 0/14 semi-grained mix according to the SETRA-LCPC recommendations.Les courbes granulométriques des mélanges sont bien continues dans le fuseau de référence.

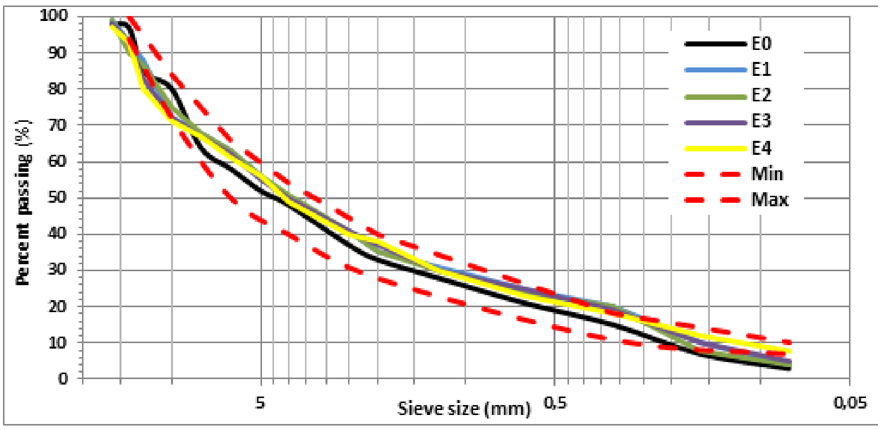


Fig. 4 *Particle size distribution for different mixtures*

The conventional specific surface (∑) calculated for each mixture according to the French method (1) resulted in the values given in table 5.

Binder contents (TL) are evaluated using the fifth root method (2).

$$\sum = 0.25G + 2.3S + 12s + 135l \qquad [m2/kg] \tag{1}$$

$$TL = k.\alpha.\sqrt[5]{\Sigma} \tag{2}$$

Table 5 *Specific surfaces and bitumen contents of the different mixes*

	E0	E1	E2	E3	E4
∑ (m2/kg)	9.27	8.40	10.04	10.48	9.18
TL (%)	5.68	5.70	5.83	5.80	5.77

According to Table 5, it can be seen that the E3 mixture has the largest specific surface area since it contains the highest filler content. The E0 and E1 mix contain the lowest bitumen contents.

2.2 Marshall Test Preparation

This test method, carried out according to standard n° ASTM-D1559, aims to design cylindrical samples of compacted asphalt mixture with dimensions of approximately H63.5mm x Ø101.6mm. The compaction is carried out by a metal hammer with a diameter of 98.4mm and 4.5kg, which falls freely from a height of 45cm.

For the Marshall tests, the mentioned samples are crushed between the jaws of the press after being placed in a water bath at 60°C for 30min.

3. Experimental Program

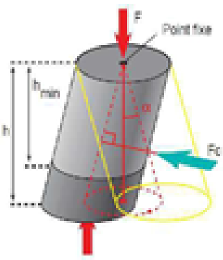
For the purposes of the study, two asphalt concrete behavior tests were adopted, namely the Rutting resistance and the Gyratory shearing press test in accordance with the respective standards NF-EN 12697-22 and NF EN 12697-31 [28.29].

3.1 Gyratory Shearing Press Test

This test studies the compaction of hydrocarbon asphalt, it aims to study the behavior of the bituminous mixture prepared in the laboratory in a cylindrical mold subjected on its top to a vertical pressure of 600 KPa at the same time is inclined at an angle of 1.25° and subjected to a circular motion of 30 rpm. These different actions exert compaction by kneading.

For the preparation of the samples, the various materials as well as the compacting molds were preheated in an oven, adequate mixing is carried out until a homogeneous mixture is obtained and ready to be compacted.

The principle is to carry out 200 turns of gyrations with asphalt under 60 °C. The aim is to measure the evolution of the percentage of voids in the mixture as a function of the number of turns. The roundabout shear press is shown in Figure 5 while its principle of operation is schematized in Figure 6.



