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Experimental investigation and evaluation of the compactness and moisture damage of asphalt mixes incorporating dune and river sand

Investigação experimental e avaliação da compactação e danos à umidade de misturas de asfalto incorporando dunas e areia fluvial

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Abderahman Younsi
PhD in Civil Engineering
Institution: Department of Civil Engineering, Faculty of Technology, University of Medea
Address: Medea, 26000, Algeria
E-mail: younsi.abderrahman@univ-medea.dz

Abdelhalim Bensaada
PhD in Civil Engineering
Institution: Department of Civil Engineering, Faculty of Technology, University of Medea
Address: Medea, 26000, Algeria
E-mail: bensaada.abdelhalim@univ-medea.dz

Naas Allout
PhD in Civil Engineering
Institution: Department of Civil Engineering, Faculty of Technology, University of Djelfa
Address: Djelfa, 17000, Algeria
E-mail: naasallout@yahoo.fr

Haddadi Smail
PhD in Civil Engineering
Institution: Environment Laboratory, Water, Geomechanics and Structures, Faculty of Civil Engineering, University of Sciences and Technology Houari Boumediene (LEEGO - USTHB)
Address: Algiers, 16000, Algeria
E-mail: smail.haddadi@gmail.com

Belgacem Choungache
Master in Civil Engineering
Institution: Department of Civil Engineering, Faculty of Technology, University of Djelfa
Address: Djelfa, 17000, Algeria
E-mail: b.choungache@univ-djelfa.dz

ABSTRACT
Road construction is mainly based on the use of raw materials that must be in compliance with the standards, thus ensuring the quality and durability of the road. The use of dune sand and river sand in road geotechnics is an interesting subject. Both types of sand can be used in road construction and maintenance for a variety of applications. Dune sand is often appreciated for its uniform grain size and drainage capacity, while river sand can offer good mechanical strength. The majority of common bituminous mixes contain fillers made of quarry sand, whose amounts are difficult to regulate because of the variety of rock deposits and the conditions under which they are manufactured. In this paper, the compactness and moisture damage of asphalt mixes with two sand types, River sand (RS) with (0/4) size was sourced from the valley in the province of Medea (Algeria) and Dune Sand (DS) with a particle size of (0/0.5) was obtained from a dune in the Algerian province of Djelfa, were examined. Furthermore, a 100% replacement rate by weight of Crushed Sand (CS) with (0/3) mm size was used (quarry sand). The investigation employed a comprehensive approach, utilizing Marshall and gyratory shear compaction tests to assess compactness, while moisture damage was evaluated through rigorous water resistance testing and compressive strength methodology. The results of the study reveal a notable disparity in the mechanical performance of asphalt mixtures containing dune and river sand, showcasing diminished compactness and heightened susceptibility to moisture-induced damage when compared to alternative mix formulations. These findings underscore the critical role of sand type selection in asphalt mix design, emphasizing the need for careful consideration to optimize performance and durability.

Keywords: asphalt mixes, dune sand, river sand, compactness, moisture damage.

RESUMO
A construção de estradas baseia-se principalmente na utilização de matérias-primas que devem estar em conformidade com as normas, garantindo assim a qualidade e a durabilidade da estrada. O uso de areia de dunas e areia de rios na geotécnica rodoviária é um assunto interessante. Ambos os tipos de areia podem ser usados na construção e manutenção de estradas para uma variedade de aplicações. A areia dunar é muitas vezes apreciada por seu tamanho de grão uniforme e capacidade de drenagem, enquanto a areia fluvial pode oferecer boa resistência mecânica. A maioria das misturas betuminosas comuns contém cargas feitas de areia de pedreira, cujas quantidades são difíceis de regular devido à variedade de depósitos de rochas e as condições em que são fabricados. Neste artigo, foram examinados a compacidade e os danos à umidade das misturas de asfalto com dois tipos de areia: areias fluviais (RS) com (0/4) tamanho foram provenientes do vale na província de Medea (Argélia) e areias dunas (DS) com um tamanho de partícula de (0/0,5) foram obtidas de uma duna na província argelina de Djelfa. Além disso, foi utilizada uma taxa de substituição de 100% em peso de Areia Triturada (CS) com (0/3) mm de tamanho (areia de pedreira). A investigação empregou uma abordagem abrangente, utilizando testes de compactação de cisalhamento Marshall e giratório para avaliar a compacidade,

enquanto os danos à umidade foram avaliados por meio de testes rigorosos de resistência à água e metodologia de resistência à compressão. Os resultados do estudo revelam uma notável disparidade no desempenho mecânico de misturas de asfalto contendo dunas e areia fluvial, apresentando menor compacidade e maior susceptibilidade a danos induzidos pela umidade quando comparados a formulações alternativas de mistura. Esses achados ressaltam o papel crítico da seleção do tipo de areia no design da mistura de asfalto, enfatizando a necessidade de uma consideração cuidadosa para otimizar o desempenho e a durabilidade.

