EFFECT OF SANDS ON THE EVOLUTION OF THE MODULUS OF DEFORMABILITY AND LONGITUDINAL AND TRANSVERSE ELASTO-INSTANTANEOUS DEFORMATIONS AS A FUNCTION OF THE RELATIVE CONSTRAINT IN CONCRETE

M.L.K. Khouadjia[a]*, K. Abdou[a], A.A. Belkadi[b], O. Kessal[b], B. Mezghiche[c]

[a*] Department of Civil Engineering, Laboratory of Materials and durability of constructions (lMdc), University of Mentouri Constantine 1, 25000 Constantine, Algeria, E-mails: * lyes.khouadjia@umc.edu.dz, kamel172000@yahoo.fr
[b] Department of Civil Engineering and Mechanical, EL Bachir EL Ibrahimi, University of Bordj Bou Arreridj, 34000 Bordj Bou Arreridj, Algeria, E-mails: belkadi_ms@hotmail.fr, oussama.kessal@yahoo.fr
[c] Department of Civil Engineering and Hydraulics, University of Mohamed Kheider Biskra, 07000 Biskra, Algeria, E-mail: bouzidi.mezghiche@univ-biskra.dz

Received: 27.04.2022 / Accepted: 02.05.2022 / Revised: 15.07.2022 / Available online: 15.12.2022

DOI: 10.2478/jaes-2022-0025

KEY WORDS: Modulus of deformability, longitudinal and transverse elasto-instantaneous deformations, crushed sand, fine particles, correlation coefficient.

ABSTRACT:

The production of crushed sand is accompanied by the production of fine particles. The proportion of these fine particles varies from one sand to another. The current publications of standards for reference in the construction industry have been adapted by increasing the limit of fine particles in crushed sand, but this is insufficient because sands with high rate of fine particles are not used in the industry. The principal objective of this study is to investigate the influence of crushed sands with different mineralogical natures (limestone and siliceous) and with varying proportions of fine particles on the evolution of the modulus of deformability and of longitudinal and transverse Elasto-instantaneous deformations. The experimental results showed that the longitudinal and transverse Elasto-instantaneous deformations and the modulus of deformability varied according to the nature of the sands (river sand, quarry sand, dune sand) and according to the fine content of the sands. Logarithmic regressions showed an accurate fit for the correlation coefficient R^2. The test results demonstrated that deformations are influenced by sand type and indicated an optimal of 10% of fine particles. Empirical equations can predict the modulus of deformability from prismatic concretes.

1. INTRODUCTION

It is widely believed that the consumption of materials is increasing worldwide due to the boom in the industry. Among these materials include sand, which is considered to be the third most used resource after water and air in more than 200 economic sectors (Khouadjia et al. 2016). Careful and economical use of sand is vital to preserve this resource and prevent environment harm.

However, in the sand manufacturing industry practice, many of the sands are not used due to their fine content, which does not meet current standards, despite the fact that several studies have provided solutions to the use of these sands. In 2019, 68 million tonnes of crushed sand were produced in Algeria, including 16 million tonnes of sand considered unusable, resulting in environmental problems (Khouadjia et al. 2015).

Sand is an inert element making up 35% of concrete volume, making it one of the main components. Sand presence helps to ensure granular continuity between the gravel and the cement, for better cohesion of the concrete (Khouadjia et al. 2016). Sands properties (morphology, hardness, density, and physical and chemical stability) affect the workability, mechanical properties, durability, and deformability of concrete. These properties depend on the source and methods of extraction (Khouadjia et al. 2015; Khouadjia et al. 2016; Chen et al. 2019; Karapetyan 2019).

The modulus of deformability of concrete is important parameters for structural assessment. Consequently, various studies are in progress or have been carried out in this context. Researchers (Malaikah et al. 2005) found that specimen size affected the modulus of elasticity “MOE” of concrete, and researchers (Yıldırım and Sengul 2011) demonstrated that the MOE was lower for aggregate sizes of 4 mm than larger sizes (8, 16 and 32 mm).

Moreover, Alsalman et al. (2017) indicated that the use of natural sand reduces the MOE, while (Nematzadeh and Naghipour 2012) found that compressing the fresh concrete increases the MOE of the concrete. (Parra et al. 2011) studies concluded that the MOE of self-compacting concrete tends to be approximately 2% less than that of normally vibrated concrete. This is due to the greater content of paste in self-compacting concrete.
Furthermore, another study (Silva et al. 2016) examined the effect of recycled aggregate on the MOE of concrete and found that the MOE decreased with increasing recycled aggregate content. In addition, an interesting solution to improving

strength and deformability is to add compression steel or transverse steel (Zhou et al. 2011; Brooks 2014).

Nevertheless, many researchers (Yıldırım and Sengul 2011; Sarıdemir 2013), investigated the impact of the additions (fly ash, silica fume) on the MOE of concrete and found little effect. It was reported by (Yıldırım and Sengul 2011) that the MOE of concrete produced using limestone aggregates was lower compared with that of concrete produced with dolomite, basalt, or quartz aggregates.

