Mechanical Performance Evolution of a Bituminous Mix Based on Dune Sand and a Polymer Modified Bitumen

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Abstract:
This work aims to evaluatelocal sand in road surface to replace the 0/3 crushed sand used in bituminous concrete thin surface layers for classical roads. The binder used is a 40/50 bitumen modified with a polymer called Lucobit 1210A produced locally. The approach followed is to vary the percentage of crushed and determine the optimal formulation. The resulting composites are subjected to the Hubbard Field stability test to evaluate their load resistance and corresponding deformation.Non-destructive tests using sonic wave propagation tests are also carried out in order to find possible correlations under two distinct conservation modes; in the open air and in the water.For this reason, the mechanical and sonic characteristics of bituminous concrete specimens in the presence of water at 18 and 60 °C are evaluated and compared with those kept in the open air.The obtained results correspond to the optimal composition: 60% SD + 40% SC for which a gain of more than 40% is recorded in the HF stabilities. To this end, the findings are more than satisfactory compared to local specifications, particularly in the case of roads with medium to low traffic.

Key words :bituminous concrete,sable de dunes,stabilityHubbard Field,Ultrasonic Testing

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Introduction:

Road infrastructures play a crucial role in the economic and social development of countries.The construction and maintenance of roads require high-quality materials, especially for the bituminous concrete used in pavement construction. However, the supply of appropriate construction materials may be limited in certain regions (desert areas). The use of dune sand as an aggregate in bituminous concrete offers potential advantages [4], such as the preservation of natural resources and a reduction in aggregate supply-related costs

Dune sand is characterized by fine and tightly packed grains (1-5) with a size generally smaller than 2 mm [8]. It is a granular material composed of small particles resulting from the breakdown of other rocks, with dimensions ranging from 0.063(silt) to 2 mm [3]. Several studies have highlighted the value of using dune sand in bituminous concrete, yielding very promising results [2-9].
The road construction industry is seeking to develop more durable and resilient bituminous mixtures capable of withstanding heavy loads, resisting extreme climatic conditions in hot zones (hot and dry climate in summer), and prolonging the lifespan of roads.
The use of polymers in bituminous mixtures is becoming increasingly common due to its undeniable advantages in terms of strength and durability, as mentioned in several studies in this field [13, 14, 17, 18]. The incorporation of polymers modifies the chemical, physical, and mechanical properties of bitumen [15, 16]. They are commonly employed in the road construction sector.
In this study, the stability of bitumen sand samples is measured using both a traditional destructive method (Hubbard-Field Test) and a non-destructive method using ultrasonic's. While these techniques are not as widely used in the field of pavements, ultrasonic waves allow for the detection and evaluation of the stiffness of these layers [19], assessment of pavement joint damage [6], and characterization of the acoustic performance of the surface layer [12]. Laboratory studies enable a good correlation with certain microstructural characteristics of the material (density, void volume [7], water content [10], optimum bitumen content) [11].

Characterization Of Materials:

Identification of granulats:

Two types of sand from different origins were used: the sand of the dunes of Elhadjira located 100 km from the capital of the wilaya of Ouargla and the crushed sand 0/3 taken from the quarry of Benbrahim (30 km from the capital of Ouargla).
Figures 1 and 2 represent photos of the materials used while the table 1 lists the characteristics of the different aggregates.

Figure 1. Crushed sand

Figure 2. Dunes sand

Table 1:Physical properties of aggregates used

Sand	Specific density	Component					
		Insoluble	$CaSO_4 2H_2O$	SO_3	$CaCO_3$	NaCl	Cl^-
Dunes	2,65	95,99	2,63	0,49	1,5	0,046	0,03
Crushed0/3	2,57	32,24	1,80	0,33	68	0,013	0,008