Palavras-chave: misturas asfálticas, areia dunar, areia fluvial, compactação, danos à umidade.

1 INTRODUCTION

For an asphalt mix used in the construction of the wearing course of flexible pavements, bitumen represents on average 5% of its mass composition (13% by volume), while the granular skeleton is made up of mineral components representing about 95% (85-87% by volume). Their choice, both in nature and in proportion, is important and directly affects the mechanical characteristics and other targeted performances of the bituminous mix, depending on the type of mix (TRANSPORTATION RESEARCH BOARD, 2011). Asphalt mix formulation consists of adjusting the composition, including qualitative and quantitative adjustments to aggregates, and hydrocarbon binder, to optimize the performances compared to a given reference for a given family of mixes. The mechanical properties of asphalt mixes vary with the volumetric composition of the mixture and depend on the maximum grain size, binder content, and void content of the mixture (JOHN; BANGI; LAWRENCE, 2021; SWATHI et al., 2021).

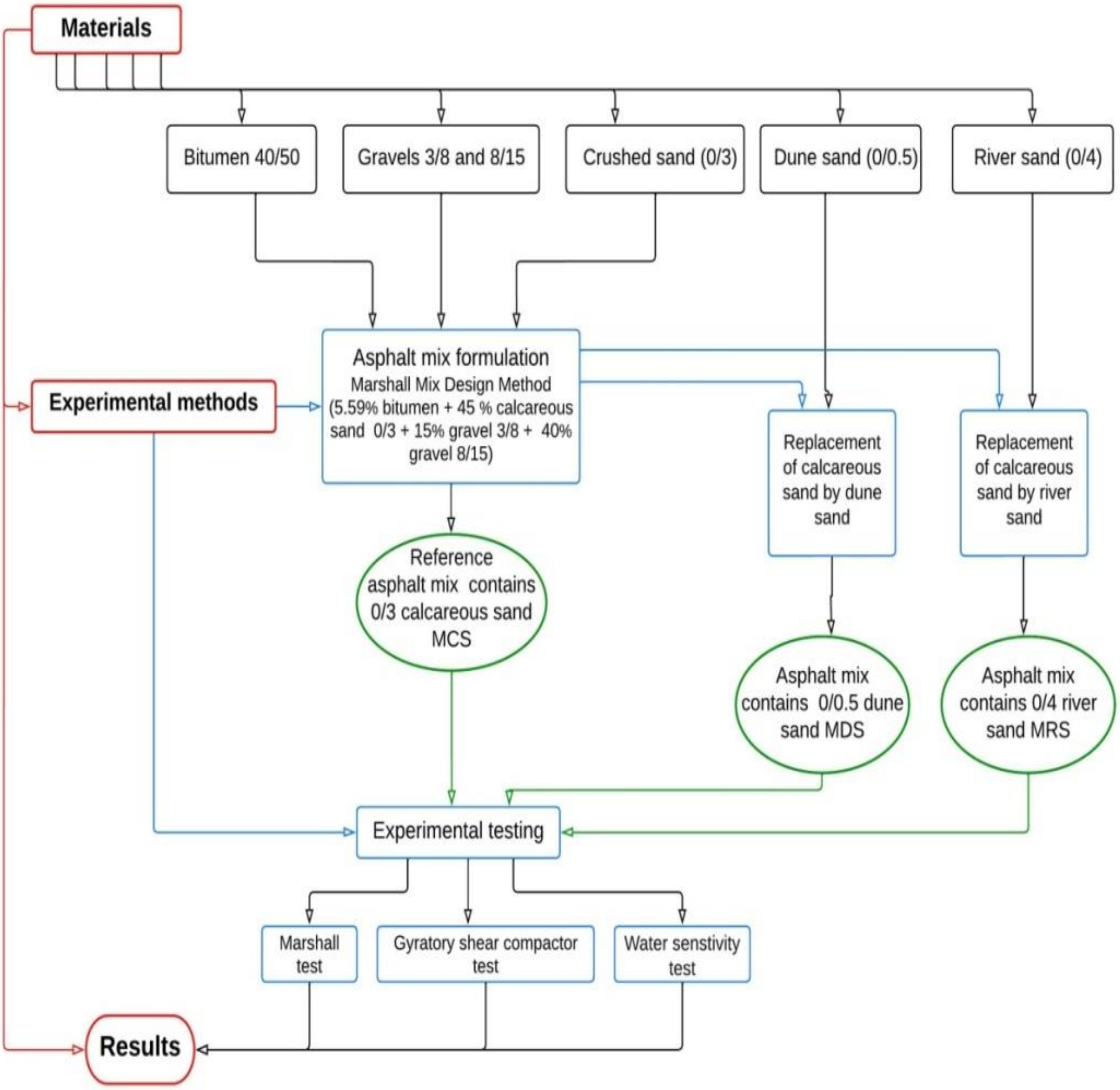
Sand is one of the fundamental components of the asphalt mix, and therefore the type and properties of the sand determine the performance and properties of the mixture. By definition, sand is a granular material composed of particles (quartz, mica and feldspar) resulting from the degradation of rocks. Sand is composed of grains more or less fine, whose dimension varies from 0.075 mm to 4.76 mm (PINARD et al., 2013). All sorts of sand, whether fine, medium, or coarse, calcareous or siliceous, can be used, but for reasons of cleanliness and mechanical performance, some sands are not recommended. The natural sands are found either in deposits belonging to geological layers, in the alluvium of rivers, on the dunes, or made from rocks extracted in quarries. The diversity of sands, both in terms of their percentage of fines and their composition, makes it impossible to propose a general formulation. In each case, a grain size study is therefore necessary.