Moreover, (Kocab et al. 2017; Au et al. 2008) indicated that limestone, dune sand and the waste products of polishing improve the MOE of concrete. Other studies (Alsalman et al. 2017; Kocab et al. 2017) have reported that curing under water and the use of natural sand reduces the MOE.

Finally, it has been noted that several studies (Yıldırım and Sengul 2011; Zhou et al. 2011; Silva et al. 2016; Bilir 2016; Alsalman et al. 2017; Vakhshouri and Nejadi 2019) have focused on the development of equations and models to predict the MOE and to compare it with standards (ACI 318 and ACI 363, EN 1992-1-1, TS500).

The main objective of the current study was to provide more data on the modulus of deformability and on longitudinal and transverse Elasto-instantaneous deformations of concrete. In this investigation, the deformations of concrete were obtained by the compression of prismatic samples with a volume of (10×10×40) cm^3. An experimental program was carried out in which we combined different sands (crushed sand, river sand and dune sand) with constant water–cement ratios of 0.6. The experimental program was extended to establish the relationship between deformations and relative constraint.

2. CHARACTERIZATION OF MATERIALS

2.1. Cement

Portland cement was used (CEM I class 42.5 N MPa), which is manufactured in Tunisia in accordance with Tunisian standard NT 47.01. Table 1 presents the mineralogical compositions and mechanical properties of this Portland cement. Table 2 present the potential mineralogical composition of the clinker was calculated according to the empirical formula of (Bogue, 1955).

Chemical composition					
SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO
20.72	5.20	3.22	61.73	2.91	0.84
Loss on ignition = 2.51% Fineness = 3162 cm^2/g Specific density = 3824 kg/m^3					

Table 1. Chemical and physical characteristics of Portland cement CEM I 42.5 N

Bogue composition			
C_3S	C_2S	C_3A	C_4AF
54.15	18.38	8.33	9.79

Table 2. Mineralogical composition of the cement

2.2. Water

The water used in the mixtures was clean water that contained little sulphate and had a temperature of 20 ± 1°C. Its quality met the requirements of the standard NFP 18-404.

2.3. Sands

Crushed sand (CS) was sourced originally from different quarries (Batna, Constantine, and Biskra in Algeria). The river and dune sands (ST and SU, respectively) were used as a crushed sand substitution in the mixes and were sourced originally from Biskra (Algeria). The chemical and physical characteristics of the sands are presented in Tables 3 and 4. All properties of sands were measured using the European standards. The grading curves of the different sands are illustrated in Figure 1.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	SO_3	Cl
SA	1.82	0.40	0.27	58.13	0.06	0	0.02
SB	1.29	0.55	0.12	57.23	0.09	0	0.01
SC	1.14	0.36	0.11	59.28	0.01	0	0.012
SD	1.49	0.37	0.20	57.77	0.14	0.06	0.017
SE	1.43	0.32	0.25	57.67	0.15	0	0.017
ST	55.08	0.32	0.60	20.15	0	0.02	0.02
SU	86.45	0.39	1.47	9.42	0.13	0	0.018

Table 3. Chemical properties of sands

SA: Batna crushed sand (Algeria)
SB: Biskra crushed sand (Algeria)
SC: Constantine crushed sand (Algeria)
SD: Biskra crushed sand (Algeria)
SE: Biskra crushed sand (Algeria)
ST: Biskra river sand (Algeria)
SU: Biskra dune sand (Algeria)

	Physical properties				
	Specific density (kg/m^3)	Apparent density (kg/m^3)	Sand equivalent (%)	Fineness modulus	Fines content (%)
SA	2480	1569	86.82	2.94	7.2
SB	2510	1523	82.2	3.11	3.1
SC	2456	1595	77.15	2.72	21
SD	2547	1620	78.77	2.78	10.2
SE	2549	1696	85.87	2,95	14.1
ST	2560	1820	67.27	2.52	1.6
SU	2478	1565	92.17	/	/

Table 4. Physical properties of sands

2.4. Gravel

Gravels (8/16 and 16/25 mm) were used for the manufacture of concrete. It had an apparent density of 1493 kg/m^3, a specific density of 2612.2 kg/m^3 and a coefficient of Los Angeles of 21.5%. The grading curves of the gravels are illustrated in Figure 1.

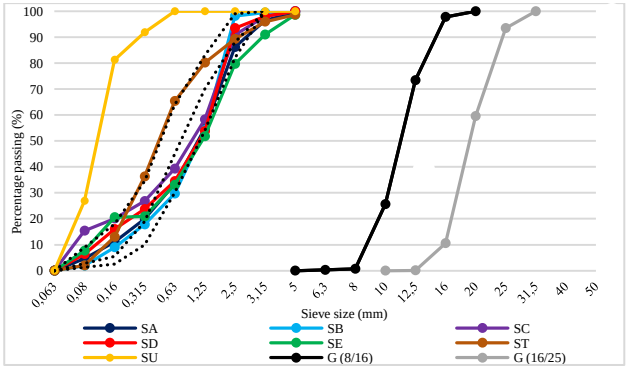


Figure 1. Grading curves of gravels and sands compared with the normalized curve

3. MIX PROPORTIONS

In the current study, 48 prismatic specimens with a volume of (10×10×40) cm^3 were prepared with 16 formulations conforming to the European standards. Five crushed sands both without modification and modified with river and dune sands were tested. All concrete mixtures had a constant water–cement ratio (W/C=0.6) . The method of Scramtaiv (Mezghiche, 2005) was used for mixtures. In this study, three aspects were considered: the effect of the proportion of fine particles, the effect of dune sand, and the effect of river sand. The details of the concrete mixtures are given in Table 5.