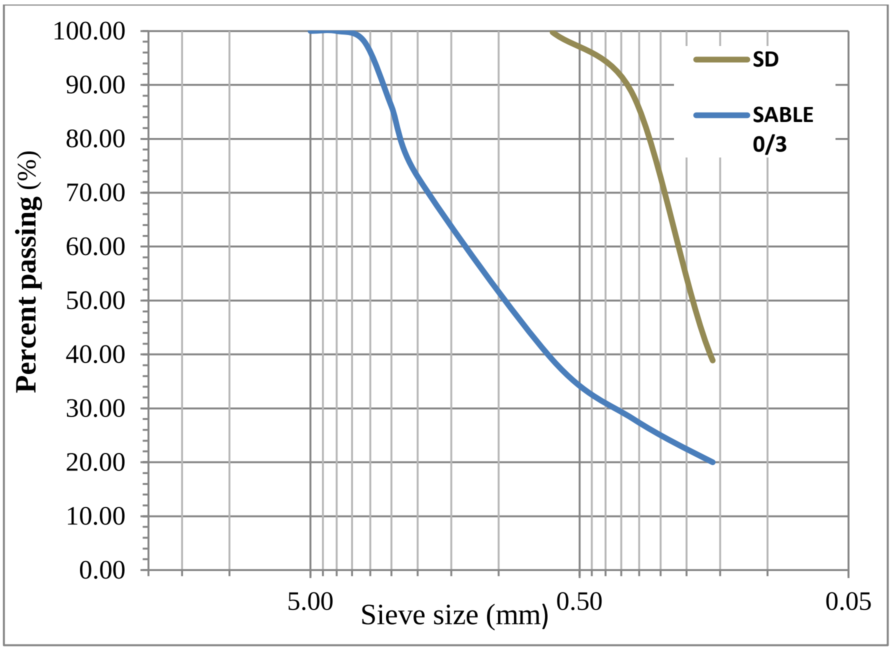


Fig. 3: Granulometric analysis of aggregates

Filler:

Fig. 4 crushed dune sand

The physico-chemical characteristics of limestone filler and crushed dune sand are presented in Table 2.

Table 2: Physical properties crushed dune sand

	Component					
	Cao3(%)	Insoluble(%)	SO3-(%)	CL-	CaSO42H2O	So4-(mg/l)
Specimen	2.39	91.5	4.25	0.054	7.09	390

Identification du bitumen:

The binder used is class 40/50 modified bitumen from the El Eulma-Sétif asphalt plant (Algeria) whose rheological properties were modified during its manufacture by the use of synthetic polymers. Table 3 gives the physical properties of the bitumen used.

Table 3: Characteristics of bitumen used

Test	Standard	Unit	Value	Specification"
Penetration at 25°C	EN 1426[22]	1/10 mm	48	40-50
Softening point	EN 1427[23]	°C	50	47-50
Density	EN 15 326 [24]	g/cm3	1,025	1.03

The modification of bitumen was done using a polymer called Lucobit 1210A, supplied by the company Lucobit Alegria, known for its excellent compatibility and high viscosity. The chemical structure of the EBA polymer consists of butyl acrylate and vinyl polymer and belongs to the Ethylene Butylacrylate Copolymer (EBC) group.
Table 4 represents the technical characteristics of this polymer.

Table 4: Technical Specifications of Lucobit 1210A.

Technical characteristics	Unit	Result
Density (23°C)	g/cm3	0.98
Elongation at fracture	%	720 - 860
Modulus of elasticity	MPa	15
Melting poin	°C	160-185

Formulations And Mechanical Performances:

The main objective of a formulation is to determine an optimal composition of aggregates, binders, and voids to achieve the desired performances.
After conducting identification and mechanical characterization tests on aggregates and bitumen, we proceed with the mixing phase of aggregates with the binder. The quantity of binder used in the sand-bitumen mixture is determined as a percentage of the total weight of aggregates, according to the formula:

$$\% \text{ of bitumen } \; L = k.\sqrt[5]{\sum}$$ [21]

Σ: specificconventionnel surface of the mixin m^2/kg

Σ = (4, 75 + 1, 3*f)

K : richness modul f : proportion elements less tham (<80 µm)

Tests and procedures:

Hubbard-Field Stability Tests (Destructive Methods):

This test aims to measure the pressure under which a standardized mortar or bituminous mix specimen can flow through a calibrated orifice.

In the case of a hydrocarbon mortar, the measurement of Hubbard-Field stability involves determining the pressure that causes the extrusion or flow of a 100g briquette with a diameter of 50.8mm through a smaller ring with a diameter of 44.5mm. This pressure is applied at a rate of 1 mm/sec on a briquette that has been kept dry at 18°C for 24 hours after its preparation. At the time of the test, the briquette is brought to either 18°C or 60°C, and it is immersed in water for one hour.