The use of sand in civil engineering is not new; however, the sand has been used for a long time in the execution of backfill work for foundations and road works, especially in the formulation of asphalt mixes, as well as in the formulation of concrete for building and bridge construction. Many studies in civil engineering (AHLRICH, 1991; ALBAYATI; ABDULSATTAR, 2020; FATHI MADWI, 2020; HARITONOVS et al., 2012; NGUYEN, 2021; NIAZI; MOHAMMADI, 2003; RAJENDRAN; CHRISTOPHER; MUTHU, 2022; RATH, 2022; TACIROĞLU et al., 2022; TOPAL; SENGOZ, 2005; VAIDYA et al., 2022) have focused on the usage of sand, whether in terms of sand type, composition, granular distribution, or others. In this study, dune and river sands, two forms of natural sand, are used to examine the performance of an asphalt mix structure. Base course mixes were made using crushed sand (CS) with a (0/3) mm size that was replaced at a 100% weight rate. In terms of compactness and moisture susceptibility, the study assessed how well asphalt mixes performed.

2 METHODOLOGY AND OBJECTIVES OF STUDY

The main objective of this research is to determine how dune sand and river sand affect the compaction and moisture damage of the hot asphalt mix, which mainly contains crushed sand (the reference mix), by replacing the crushed sand completely with dune sand at one time and river sand at another time. As shown in Figure 1, the full experimental plan was implemented.

Figure 1 - Flowchart of the experimental program



Source: Authors

3 MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 Bitumen

In this study, bitumen with a penetration grade of 40/50 is used. It was supplied by the Algerian oil refining company NAFTAL. Table 1 presents the characteristics of this bitumen.

Table 1 Characteristics of bitumen

Test	Results	Standard	Specification
Penetration (1/10 mm)	42.7	NF EN 1426 (EUROPEAN AND FRENCH NORMS, 2007a)	40-50
Softening point (°C)	52.2	NF EN1427 (EUROPEAN AND FRENCH NORMS, 2018a)	50-58
Specific gravity (g/cm^3)	1.02	NF EN 15326 (EUROPEAN AND FRENCH NORMS, 2007b)	1.0 - 1.1

Source: Authors

3.1.2 Aggregates

In this study, we used 3/8 and 8/15 gravels (crushed limestone) were obtained from the EGUVA (Reghaia) quarry in the province of Algiers (Algeria). Crushed Sand (CS) with a size of 0/3 mm was obtained from the EGUVA (Reghaia) quarry in the province of Algiers (Algeria). River sand (RS) with (0/4) size was sourced from the valley in the province of Medea (Algeria). Dune Sand (DS) with a particle size of (0/0.5) was obtained from a dune in the Algerian province of Djelfa.

Based on the results of the chemical analysis of the sands presented in Table 2, it should be noted that dune sand and river sand are siliceous sands, formed in large quantities of SiO_2 (silica), whereas crushed sand is a calcareous sand, formed in large quantities of $CaCo_3$ (calcareous). Figure 2 illustrates the different types of sand used in this study. The technical specifications of the sands and gravels used in this study are presented in Table 3. Figures 3 and 4 show grading curves for sands and gravels respectively.