Compositions	Concrete type	W/C ratio	Cement (kg/m^3)	Water (l/m^3)	CS (kg/m^3)	SU (kg/m^3)	ST (kg/m^3)	G (8/16) (kg/m^3)	G (16/25 (kg/m^3)
Concretes with 100 % crushed sand	100 % SA	0.6	350	210	651.49	/	/	369.76	739.52
	100 % SB	0.6	350	210	652.25	/	/	398.85	736.98
	100 % SC	0.6	350	210	608.95	/	/	371.64	781.25
	100 % SD	0.6	350	210	639.38	/	/	372.97	763.70
	100 % SE	0.6	350	210	675.07	/	/	355.30	746.13
Concretes with 80 % crushed sand + 20% river sand	80% SA + 20% ST	0.6	350	210	514.47	/	128.6	375.12	768.11
	80% SB + 20% ST	0.6	350	210	501.06	/	125.26	421.85	736.78
	80% SC + 20% ST	0.6	350	210	498.05	/	124.5	382.28	758.70
	80% SD + 20% ST	0.6	350	210	501.44	/	125.36	393.98	770.07
	80% SE + 20% ST	0.6	350	210	516.41	/	129.10	394.47	753.09
Concretes with 90 % crushed sand + 10% dune sand	90% SA + 10% SU	0.6	350	210	548.01	60.88	/	393.99	787.98
	90% SB + 10% SU	0.6	350	210	566.00	62.68	/	394.15	736.20
	90% SC + 10% SU	0.6	350	210	568.85	63.20	/	389.68	780.44
	90% SD + 10% SU	0.6	350	210	561.38	62.37	/	392.07	766.32
	90% SE + 10% SU	0.6	350	210	578.77	64.30	/	392.98	750.25
Concretes with 100 % river sand	100 % ST	0.6	350	210	/	/	602.61	372.20	797.84

Table 5. Compositions of concretes

100 % SA: Concrete with 100 % crushed sand 1: 0.6 (350)
100 % SB: Concrete with 100 % crushed sand 2: 0.6 (350)
100 % SC: Concrete with 100 % crushed sand 3: 0.6 (350)
100 % SD: Concrete with 100 % crushed sand 4: 0.6 (350)
100 % SE: Concrete with 100 % crushed sand 5: 0.6 (350)
90% SA + 10% SU: Concrete with 90% crushed sand 1 and 10% dune sand: 0.6 (350)
90% SB + 10% SU: Concrete with 90% crushed sand 2 and 10% dune sand: 0.6 (350)
90% SC + 10% SU: Concrete with 90% crushed sand 3 and 10% dune sand: 0.6 (350)
90% SD + 10% SU: Concrete with 90% crushed sand 4 and 10% dune sand: 0.6 (350)
90% SE + 10% SU: Concrete with 90% crushed sand 5 and 10% dune sand: 0.6 (350)
80% SA + 20% ST: Concrete with 80% crushed sand 1 and 20% river sand: 0.6 (350)
80% SB + 20% ST: Concrete with 80% crushed sand 2 and 20% river sand: 0.6 (350)
80% SC + 20% ST: Concrete with 80% crushed sand 3 and 20% river sand: 0.6 (350)
80% SD + 20% ST: Concrete with 80% crushed sand 4 and 20% river sand: 0.6 (350)
80% SE + 20% ST: Concrete with 80% crushed sand 5 and 20% river sand: 0.6 (350)
100 % ST: Concrete with 100 % river sand: 0.6 (350)

4. DEFORMABILITY (DEFORMATION OF CONCRETE)

Under the effect of the load that is applied to it, the concrete specimen deforms. There is an approximate proportionality between the stress σ_c and the deformation ε_c. If E_c is this coefficient of proportionality, then:

$$E_c = \sigma_c / \varepsilon_c, \quad (1)$$

where: E_c is the modulus of elasticity, and:

$$\sigma_c = P_c / F \quad (2)$$

where: F is the section air of the test piece in cm^2 and P_c is the breaking load of the concrete.

We applied increasing stresses to a test piece of this concrete and measured the corresponding deformations up to a value of:

$$\sigma_c = 0.3\, P_c \quad (3)$$

It was then possible to draw the curve $\sigma = P_c(\varepsilon_c)$ for values of σ_c from 0 to $0.3P_c$.

In this part of the study, we determined:

- The evolution of instantaneous relative deformations with the increase in relative constraint.

- The variation of modulus of deformability with an increase in relative constraint.

To study the deformability of the concrete, we made 48 prismatic specimens with a volume of (10×10×40) cm^3. Compression tests were performed on a Controls brand manual press after a 28-day cure in water. The apparatus used to measure the deformations of the specimens was not standardized; there were several types (Dupain et al., 2000).