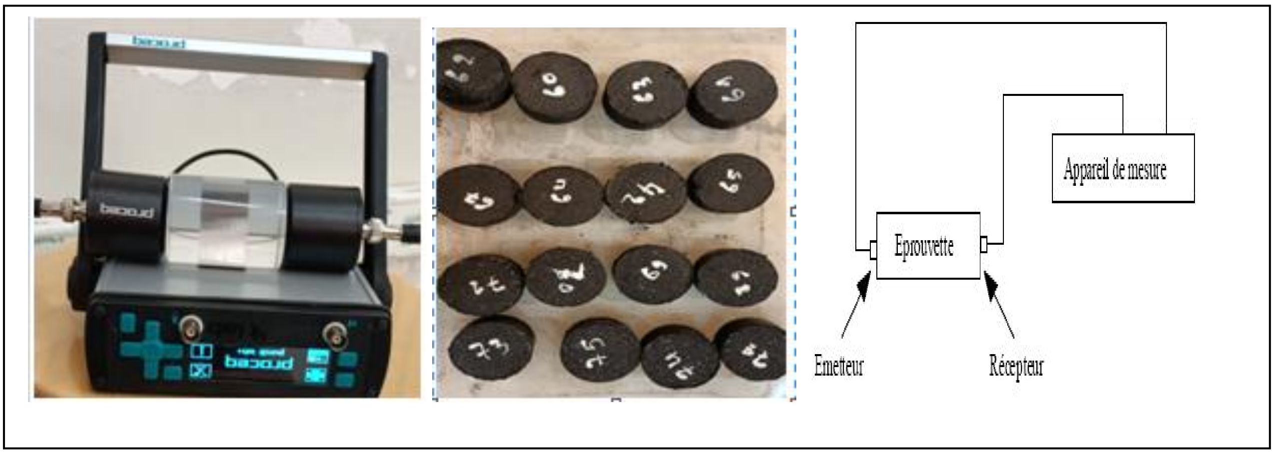
Hubbard-Field stability, denoted as H.F., is expressed in kilograms and represents the load required to induce this flow.

These three tests are performed to experimentally study bituminous mixtures and determine the best formulation to be adopted.

Ultrasonic Testing (Non-Destructive Method):

Researchers have used the pulse velocity technique to assess the strength of bituminous concrete structures, aiming to establish a correlation between pulse velocity, strength, and other properties of the concrete. This testing method is based on the principle that the propagation time of the pulse is related to the material's density, which correlates with compressive strength. By measuring the pulse velocity, it is also possible to detect heterogeneous regions or verify the concrete's capacity [20].

Figure 5. Schematic diagram of the ultrasonic testing.



Results And Discussion:

Hubbard-Field Stabilities

Figure 6 shows the variation of Hubbard-Field stabilities for the samples according to the bitumen dosage in a mixture of 100% dune sand.

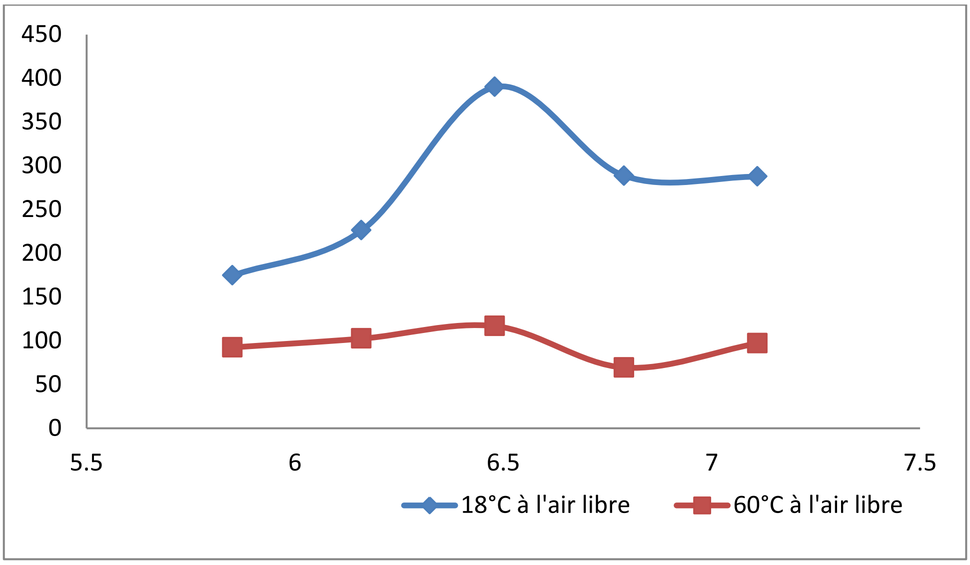


Figure 6. Influence of bitumen content on HF stability.

According to Figure 6, the optimum stability is achieved with a bitumen content of 6.48%. However, the stabilities remain insufficient even with high bitumen contents. This can be explained by the absence of a mineral skeleton that should be compensated by the hardness of the binder. On the other hand, if the content is lower than this value, the mixture becomes less stable due to the influence of coating.

To improve performance, the fraction 0/3 (crushed sand) is replaced with dune sand in proportions ranging from 0 to 40% of the aggregates, along with 3% of crushed dune sand.

The evolution of performances is represented in both table 3 and figure 3.