Table 2 - Chemical analysis of sands

Chemical component	Sand		
	CS	**DS** (CHOUKRI; BAITICHE, 2017)	**RS**
$CaCo_3$	94.01%	3.39%	2.81%
Sio_2 + Silicates	4.37%	93.56%	94.03%
NACL	0.17%	0.29%	0.13%

Source: Authors

Figure 2 - Crushed sand (CS), river sand (RS), and dune sand (DS)

CS	DS	RS

Source: Authors

Table 3 - Characteristics of the gravels and sands

Test	Sand			Gravel		Standard	Specification
	CS	DS	RS	G 3/8	G 8/15		
Flatness coefficient (%)	-	-	-	Cubic	Cubic	EN 933-2 (EUROPEAN AND FRENCH NORMS, 2020a)	-
Sand equivalent coefficient (%)	68	55	69	-	-	EN 933-8 (EUROPEAN AND FRENCH NORMS, 2015)	> 40
Los Angeles abrasion value (%)	-	-	-	19.87	23.25	EN 1097-2 (EUROPEAN AND FRENCH NORMS, 2020b)	20 - 25
Micro Deval coefficient (%)	-	-	-	14.2	13.5	EN 1097-1 (EUROPEAN AND FRENCH NORMS, 2011)	10 - 15
True density value (g/cm^3)	2.66	2.63	2.68	2.72	2.69	EN 1097-6 (EUROPEAN AND FRENCH NORMS, 2022)	-

Source: Authors

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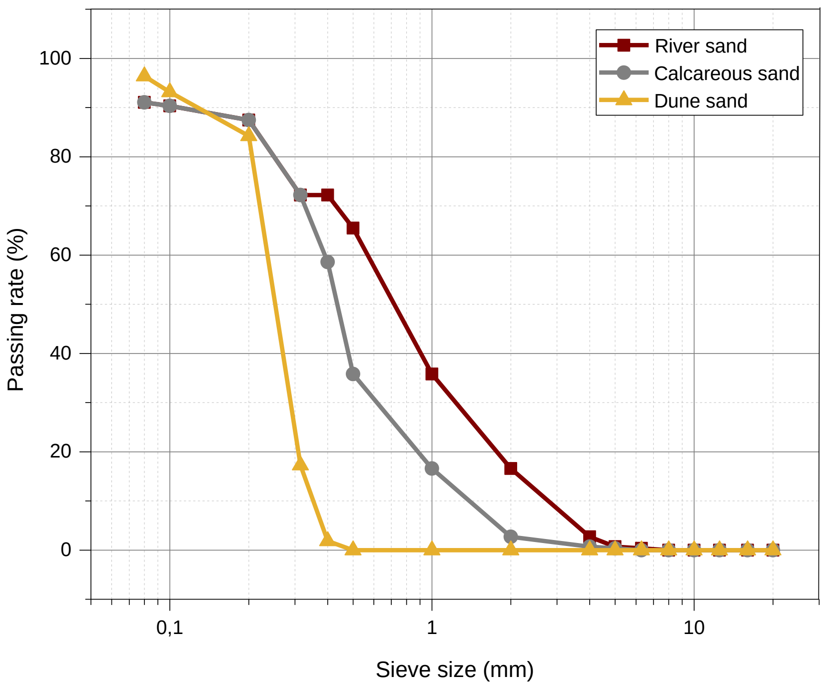
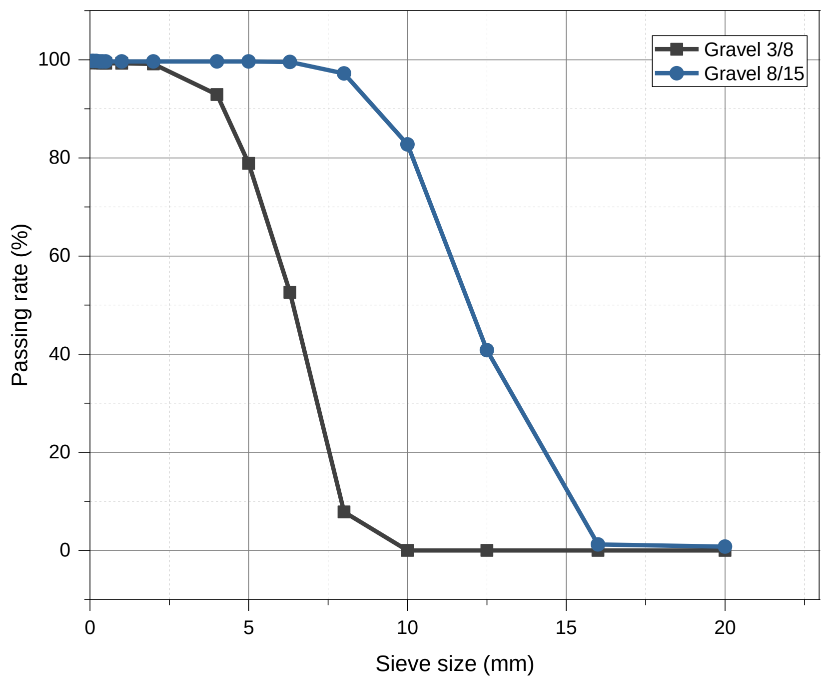
Figure 3 - Grading curves of sands



