Effect of crushed limestone sand and dust on the mechanical behaviour of river sand mixtures: an experimental study

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doi https://doi.org/10.5937/vojtehg73-56170

FIELD: materials
ARTICLE TYPE: original scientific paper

Abstract:

Introduction: The present study aims to investigate the effect of crushed limestone sand (CLS) and limestone crushed sand dust (LCSD) on the physical and mechanical behaviour of reconstituted river sand (RS) using the volumetric substitution method.

ACKNOWLEDGEMENTS: All tests were carried out at the Civil Engineering Laboratory - University of Medea, Algeria. The authors express their gratitude to the engineer who contributed to this experimental program; this work was supported by the General Directorate for Scientific Research and Technological Development (DGRSDT) in Algeria.

Methods: The study involved conducting direct shear tests on two substitution series to evaluate the effect of CLS sand with incremental increases of 0, 10, 20, 30, and 40%, and LCSD dust ranging from 0 to 35% in 5% steps on the mechanical behaviour of reconstituted river sand. All samples are prepared with 50% relative density and tested under three different normal stresses of 100, 200, and 300 kPa, respectively.

Results: The results show that the substitution of river sand with CLS up to 30% enhances its mechanical properties; the peak shear strength reached a maximum value of 29% under 200 kPa of normal stress. The substitution of river sand for LSCD leads to a decrease in mechanical properties. However, a more in-depth analysis of the results obtained reveals an improvement in residual parameters, with up to 15% of substitution.

Conclusion: Following a rigorous analysis of the obtained results, it was determined that sand reconstituted from a combination of 30% CLS and 15% LCSD offers optimal performance in terms of enhanced mechanical properties. This solution aligns significantly with the sustainable development of the Algerian government strategy promoting improved characteristics and preserving natural resources while meeting the stringent requirements of the geotechnical sector.

Key words: river sand, crushed limestone sand, limestone crushed sand dust, substitution, shear strength, sustainable development.

Introduction

Recently, Algeria has seen a notable expansion of its road and railway infrastructure, which has occurred in parallel with advancements in the urban sector. Therefore, the demand for fundamental construction materials in terms of aggregates and raw materials has increased considerably; aggregates, being one of the most extensively utilised resources in this sector, are responsible for the generation of approximately 20% of waste products (equivalent to 13.5 million tonnes) due to their high fines content (15-25%) (Guemmadi & Houari, 2009).

On the other hand, a substantial amount of waste is generated, along with the production of additional dust. Research indicates that these by-products can pose serious environmental and health risks, posing a risk to both human populations and the country's biodiversity (Safiddine et al, 2017, 2021).The use of this particular type of aggregate, which contains a high level of fine limestone, necessitates a series of washing and other treatment procedures. Several studies were conducted with the objective of recovering this particular industrial by-product in Algeria as crushed sand and limestone crushed sand dust in concrete technology (Safiddine et al, 2017, 2021; Abbou et al, 2020; Skender et al, 2021; Logbi et al, 2023).

Recycling this type of waste could be a way of improving the mechanical properties of sandy soils, according to other researchers (Abbou et al, 2020; Ibrahim et al, 2020). Soils containing more angular grains have higher shear strengths than soils based on more rounded river sand (Holtz & Gibbs, 1956). Furthermore, the maximum shear stress and the angle of internal friction were improved by varying the shape of soil grains and increasing their roughness (Cho et al, 2006; Altuhafi et al, 2016; Kandasami & Murthy, 2017). The presence of angular particles in soils can favour the rearrangement of grains and develop additional friction between particles, thus enhancing mechanical resistance under variable and high loads (Holtz & Gibbs, 1956; Holtz et al, 2022; Santamarina & Cho, 2001; Guo & Su, 2007; Li, 2013; Yang & Wei, 2014; Borhani & Fakharian, 2016).