The prismatic test tube was equipped with frames fixed by four needles, which were installed on a surface of 200 mm in the longitudinal direction and 10 mm in the transverse direction.

Deformation was measured using dial indicators with a division value of 0.01 mm, which were installed in the frames. Once the frames and their dials were fixed on the test piece, the piece was centered on the press plates as for a compression rupture test (Figure 2). According to the results of the prism tests, we created graphs showing the evolution of the relationship between the modulus of deformability and relative constraint.

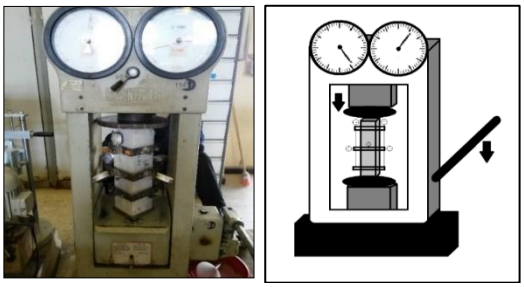
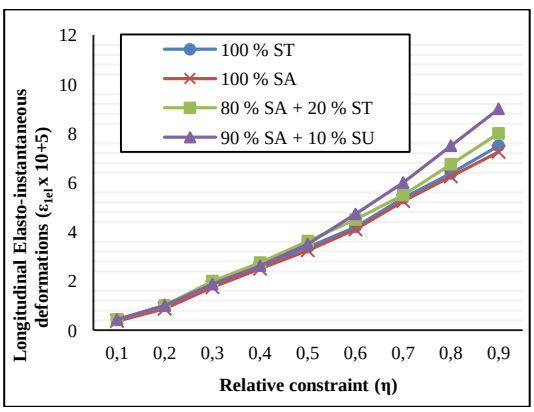


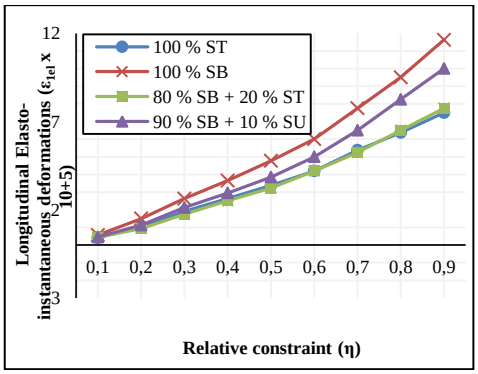
Figure. 2. Testing device

5. RESULTS FOR LONGITUDINAL ELASTO-INSTANTANEOUS DEFORMATIONS ε_{1el} AS A FUNCTION OF THE RELATIVE CONSTRAINT η

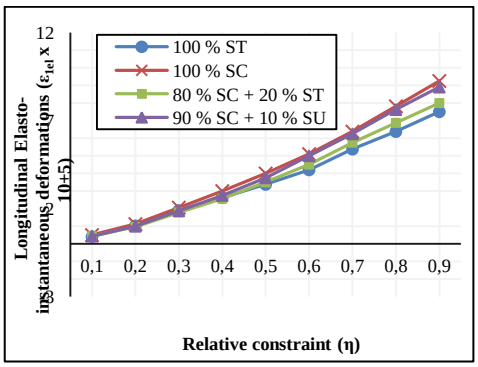
The test was performed on prismatic concretes based on concretes with crushed sand both without modification and modified with 20% river sand and 10% dune sand. The results obtained are shown in Figure 3.



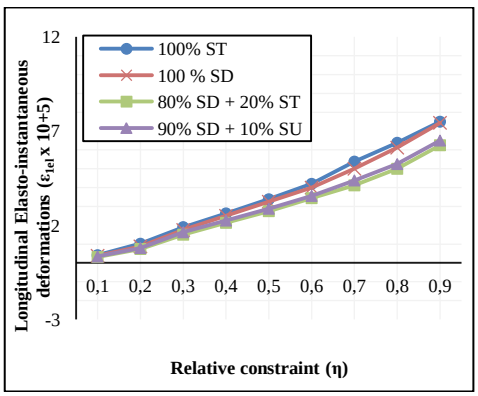
(a)



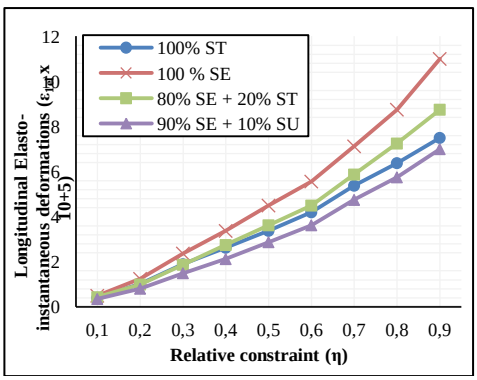
(b)



(c)



(d)



(e)

Figure 3. Longitudinal Elasto-instantaneous deformations ε_{1el} as a function of the relative constraint η for crushed sand without modification and modified with river and dune sand a) sand SA, b) sand B, c) sand C, d) sand D, e) sand E

Analysis of the data in Figure 3 showed that:
- There was a linear elastic relationship (rectilinear character) between the relative constraint and the longitudinal Elasto-instantaneous deformations of the concrete for η = 0.1–0.3;