Source: Authors

Figure 4 - Grading curves of gravels



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3.2 METHODS

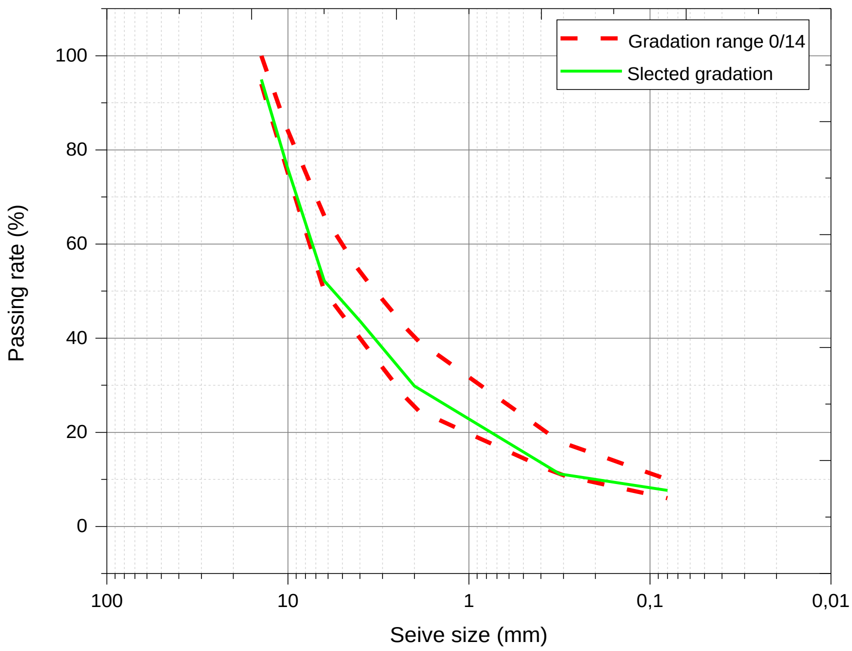
3.2.1 Asphalt Mix Formulation

In this study, a semi-granular asphalt concrete 0/14 known as BBSG was employed (REGIONAL LABORATORY, 2003). The Marshall Mix Design Method was used to prepare it. In this regard, one must first determine the bituminous mixtures aggregate gradation composition, followed by its appropriate bitumen content, which offers the asphalt mix better compaction abilities on the one hand and good mechanical properties on the other.

A mix with three granular classes (0/3 crushed sand, 3/8 and 8/15 gravels) that fit the specification range 0/14 was selected. Furthermore, the particle size curve fit within the specification range for the following proportions: 45% crushed sand (0/3), 15% gravel (3/8), and 40% gravel (8/15). Figure 5 represents the graduation curve for the asphalt mix 0/14.

Asphalt mixes with varying bitumen contents (5.59, 5.83, 6.08, and 6.32% by weight of the total mix) were made and tested using the Marshall test according to Standard EN 12697-34 (EUROPEAN AND FRENCH NORMS, 2020c). The optimal bitumen content to ensure maximum stability, appropriate flow, and a tolerable percentage of air voids was determined to be 5.59%.

Figure 5 - Graduation curve for the asphalt mix 0/14



Source: Authors

3.2.2 Samples Preparation

First, the required masses of 0/3 calcareous sand, 3/8 and 8/15 gravel were weighed in accordance with the previously defined percentages in the formulation study. Next, these masses were placed in a container, which was introduced into an oven set to 170 °C, for a period of 4 hours before mixing. At the same time, the bitumen (optimum content) was heated to a temperature of 160 °C. After that, the bitumen and 0/3 calcareous sand and 3/8 and 8/15 gravel were mixed at the same time. The mixing speed and time were, respectively, 60 rpm and 5 minutes.

We also prepare the asphalt mixes in the same steps, by completely replacing the calcareous sand (0/3) with dune sand (0/0.5), then with river sand (0/4). Table 4 shows the designation of asphalt mixes prepared in this study with various sands.