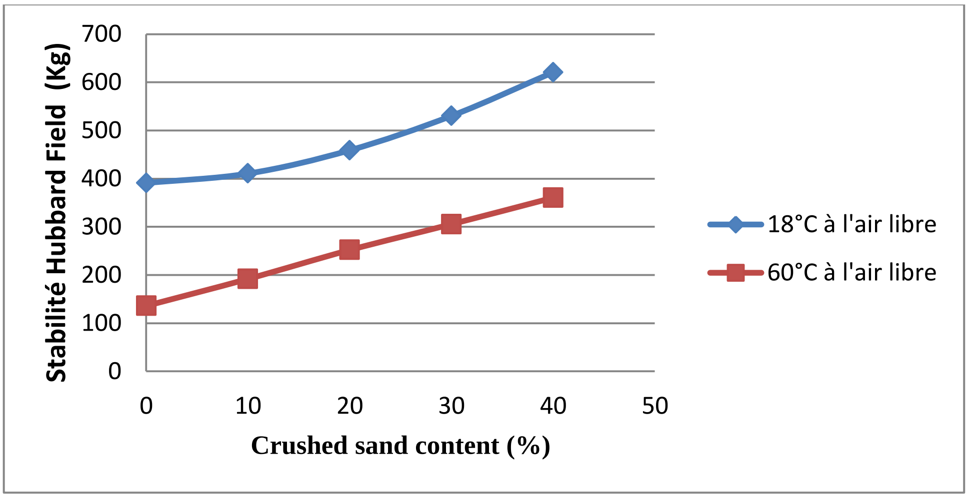


Figure 7. Influence of crushed sand on Hubbard Field stability in open air.

The above figure show an improvement in stability compared to the first mixture (100% dune sand).

• It can be concluded that the addition of crushed sand significantly enhances stability due to the better angularity of these grains, which improves the behavior of the bitumen/filler mastics by providing more rigidity.

• In addition, an increase in temperature leads to a decrease in stability

Ultrasonic tests results:

The results of the test campaign are presented in the table below:

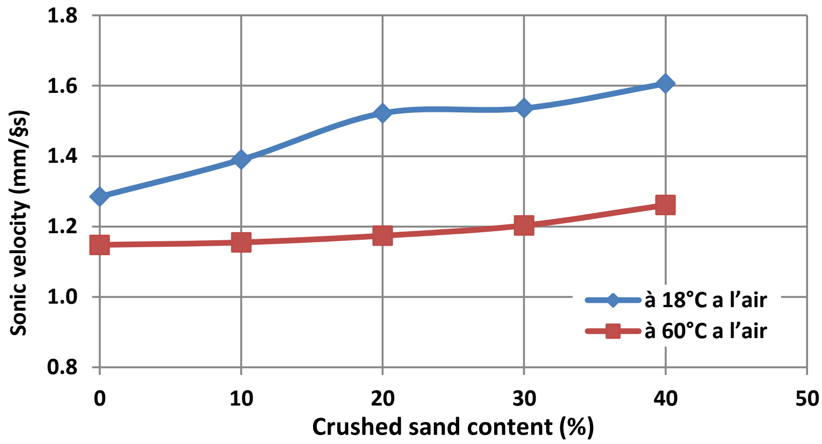


Figure 8. Ultrasonic Results in Open Air

Following the above figure, it can be observed that:

- The ultrasonic pulse velocity was low and tended to increase with an increase in the crushed sand content.
- The figure indicates that with an increase in temperature, the time taken for the ultrasonic pulse to pass through the material also decreases.

The relationship between Hubbard-Field Stabilities and ultrasonic test results

The results of the graph clearly show that an increase in temperature leads to a significant decrease in stability and ultrasonic passage time. Moreover, the ultrasonic pulse velocity also decreases with increasing temperatures. This phenomenon can be explained by the fact that, under high-temperature conditions, the bitumen binder becomes more fluid and fills the internal voids of the sample. As a result, this leads to a reduction in stability and ultrasonic passage time..

Conclusion

In this study, an analysis was conducted on all experimentally obtained data, leading to the following conclusions:

- The stability and compaction of the 100% dune sand mixture are insufficient.
- The addition of crushed sand and ground dune sand significantly improves stability.

- The addition of crushed sand and ground dune sand results in a gain of over 40% in HF stabilities.
- Ultrasonic pulse velocity is a highly interesting method for detecting damages in asphalt concrete and can be easily applied on-site.
- It was observed that the stability of the samples has an inverse relationship with the ultrasonic passage time.
- The ultrasonic velocity decreased with an increase in voids when the sample was exposed to high temperatures. In other words,
- With an increase in temperature, the stability of the asphalt mixtures decreased significantly.

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