The incorporation of fine content led to a decrease in the mechanical properties of granular soil (Belkhatir et al, 2010; Monkul et al, 2016; Monkul et al, 2017; Cherif Taiba et al, 2018; Benessalah et al, 2021; Ezziane et al, 2025); the fine content effect becomes significant at rates of up to 20%, particularly in the behaviour of undrained mixtures, leading to a linear decrease in the shear strength of silty sand (Belkhatir et al, 2010). It is important to note that the optimum percentage of fine limestone used to enhance the volume change of clay soils is 18%; otherwise, up to 12% of limestone powder amount, the initial void index is significantly reduced (Ibrahim et al, 2020). In accordance with the findings of preceding research (Brooks et al, 2011; Sabat & Muni, 2015; Ibrahim et al, 2020; Cabalar & Omar, 2023), it was determined that two parameters previously examined, namely grain shape and fine content, are present in the used sand from aggregate production quarries, represented by crushed limestone sand (CLS) and limestone crushed sand dust (LCSD).

The present study aims to investigate the incorporation of crushed sands and their limestone fines on the physical and mechanical behaviour of reconstituted river sands and to align with the Algerian sustainable development strategy.

Experimental materials and methods

Materials

In the present study, two different types of clean sand presented in Figure 1 were used. The first is the river sand (RS) from the M'zi River (Laghouat city), 400 km south of Algiers, and the second one is the crushed limestone sand (CLS) from the Montgorno quarry (Medea city) situated 90 km south of Algiers. Both RS and CLS were characterized by a continuous particle size distribution between 0.08 and 2mm. LCSD is obtained from CLS sieving through an 80 µm sieve.

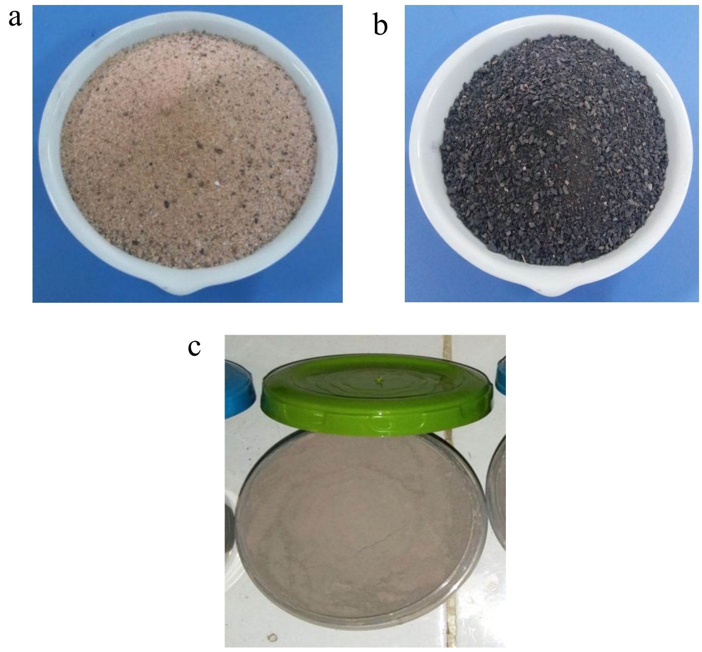

Figure 1 – (a) river sand (RS), (b) crushed limestone sand (CLS) and (c) limestone crushed sand dust (LCSD)

Figure 2 shows the grain size distribution curves of clean river and clean crushed limestone sands and limestone crushed sand dust (LCSD); river sand (RS) is characterized by rounded particles with smooth surfaces, classified as poorly graded (SP) according to the Unified Soil Classification System. It is medium-sized sand with a wide grain size distribution. On the other hand, crushed limestone sand (CLS) is well-known by angular particles with rough surfaces. It is classified as well-graded (SW) and exhibits a more dispersed grain size distribution compared to RS. LCSD particle sizes predominantly smaller than 80 µm are characterized by a wide particle size distribution. The particle size distributions of sands and LCSD were determined according to the AFNOR (1992, 1996) standards, respectively.