- There was a curvilinear relationship between relative constraint (η) and the deformations in the interval η = 0.4–0.9, indicating the development in the concrete of irreversible deformations, which generated cracks opening up through the concrete matrix, confirming the results of the literature (Brooks 2014),

- The longitudinal Elasto-instantaneous deformation of concrete based on river sand (ST) was less than that of concrete made from unmodified crushed sand, possibly due to the difference in granular distribution and grain morphology, which influenced the adhesion between the dough and aggregate;

- Concrete based on SB crushed sand (few fine particles) had relatively high numbers of deformations compared with other types of concrete, probably due to a lack of adhesion between the cement paste and the aggregates, which increased the deformation;

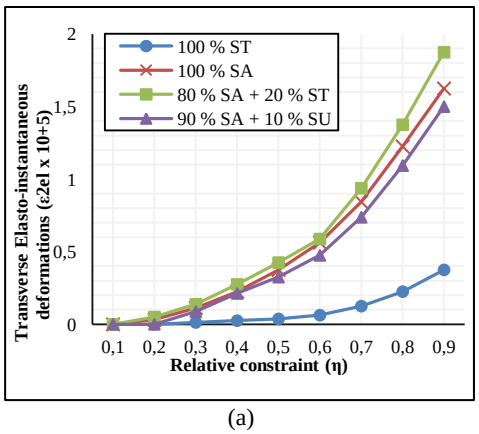
- There was a reduction (37.63%) in the evolution of deformability for unmodified sands with an increase in the percentage of fine particles up to a threshold of 10%;

- The modification of the granular distribution with river sand or dune sand reduced the deformations for concrete based on crushed sand with few fine (2%) and many fine (10%, 14%, 20%) particles;

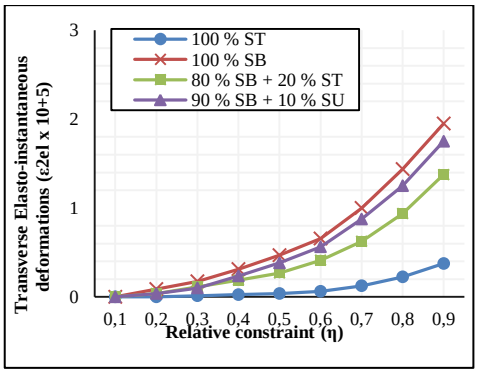
- The incorporation of river sand or dune sand increased the deformation for crushed sands with a fine content of 7%, confirming that an optimal percentage of fine particles in concrete is essential (in this case study, the optimal percentage of fine particles is reached at a threshold of 7–10%).

6. RESULTS FOR TRANSVERSE ELASTO-INSTANTANEOUS DEFORMATIONS ε_{2el} AS A FUNCTION OF THE RELATIVE CONSTRAINT η

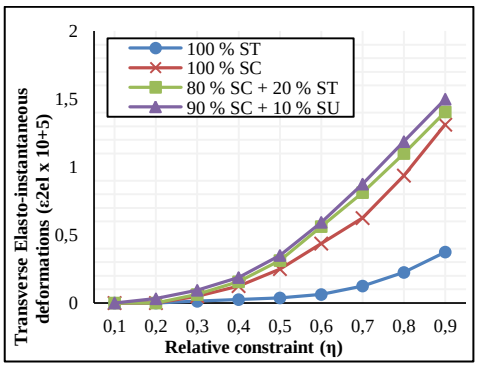
The experimental results of prismatic concretes based on concretes with crushed sand both without modification and modified with 20% river sand and 10% dune sand are illustrated in Figure. 4.



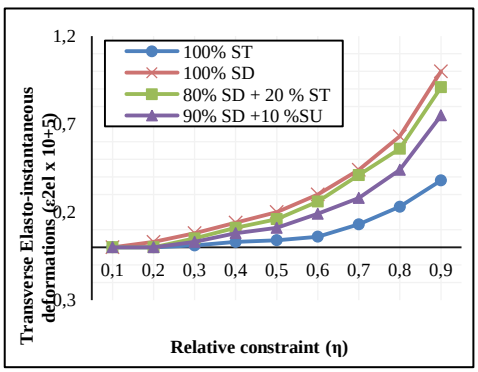
(a)



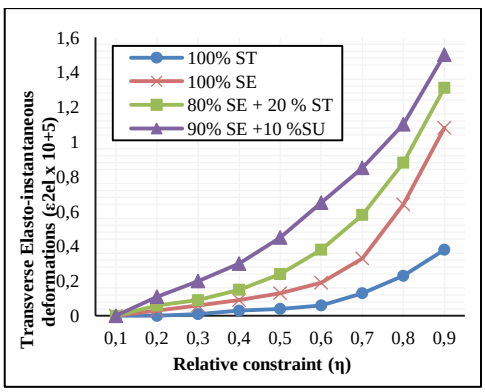
(b)



(c)



(d)



(e)

Figure 4. Transverse Elasto-instantaneous deformations ε_{2el} as a function of the relative constraint η for crushed sand without modification and modified with river and dune sand
a) sand SA, b) sand B, c) sand C, d) sand D, e) sand E