Hmin : minimum height for 0% void
H: apparent height for N gyrations
F, Fc: axial and shear force
α: angle of inclination

Fig. 5 *Superpave Gyratory Compactor*

Fig. 6 *Schematic diagram of the GSC test [30]*

3.2 Rutting Resistance

The rutting test is carried out on asphalt concrete slabs designed in the laboratory to determine their resistance to permanent deformation under the effect of loads similar to those applied on roads and at defined temperatures.

This test makes it possible to simulate the resistance of the asphalt mix to rutting, in particular for roads frequented by heavy goods vehicles. Evaluation of resistance to permanent deformation and rutting test results showed excellent correlation with in-service pavement deformation [30].

The surface of a parallelepiped hydrocarbon mixture specimen is subjected to the action of a wheel load describing a rectilinear round trip movement, at a given frequency and at a constant temperature. The depth of rut, at a point on the surface of the specimen, is its permanent vertical drop relative to the lips of the rut.

The depth of the rut, measured to an accuracy of at least 0.1mm, at 1000, 3000, 10,000, 30,000, 100,000 cycles is measured and compared to the current standard.

According to BS 598: Part 110, the sample dimensions are as follows: 300×300×50mm. The mass of the slab tested can be evaluated according to its density calculated from the Marshall test.

The rutting test is carried out at temperatures of 40, 50 and 60 °C and the applied load is equivalent to 100 and 200kPa.

Fig. 7 *Photo of the wheel track test and wheel track test apparatus*

4. Results and Discussion

4.1 Superpave Gyratory Compactor Test Result

The roundabout shear press test has been developed for the formulation of French bituminous asphalt since 1972 [31].

Superpave Gyratory Compactor was used to prepare cylindrical specimens to determine the optimum asphalt content to each type the five aggregate blending according to AASHTO Designation: T 312-2010.

For the purposes of the PCG tests, four mixtures were made in addition to the control mixture (E0). The void content corresponding to 80 gyrations for each mixture is given in Table 6.

Table 6 *Percentage of voids at 80 gyrations*

Mixture n°	E0	E1	E2	E3	E4	Standards
Void (%)	4,90	4,91	6,71	7,03	6,24	4,0% - 9,0%

According to Table 6, all the mixtures produced are compactable and therefore easily implemented and fit p erfectly into the standards, that is to say in the gap between 4% to 9% at 80 turns (NF EN 13108-1:BSG Class 03). The mixtures E2 and E3 that contain the highest bitumen contents.

Figure 8 shows the decrease in the percentage of voids as a function of the increase in the number of gyrations according to a logarithmic scale. It should be noted that all the mixtures have similar behavior, the compactness increases by about 10% between 10 and 100 gyrations.

The mixture E0 seems to be the most compactable compared to the other mixtures.

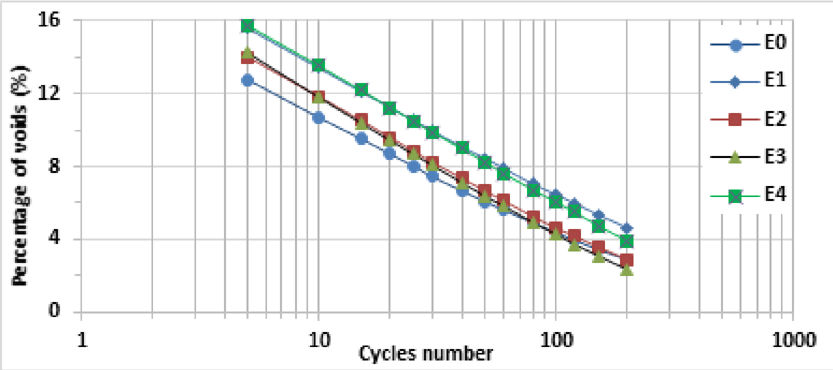


Fig. 8 *Evolution of the vacuum according to the number of gyrations*

4.2 Wheel Track Test Result

The mixtures previously produced were used to produce test specimens for the rutting tests in accordance with the EN 1267-31 standard. The test conditions are as follows;

- Storage duration: 02 days
- Storage temperature: 25°C
- Test temperature: 60ºC.

Table 7 gives the dimensions and properties of the specimens produced.