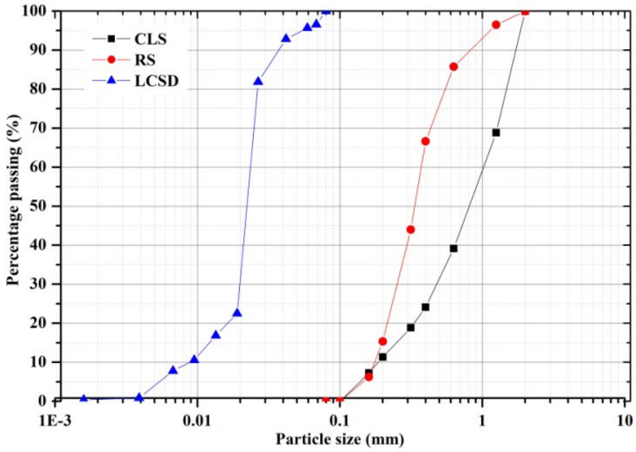

Figure 2 – Grain size distribution curve for sands and CLS dust used

The physical characteristics of the used sands and LCSD are presented in Table 1.

Table 1 – Physical properties of clean sands used in the experimental program

Sands	**RS**	**CLS**	**LCSD**
G_s (g/cm3)	2.646	2.741	2.741
e_{max} (-)	0.904	1.097	-
e_{min} (-)	0.607	0.722	-
D_{50} (mm)	0.330	0.790	0.022
D_{60} (mm)	0.394	0.987	0.023
D_{30} (mm)	0.259	0.390	0.020
D_{10} (mm)	0.177	0.120	0.010
Cu **(-)**	2.226	8.225	2.300
Cc **(-)**	0.962	1.284	1.739
W_L (%)	-	-	26.25
W_P (%	-	-	21.11
I_P (%)	-	-	5.14

Specimen preparation

In the first part of this experimental program, five clean sand mixtures were formulated; river sand (RS) was used as a base material, with crushed limestone sand (CLS) incorporated in various volumetric proportions of 0, 10, 20, 30, and 40% to investigate their effect on the properties of reconstituted clean sand (RCS).The second part of the study involves an investigation of the effect of fine limestone on the mechanical behaviour of the best-reconstituted sand from the first part, with reference to its mechanical properties. These mixtures are obtained by replacing RCS with a volumetric percentage of fine limestone ranging from 0 to 35%, with an increment of 5%.

Physical properties

A series of three tests was conducted in order to characterise the physical parameters of the various mixtures: granulometry analysis, specific gravity measurement, and void ratio determination according to the (AFNOR, 1991, 1996, 2000) standards, respectively. The grain size distributions of the reconstituted sand mixtures are illustrated in Figure 3 (a, b).

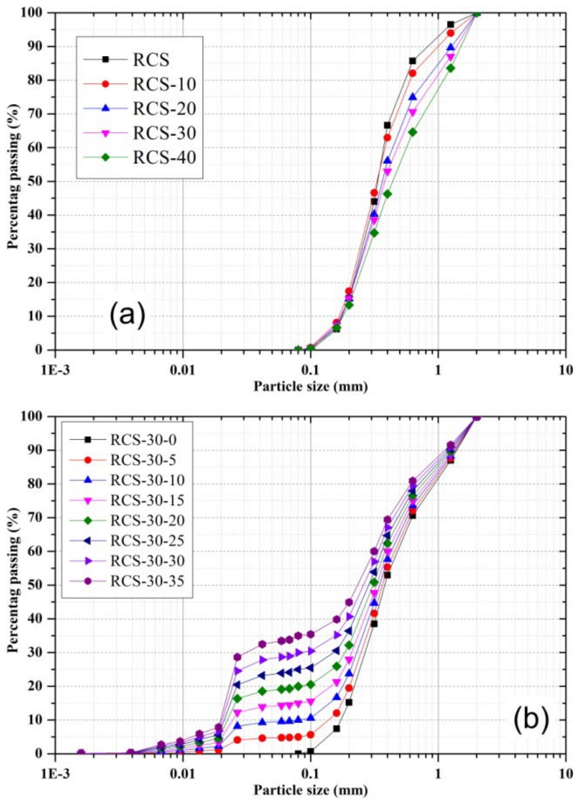

Figure 3 – Grain size distribution curve for the sands used in the experimental program: (a) RCS mixture, (b) RCS with LCSD