Analysis of the data in Figure 4 showed that:
- The transverse Elasto-instantaneous deformations of concrete with river sand (ST) were always lower than those of concrete with modified or unmodified crushed sand, indicating that the morphology of the grains influenced the behavior of concrete;

- Concrete based on crushed sands SB and SD had a relatively high number of deformations compared with other types of concrete, likely due to the quality of the sands (high degree of absorption and coarse granular distribution at the level of the sieve size 1.25 mm);

- Generally, the partial substitution of crushed sand with river sand or dune sand increased the deformations (up to 39.53%) for crushed sands (SA, SC, SE). However, this substitution reduced deformations (up to 29.48%) for the crushed sands SB and SD, confirming that, in addition to the fine content, the granular distribution must be taken into account when choosing the sands.

7. RESULTS FOR THE EXPERIMENTAL AND THEORETICAL MODULUS OF DEFORMABILITY E_C OF THE CONCRETE AS A FUNCTION OF THE RELATIVE CONSTRAINT η

We determined the values of the modulus of deformability of the concrete for different relative constraint. The dependence of this modulus on the relative constraint is showed in Figures 5, 6 and 7. In addition, we have drawn the graphs of the logarithmic function of the equation: y = ln(x) + b, which offered the best approximation of the data and thus have an almost perfect fit of the correlation coefficient R^2.

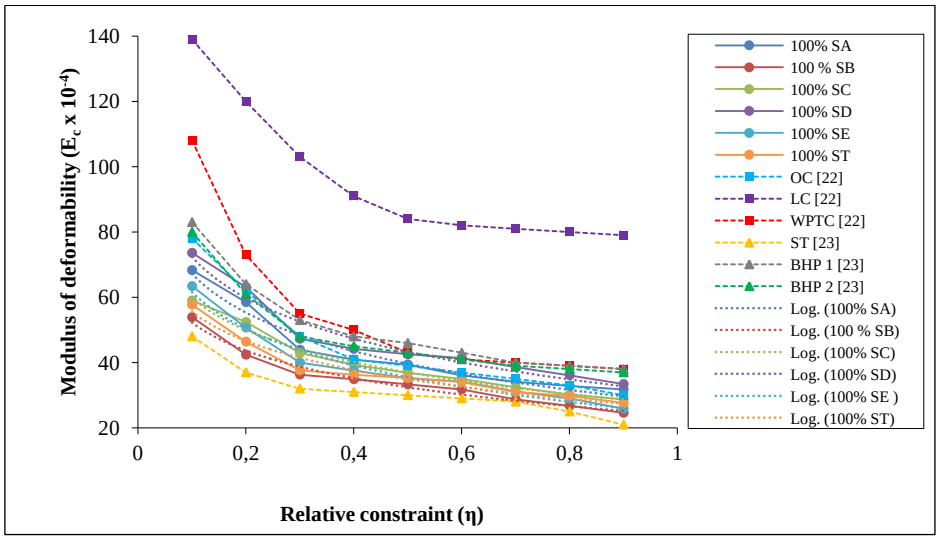


Figure 5. Results for the modulus of deformability E_c of the concrete as a function of the relative constraint η for concrete with 100% crushed sands

OC: Ordinary concrete with gravel 3/8 and 8/15
LC: Concrete with gravel 3/8 and 8/15 + 10% Limestone
WPTC: Concrete with gravel 3/8 and 8/15 + 15% Waste of polishing of tiling concrete
ST: 100% River sand
BHP 1: BHP with 100% gravel 5/10 + 8 % silica fume + 25% Pozzolan
BHP 2: BHP with 50% gravel 5/15 and 50% gravel 15/25 + silica fume + 25% Pozzolan

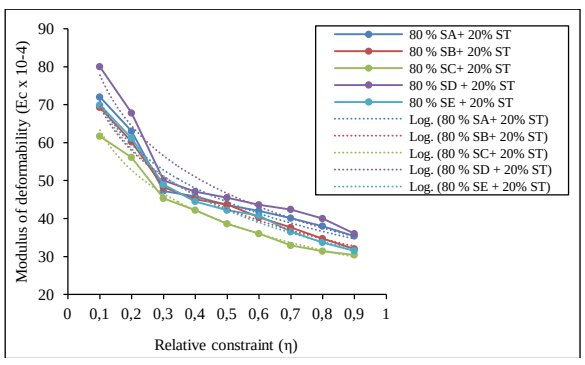


Figure 6. Results for the modulus of deformability E_c of the concrete as a function of the relative constraint η for concrete with 20% river sand

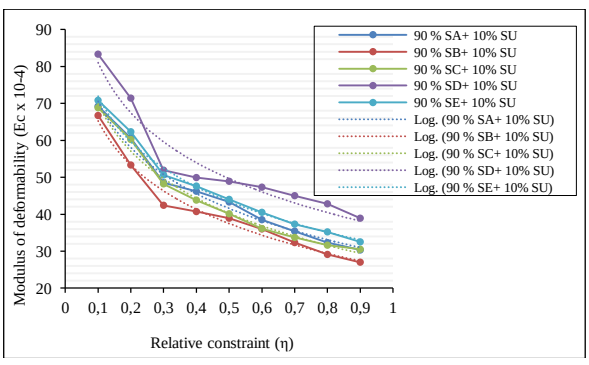


Figure 7. Results for the modulus of deformability "E_c" of the concrete as a function of the relative constraint "η" for concrete with 10% dune sand

From Figs 5–7, we noted that the modulus of deformability Ec decreased with increasing relative constraint. The modulus of deformability of concrete based on river sand (100% ST) and based on crushed sands (100% SB and 100% SC) was the lowest. In general, concretes containing a fine content between 7% and 14% had a higher modulus of deformability than other concretes, due to the compactness of these concretes and their optimal fine content.