Table 7 *Physical characteristics of specimens*

Length (mm)	Width (mm)	Thickness (mm)	Mass (kg)	MVA (kg/m3)	MVR (kg/ma)	Voided (%)
500	180	101.73	20288	2215.9	2400	7.67

The deformation behavior of bituminous materials is evaluated by the depth of the rut which forms following repeated passages of a rolling load at constant temperature. In fig 10, the results obtained from the evolution of the percentage of voids according to the number of cycles for each mixture, i.e. its workability, are reported.

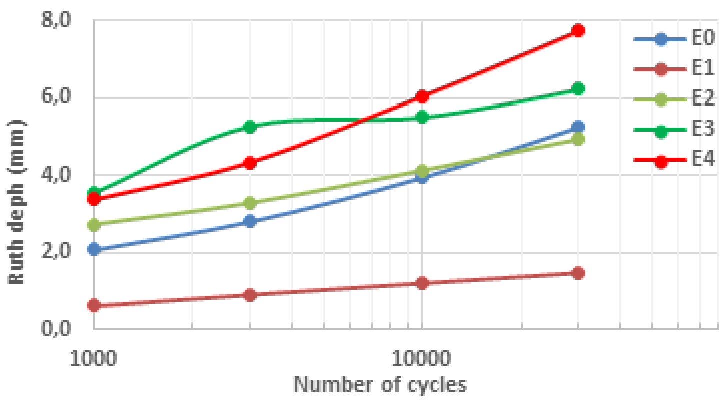


Fig. 9 *GSC test results*

According to figure 10, it appears that the mixtures E3 and E4 present the best performances in terms of depth of deformation produced during the passage of the wheel according to the number of cycles, which reflects the importance of use of filler of contribution and the relatively low bitumen content.

Sample E1 is the least prone to rutting compared to other blends as shown in figure 11. Figure 12 clearly shows the condition of sample E3 plate before and after the test.

From an analytical point of view, we notice a linear relationship between rutting and compact ability for all mixtures; the rutting depth increases with the number of cycles, which is logical.

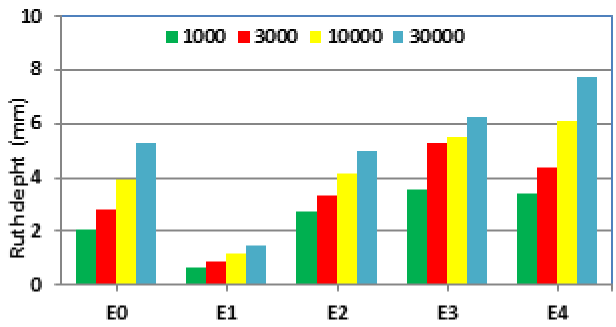


Fig. 10 *Ruth depth of mixtures at different cycles*

Fig. 11 *E3 mixture before and after rutting*

5. Conclusion

In this research, we studied a modified asphalt concrete based on dune sand, its properties and behavior under simulation condition to the reality or site conditions. It was attempted to characterize the rutting behavior of sandy asphalt mixture under static loadings, and find the relationships between the deformation by wheel track test and other mix properties.

The use of bituminous concrete made partially from dune sands aims to preserve the best quality non-renewable aggregates and reduce production costs, which classifies this technique in the context of sustainable development.

Based on the results, the following conclusion can be derived:

Dune sand-based bituminous concretes generally have mechanical performance comparable to that of conventional bituminous concretes in terms of compact ability and rutting. Nevertheless, the addition of dune sand has a positive influence on rutting resistance.

The addition of only 5% of dune sand generates a gain of more than 60% in terms of rutting compared to concrete without dune sand and filler, which improves the rheological behavior of the mixtures.

In terms of compaction, evaluated by the PCG test, all the mixtures respond favorably to the reference standards and present percentages of voids included in the interval between 4% - 9%. Indeed, the addition of 15% dune sand significantly improves the ability to compaction by about 35%.

The addition of 5% filler in the presence of dune sand significantly improves resistance to rutting by 30 to more than 60% depending on the number of cycles.

In general, the increase in dune sands in the 5-10% range results in a 20% rise in voids and a marked improvement in rutting, with the same bitumen content.

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