As illustrated in Figure 4 below, the reconstituted void ratios (e_{min} and e_{max}) are presented. It has been observed that both maximum and minimum void ratios underwent a linear decrease with increasing CLS content up to 40%. This phenomenon could be explained by a change in particle size, resulting in increased dispersion. However, beyond this content level (40%), an increase in void ratio values was observed with increasing the CLS content. This behavior can be attributed to the fact that as particle angularity rises, voids between particles also increase, thereby reducing particle mobility and leading to a decrease in the sample's potential density. In contrast, rounded particles tend to minimize voids and enhance density. These findings are consistent with previous studies (Youd, 1973; Cho et al, 2006; Al-Tuhafi et al, 2016).

The second part deals with the effect of limestone crushed sand dust (LCSD) where the variation of the void ratios of the reconstituted silty sands is illustrated in Figure 4(b). The more the dust amount is increased, the more the void ratio decreased up to 20% - this can be explained by the filling role of fine particles until saturation. Following this percentage, an increase in the void ratio was observed (Cubrinovski & Ishihara, 2002; Belkhatir et al, 2011; Monkul et al, 2016; Cherif Taiba et al, 2018; Ezziane et al, 2025).

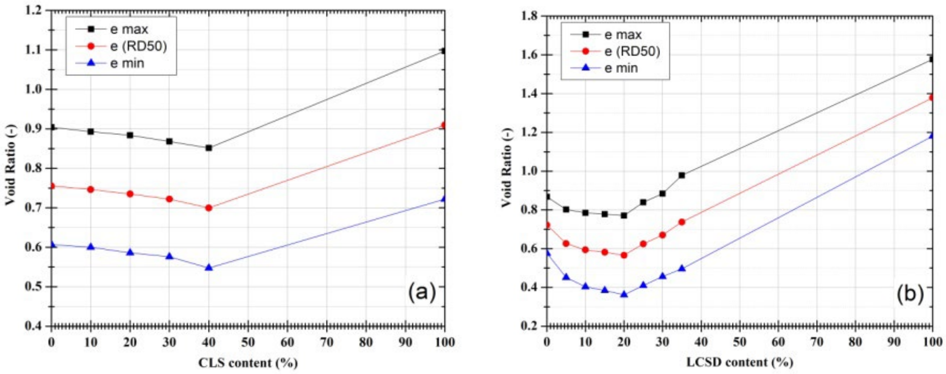

Figure 4 – Variation of the maximum and minimum void ratio of sand mixtures: (a) with different CLS content, (b) with different LCSD content

The physical characteristics of the sand mixtures used in this experimental program are represented in Tables 2 and 3.

Table 2 – Physical characteristics of the reconstituted clean sand mixtures

Reconstituted clean sands mixtures									
CLS **(%)**	**G_s (-)**	**e_{max} (-)**	**e_{min} (-)**	**D_{50} (mm)**	**D_{60} (mm)**	**D_{30} (mm)**	**D_{10} (mm)**	**Cu (-)**	**Cc (-)**
0	2.646	0.904	0.607	0.330	0.394	0.259	0.177	2.226	0.962
10	2.656	0.893	0.600	0.345	0.381	0.241	0.164	2.323	0.930
20	2.663	0.884	0.586	0.362	0.434	0.258	0.168	2.583	0.913
30	2.674	0.868	0.576	0.391	0.479	0.267	0.172	2.785	0.865
40	2.682	0.852	0.547	0.451	0.562	0.285	0.179	3.139	0.807
100	2.741	1.097	0.722	0.790	0.987	0.390	0.120	8.225	1.284