The substitution of 20% river sand and 10% dune sand in the crushed sands showed that the modulus of deformability of the concrete did not change shape comparing to the control concrete (100% crushed sands). Indeed, whatever the range of relative constraint, the modulus of deformability of concretes based on crushed sands modified with river sand or dune sand (SB or SC, respectively) was always the lowest. On the other hand, the use of river sand or dune sand in the other concretes (SA, SD, and SE) slightly increased the modulus of deformability, indicating a reduction in the deformation, which is in agreement with the results in the literature (Mezghiche 1989; . Ben messaoud and Mezghiche 2011; Benamara and Mezghiche 2014). These results can be explained by the fact that the modulus of deformability of basic concrete depends essentially on the quality of the sand in the concrete. For low or high fine content, the macrographic structure of the material affects the deformation characteristics, which makes the concrete fragile. For optimum fine content between 10% and 14%, the macrographic structure represents a conglomerate, well linked to the aggregate, with grains of aggregates distributed regularly, reducing deformations.

The experimental results for the modulus of deformability in prismatic specimens were in accordance with the experimental results found by (Ben messaoud and Mezghiche 2011; Benamara and Mezghiche 2014).

The analysis of logarithmic regressions from Figures 5, 6 and 7 and Table 6 demonstrated that the empirical equations provide the best approximation of the data and thus had an almost perfect fit for the correlation coefficient R^2 (>0.95).

Compositions	Concrete type	Logarithmic regression (Log)	
		E_c	R^2
Concretes with 100 % crushed sand	100 % SA	-17,1 ln(η) + 27,81	0,964
	100 % SB	-12,3 ln(η) + 23,91	0,977
	100 % SC	-14,1 ln(η) + 27,18	0,988
	100 % SD	-18, ln(η) + 30,82	0,960
	100 % SE	-16,1ln(η) + 24,36	0,976
Concretes with 80 % crushed sand + 20% river sand	80% SA+20% ST	-16,5 ln(η) + 32,92	0,953
	80% SB+20% ST	-16,7 ln(η) + 30,92	0,985
	80% SC+20% ST	-15,2 ln(η) + 28,23	0,983
	80% SD+ 20% ST	-19,3 ln(η) + 33,22	0,946
	80% SE+ 20% ST	-17,6 ln(η) + 29,96	0,984
Concretes with 90 % crushed sand + 10% dune sand	90% SA+10% SU	-17,9 ln(η) + 29,08	0,986
	90% SB+10% SU	-17,2 ln(η) + 25,52	0,981
	90% SC+10% SU	-18,3 ln(η) + 27,48	0,989
	90% SD+10% SU	-19,5 ln(η) + 36,09	0,935
	90% SE+10% SU	-17,6 ln(η) + 31,18	0,990
Concretes with 100 % river sand	100 % ST	-12,8 ln(η) + 26,01	0,964

Table 6. Equation of logarithmic regression E_c= ln(η) + b and values of correlation coefficients R

The logarithmic regressions and R^2 values indicated that all of the proposed equations can predict the modulus of deformability from the prismatic concretes based on concretes with crushed sand both without modification and modified with 20% river sand and 10% dune sand.

8. CONCLUSION

The major conclusions from the present study are summarized as follows:

- High-intensity deformations and cracks open up through the concrete above a relative constraint of η = 0.4.
- River sand gives fewer longitudinal and transverse deformations than concrete with crushed sand.
- A threshold of 10% of fine particles is considered optimal. Below this percentage, a lack of adhesion between the cement paste and the aggregates increases the deformation.
- Above 10% of fine particles in the concrete, the water absorption increases, this increases deformation.
- The use of river and dune sands did not improve the deformations or the modulus of deformability of the concretes regardless of the range of relative constraint.
- Apart from the morphological aspect, the fine content, the type and the quality of sands, and the coarse granular distribution at the level of sieve size 1.25 mm are important parameters.
- The logarithmic regressions help in predicting the relationship between the modulus of deformability E as a function of the relative constraint η.
- The results of the logarithmic regressions also demonstrated that empirical equations provide an excellent approximation of the data and can predict the modulus of deformability from the prismatic concretes based on concretes with crushed sand both without modification and modified with 20% river sand and 10% dune sand.

References

Alsalman, A., Dang, C. N., Prinz, G. S., & Hale, W. M. (2017). Evaluation of modulus of elasticity of ultra-high performance concrete. *Construction and Building Materials*, 153, pp. 918-928, https://doi.org/10.1016/j.conbuildmat.2017.07.158.