Table 4 - Designation of the asphalt mixes

Asphalt mix	Sand type
MCS (Reference mix)	Calcareous sand (0/3)
MDS	Dune sand (0/0.5)
MRS	River sand (0/4)

Source: Authors

3.2.3 Experimental Testing

The **c**ompactness of asphalt mixes is tested in this study utilizing a Marshall and gyratory shear compactor, and moisture damage is tested utilizing a water resistance test by the compressive strength method.

The Marshall Test, according to European Standard EN 12697-34 (EUROPEAN AND FRENCH NORMS, 2020c), can be used to measure the Marshall Stability and Marshall Flow of a cylindrical specimen compressed along its generatrix for a given energy of compaction (55 hammer blows applied on each face of the specimen).

Gyratory shear compactor test, this test allows for the examination of the compaction capacity and the estimation of the rutting propensity of asphalt (DUMOND, 1983; MOUTIER, 1977). The procedure was carried out in compliance with European Standard EN 12697-31(EUROPEAN AND FRENCH NORMS, 2019).

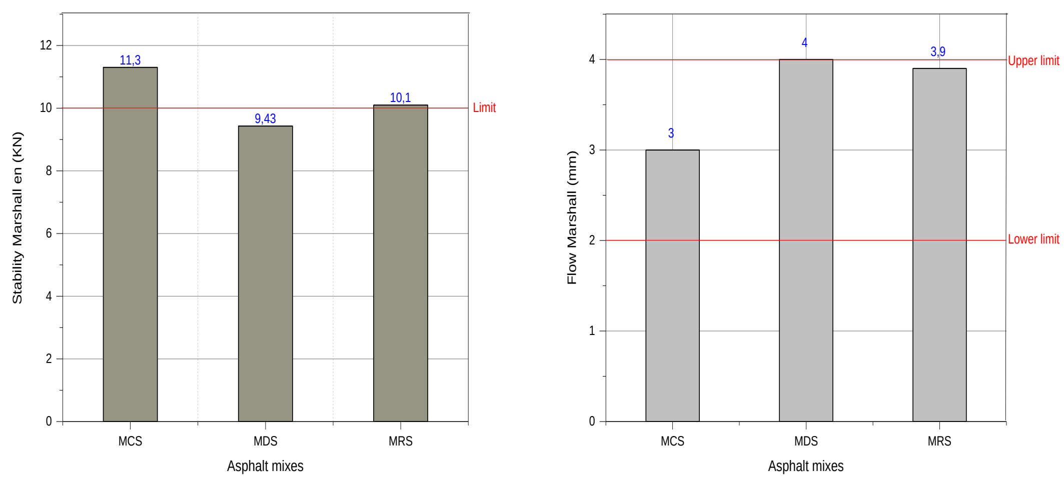
Water sensitivity test: according to Standard EN 12697-12, Method B (EUROPEAN AND FRENCH NORMS, 2018b), this test assesses an asphalt mix water resistance; it is represented as the ratio of the compressive strength of the asphalt mix retained in water to that stored in air.

4 RESULTS AND DISCUSSION

4.1 MARSHALL TEST RESULTS

Figure 6 shows the influence of dune and river sand on the Marshall properties of the asphalt mix (stability and flow Marshall). The Marshall stability and flow values of the asphalt mix containing river sand meet the requirements of Standard EN 12697-34 (EUROPEAN AND FRENCH NORMS, 2020c), which calls for a stability value higher than or equal to 10 KN and a flow value between 2 and 4 mm. This criterion, however, is not met by asphalt mix containing dune sand. In general, the results showed a decrease in Marshall Stability. The rate of deterioration varies depending on the type of sand used. When compared to asphalt containing calcareous sand (reference mix), results for river and dune sand showed a 10.61% and 16.54% decrease in stability, respectively. This effect is due to the form and composition of river and dune sand in comparison to crushed sands. The low value of sand angularity associated with dune and river sand results in less angular particles and a rougher surface texture, which reduces the adhesion between the aggregate particles and the bitumen and, consequently, reduces the stability of the mix (TOPAL; SENGOZ, 2005)

Figure 6 - Effect of dune and river sand on Marshall Properties of the asphalt mixes (stability and flow Marshall).