Table 3 – Physical characteristics of the reconstituted silty-sand mixtures

RCS%+LCSD% mixtures									
LCSD **(%)**	**G_s (-)**	**e_{max} (-)**	**e_{min} (-)**	**D_{50} (mm)**	**Cu (-)**	**Cc (-)**	**W_L (%)**	**W_P (%)**	**I_P (%)**
0	2.674	0.868	0.576	0.391	2.785	0.865	-	-	-
5	2.675	0.801	0.452	0.362	3.290	0.982	-	-	-
10	2.681	0.784	0.403	0.350	5.338	1.535	-	-	-
15	2.682	0.778	0.384	0.333	12.62	3.478	-	-	-
20	2.689	0.770	0.362	0.311	14.38	3.390	-	-	-
25	2.693	0.839	0.410	0.297	14.70	2.620	-	-	-
30	2.694	0.884	0.456	0.270	14.51	0.813	-	-	-
35	2.699	0.978	0.496	0.243	14.00	0.221	-	-	-
100	2.741	1.369	0.854	0.029	16.84	0.087	26.25	21.11	5.14

Experimental setup

The effect of incorporating CLS and LCSD on the mechanical behaviour of reconstituted sands was investigated in 36 direct shear test series.

All experiments were performed in accordance with the standard (AFNOR, 1994) ensuring a relative density of 50% under 100, 200, and 300 kPa of normal stress, with a constant displacement speed of 1.00 mm/min.

The shear box dimensions were 25 mm for the height of the sample and 60 x 60 mm² for the surface area of the horizontal section. The study's experimental program is illustrated in Table 4.

Table 4 – Testing program of mixtures

Tests (RCS-CLS %-LCSD %)	RS (%)	CLS (%)	LCSD (%)	Normal stress (kPa)
RCS	100	0	0	100, 200, and 300 kPa
RCS-10	90	10		
RCS-20	80	20		
RCS-30	70	30		
RCS-40	60	40		
RCS-30-5	67.5	27.5	5	
RCS-30-10	65.0	25.0	10	
RCS-30-15	62.5	22.5	15	
RCS-30-20	60.0	20.0	20	
RCS-30-25	57.5	17.5	25	
RCS-30-30	55.0	15.0	30	
RCS-30-35	52.5	12.5	35	

Experimental results and discussion

Effect of crushed limestone sand (CLS) on the river sand (RS) parameters

Effect of the CLS content on shear strength

Figure 5 shows the shear strength behaviour of reconstituted clean sand-based 0, 10, 20, 30, and 40% of CLS under different normal stresses (100, 200, and 300 kPa) prepared with a relative density of 50%. The test results indicate that the shear strength of all samples increases rapidly against the shear displacement to reach a peak value, followed by a partial decrease that could reflect the failure behaviour; then, a stabilisation segment is observed until the end of the shear test, which represents the typical behaviour of soils. This pattern can be attributed to the materials' strain-softening behaviour exhibited, whereby a peak shear strength is achieved at small displacements, followed by gradual strength reductions as displacement increases (Gilbert & Byrne, 1996; Igwe, 2018).

It is clear that the use of higher amounts of CLS (30 and 40%) exhibits better stability compared to lower percentages. Additionally, higher normal stress (300 kPa) enhances the stability of the shear stress curves, showing improved soil failure resistance. Furthermore, an increase in shear strength with the CLS content up to 30% is indicated by the test result; a more detailed analysis of this parameter shows that the shear strength increased by approximately 18, 29, and 17% under normal stress of 100, 200, 300kPa, respectively.