Au, F. T., & Du, J. S. (2008). Deformability of concrete beams with unbonded FRP tendons. *Engineering structures*, 30(12), pp. 3764-3770, https://doi.org/10.1016/j.engstruct.2008.07.003.

Bilir, T. (2016). Investigation of performances of some empirical and composite models for predicting the modulus of elasticity of high strength concretes incorporating ground pumice and silica fume. *Construction and Building Materials*, 127, pp. 850-860, https://doi.org/10.1016/j.conbuildmat.2016.10.054.

Benamara, D., Mezghiche, B., & Zohra, M. F. (2014). The deformability of a high performance Concrete (HPC). *Physics Procedia*, 55, pp. 342-347, https://doi.org/10.1016/j.phpro.2014.07.050.

Benmessaoud, S., Mezghiche, B. (2011). Déformabilité et module d'élasticité des bétons à hautes performances. Université Mohamed Khider – Biskra, Algérie.

Bogue RH. Chemistry of Portland cement, 1955. 2nd Ed. New York: Reinhold Publishing Corp; pp. 790.

Brooks, J. (2014). Concrete and masonry movements. Butterworth-Heinemann.

Chen, X., Sierens, Z., Vandevyvere, B., & Li, J. (2019). Experimental Study on the Optimization of Crushed Limestone Sand as Partial Replacement of Sea Sand in Concrete. In Proceedings of iiSBE Forum of Young Researchers in Sustainable Building (YRSB19) pp. 25-34.

Dupain, R., Lanchon, R., & Saint-Arroman, J. C. (2000). *Granulats, sols, ciments et bétons*. Edition Casteilla.

Karapetyan, K. (2019). Specificity of Deformation and Strength Behavior of Massive Elements of Concrete Structures in a Medium with Low Humidity. Butterworth-Heinemann, https://doi.org/10.1016/C2017-0-01105-9.

Khouadjia, M. L. K., Mezghiche, B., & Drissi, M. (2015). Experimental evaluation of workability and compressive strength of concrete with several local sand and mineral additions. *Construction and Building Materials*, 98, pp. 194-203, https://doi.org/10.1016/j.conbuildmat.2015.08.081.

Khouadjia, M. L. K. (2016). Etude des propriétés physico-mécaniques et rhéologiques des bétons à base des sables de carrières: expérimentation et modélisation *(Doctoral dissertation, Université Mohamed Khider-Biskra)*.

Kocab, D., Kucharczykova, B., Misak, P., Zitt, P., & Kralikova, M. (2017). Development of the elastic modulus of concrete under different curing conditions. *Procedia engineering*, 195, pp.96-101, https://doi.org/10.1016/j.proeng.2017.04.529.

Malaikah, A. S. (2005). A proposed relationship for the modulus of elasticity of high strength concrete using local materials in Riyadh. *Journal of King Saud University-Engineering Sciences*, 17(2), pp.131-141, https://doi.org/10.1016/S1018-3639(18)30804-3.

Mezghiche, B. (1989). Technologie des bétons aux laitiers basiques pour RADP". *Thèse de doctorat en sciences techniques. Institut de minerais de Krivoi Rog*, pp.163.

Mezghiche, B. (2005). Laboratory Testing of Construction Materials, *Publication of the University of Biskra, Algeria*, p. 120.

Nematzadeh, M., & Naghipour, M. (2012). Compressive strength and modulus of elasticity of freshly compressed concrete. *Construction and building materials*, 34, pp. 476-485. https://doi.org/10.1016/j.conbuildmat.2012.02.055.

Parra, C., Valcuende, M., & Gómez, F. (2011). Splitting tensile strength and modulus of elasticity of self-compacting concrete. *Construction and Building materials*, 25(1), pp. 201-207, https://doi.org/10.1016/j.conbuildmat.2010.06.037.

Sarıdemir, M. (2013). Effect of silica fume and ground pumice on compressive strength and modulus of elasticity of high strength concrete. *Construction and Building Materials*, 49, pp. 484-489, https://doi.org/10.1016/j.conbuildmat.2013.08.091.

Silva, R. V., De Brito, J., & Dhir, R. K. (2016). Establishing a relationship between modulus of elasticity and compressive strength of recycled aggregate concrete. *Journal of Cleaner Production*, 112, pp. 2171-2186, https://doi.org/10.1016/j.jclepro.2015.10.064.

Vakhshouri, B., & Nejadi, S. (2019). Empirical models and design codes in prediction of modulus of elasticity of concrete. *Frontiers of Structural and Civil Engineering*, 13(1), pp. 38-48, https://doi.org/10.1007/s11709-018-0479-1.

Yıldırım, H., & Sengul, O. (2011). Modulus of elasticity of substandard and normal concretes. *Construction and building materials*, 25(4), pp.1645-1652, https://doi.org/10.1016/j.conbuildmat.2010.10.009.

Zhou, K. J. H., Ho, J. C. M., & Su, R. K. L. (2011). Flexural strength and deformability design of reinforced concrete beams. *Procedia engineering*, 14, pp.1399-1407, https://doi.org/10.1016/j.proeng.2011.07.176.