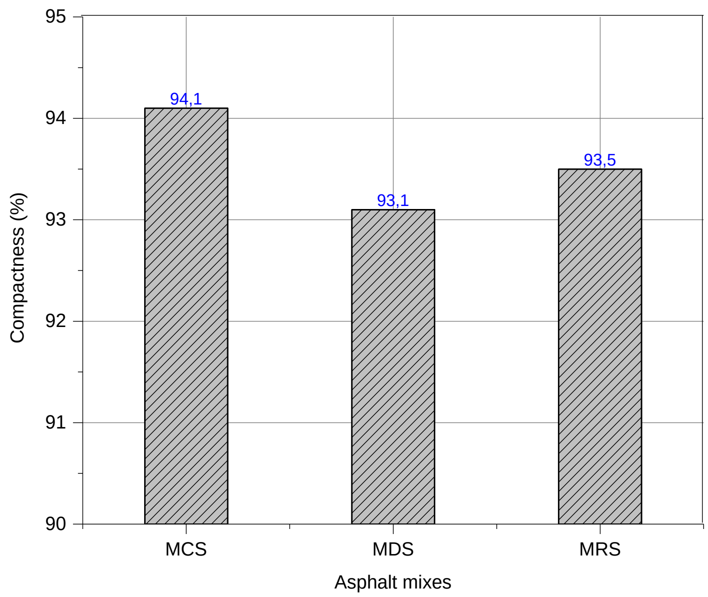


Source: Authors

Figure 7 shows the influence of dune and river sand on the compactness of the asphalt mix. The results showed that the compaction obtained by the asphalt mixes containing dune and river sand was lower than that obtained by the reference mix containing calcareous sand. The degree of compaction varies according to the type of sand utilized. This is due to the granular distribution and angularity of the sand used, which affect the organization of the granules during the compaction of the mixture.

The effect of natural sands on the Marshall properties of asphalt mixes has been extensively discussed in the literature. Several studies have shown that the use of dune sand or river sand as fine aggregate in asphalt mix designs has a negative effect on marshal properties (stability, flow, and compaction). Albayati et al (ALBAYATI; ABDULSATTAR, 2020) showed that, when the crushed sand was completely replaced with river and desert sand, the average Marshall flow value increased by 25% and 22%, respectively. Ahlrich (AHLRICH, 1991) conducted extensive laboratory research to identify the appropriate level of natural dune sand and its impact on the functional characteristics of hot asphalt mix. The results showed that as the amount of natural dune sand increased, the optimal bitumen content decreased. Natural dune sand contents also had an effect on the stability of asphalt mixes; as natural dune sand contents increased, stability values decreased.

Figure 7 - Effect of dune and river sand on compactness of the asphalt mixes.

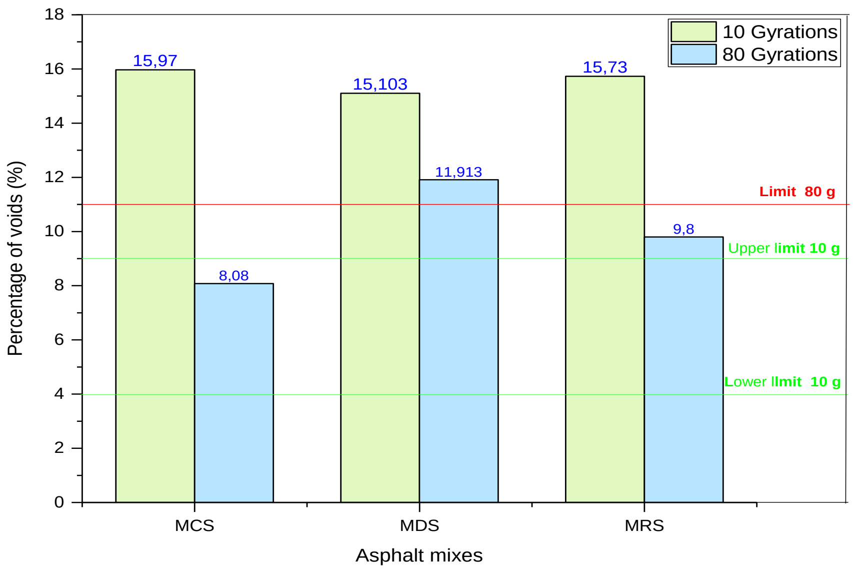


Source: Authors

4.2 GYRATORY SHEAR COMPACTOR TEST RESULTS

Figure 8 represents the evolution of the percentage of air voids as a function of the number of gyrations for the asphalt mixes studied. The results showed that the percentages of air voids for asphalt mixes containing dune and river sand met Standard EN 12697-31 (EUROPEAN AND FRENCH NORMS, 2019) standards at 10 gyrations but did not meet the specifications at 80 gyrations. It should be noted that this European Standard prescribes a minimum void percentage of 11% at 10 gyrations and 4–9% at 80 gyrations. These results indicate that asphalt mixes tested with a gyratory compactor had a low compaction capability. These sands do not provide enough workability to the granular structures in the mixture to decrease the proportion of voids between the granules.