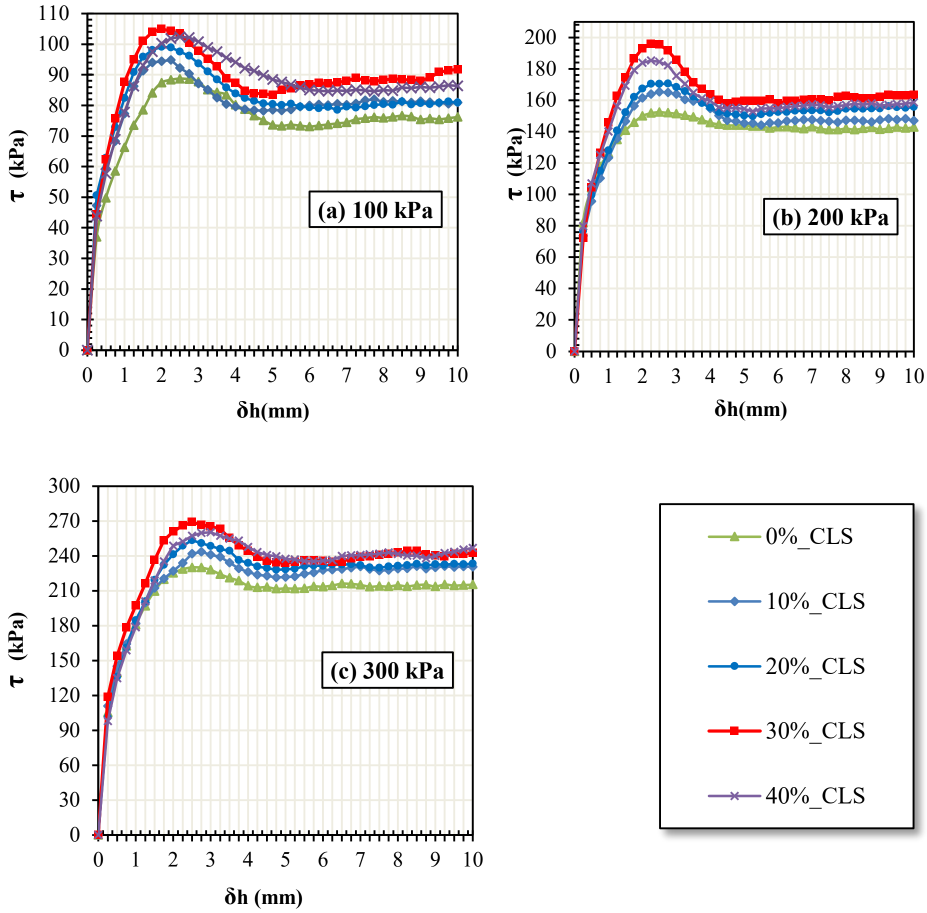

Figure 5 – Variation of shear *strength versus horizontal shear displacement for RS mixed with various contents of CLS at normal stress: (a) 100 kPa, (b) 200kPa, and (c) 300 kPa*

The enhancement in shear strength can be attributed to the influence of the angular particles of CLS, by enhancing interparticle interlocking, and contributes to developing shear resistance (Schanz & Vermeer, 1996; Hamidi et al, 2009; Nafisi et al, 2018; Nie et al, 2022; Daghistani & Abuel-Naga, 2023). However, at 40% CLS content, a slight decrease in the shear strength was observed; this is due to the increased void ratio between the particles at this stage because the increase in eccentricity leads to an increase in the e_{max} and e_{min} ratios and thus the density becomes lower, which is the reason for the decrease in resistance (Cho et al, 2006; Shabong et al, 2023).

Effect of the CLS content on the peak friction angle of RS

The results in Figure 6 present the influence of the CLS incorporation on the river sand friction angle (φ). It was observed that the more the CLS content is increased, the more the friction angle is improved, reaching its maximum value of approximately 43° at 30% CLS content, corresponding to an enhancement rate of 12%; beyond a 30% amount, a decrease of the friction angle is observed.