Figure 8 - Evolution of the proportion of air voids for asphalt mixes as a function of the number of gyrations



Source: Authors

4.3 WATER SENSITIVITY TEST RESULTS

After the compressive strength test on the specimens, we obtain the resistance of the specimens maintained in immersion (R_w) and the resistance of the specimens maintained in air (R_a). The ratio *Rw/Ra* is calculated and expresses the water resistance of the asphalt mix. When the *Rw/Ra* ratio is high, the asphalt mixes are more resistant to moisture damage. Table 5 presents the resistance of specimens maintained in water (R_w) and specimens maintained in air (R_a), as well as Figure 9, which shows the *Rw/Ra* ratio for all of the asphalt mixes studied.

Table 5 - Water resistance (R_w) and air resistance (R_a) of the asphalt mixes

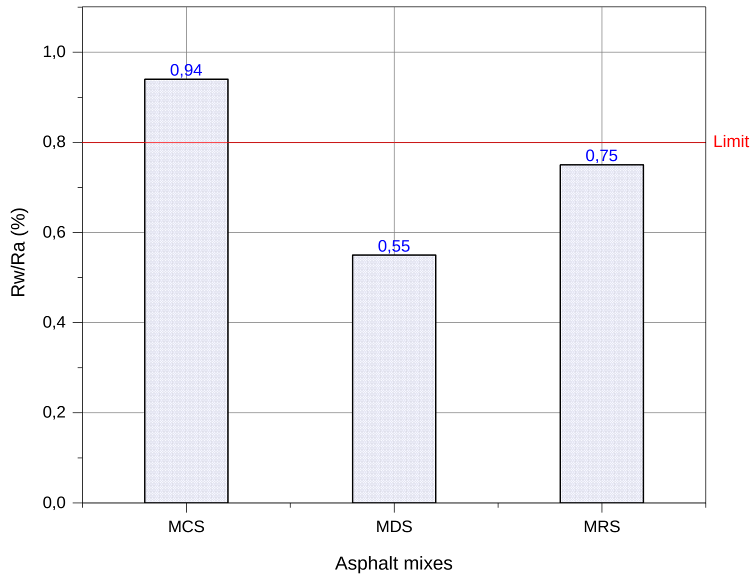
Asphalt mixes	***Rw* in (MPa)**	***Ra* in (MPa)**
MCS	12.09	15.57
MDS	6.25	8.85
MAS	6.89	12.25

Source: Authors

The results demonstrate that asphalt mixes containing dune sand and river sand do not meet the standards of EN 12697-12 method B (EUROPEAN AND FRENCH NORMS, 2018b), which requires *Rw/Ra* to be larger than or equal to 0.8. This indicates that these asphalt mixes are more sensitive to moisture damage. the matter that might be due to the lower angularity of this type of sand in compared to calcareous sand, resulting in less interlock between the particles on one hand and adhesion between the aggregate and the bitumen on the other, which did not help in achieving the required compressive strength of the mixture.

It is worth noting that the findings of this study on water sensitivity are congruent with those of Albayati et al. (ALBAYATI; ABDULSATTAR, 2020), who discovered that high natural sand content increases moisture damage. Further, According to Niazi et al. (NIAZI; MOHAMMADI, 2003), compressive strength tests revealed that natural sand lowered the bearing capacity and energy absorption of asphalt mix; he also enhanced the likelihood of persistent deformation and bleeding in the pavement surface layers.

Figure 9 - *Rw/Ra* ratio for all of the asphalt mixes studied.



Source: Authors

5 CONCLUSION

The aim of this research is to investigate the impact of dune and river sand on asphalt mix compaction and moisture damage. The following key points are summarized:

- The results from the Marshall experiment revealed that compaction in asphalt mixtures containing dunes and river sand was lower compared to the reference mixture with limestone sand. The level of compaction varied based on the type of sand used, influenced by the granular distribution and angle of the sand, affecting granule organization during compaction.
- Asphalt mixes tested with a gyratory compactor exhibited poor compaction capability, as these sands did not provide sufficient workability to reduce the proportion of voids between granules in the mixture.
- Findings from the Water sensitivity experiment indicated that asphalt mixes containing dunes and river sand were more susceptible to moisture damage.

In light of this study, it was observed that substituting crushed sand with dunes and river sand did not lead to significant improvements. Therefore, using dune and river sand in equal proportions as a replacement for crushed sand is not recommended.

Future research aims to explore the effects of replacing limestone sand with dune sand or river sand in small percentages (10%, 20%, and 30% by weight of crushed sand) on asphalt mix characteristics such as rutting and fatigue resistance.

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