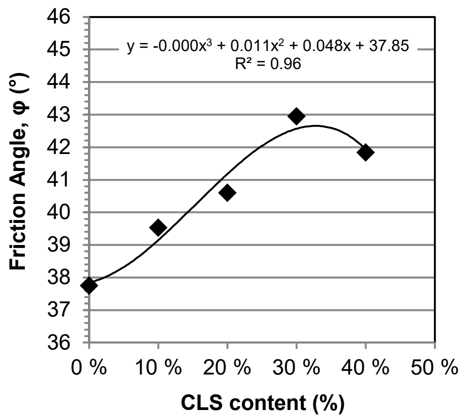

Figure 6 – Effect of the CLS content on the friction angle

The enhancement in the friction angle is attributed to the angularity of the CLS particles. These particular shapes of angular grains could enhance the interlocking and frictional resistance between particles up to a critical threshold (Been & Jefferies, 1985; Thevanayagam et al, 2002; Cho et al, 2006; Guo & Su, 2007; Li, 2013, Abbireddy & Clayton, 2015). Following this percentage, the friction angle decrease can be attributed to the excess of fine particles generated by higher CLS content, reducing the effective interparticle interactions and limiting the beneficial effects of angularity (Vallejo, 2001; Shabong et al, 2023).

Effect of the CLS content on the volume change behaviour

Figure 7 illustrates the effect of the CLS content on the volume change behaviour of RS, under 100, 200, and 300 kPa of normal stresses. The vertical displacement versus horizontal shear displacement curves reveal three primary phases during shearing: initial contraction, dilation to vertical displacement peak, and subsequent contraction until failure.

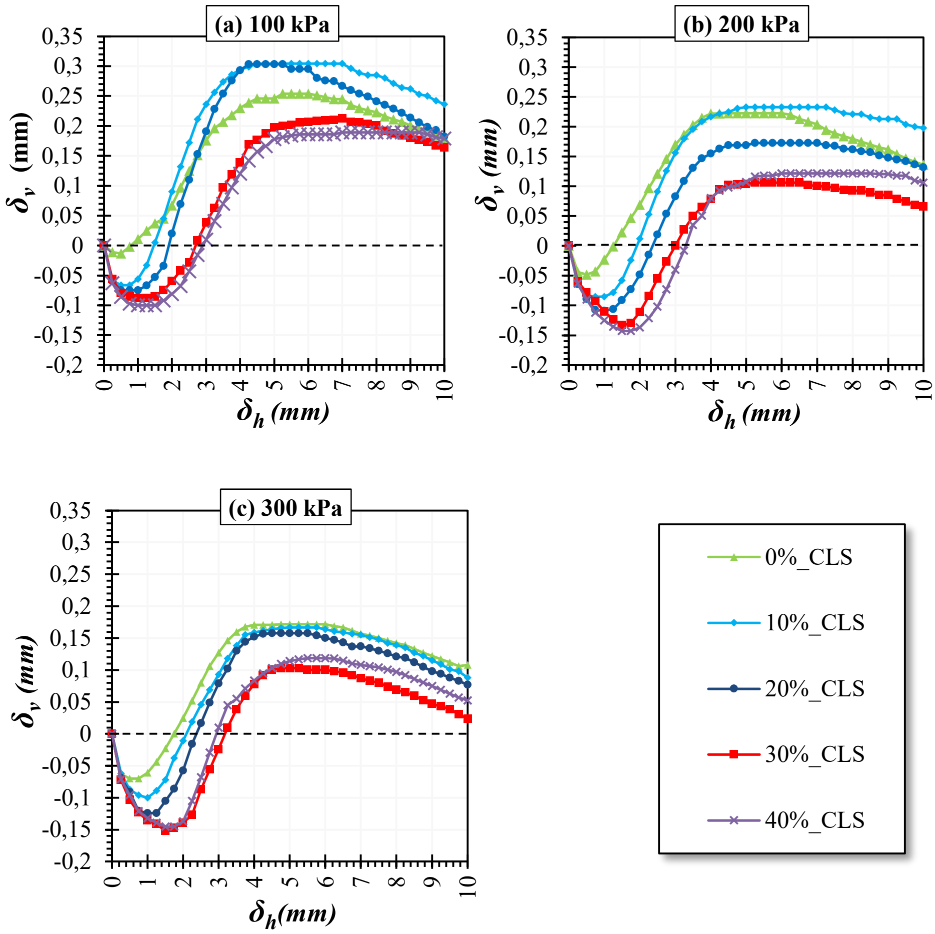

Figure 7 –Vertical displacement/horizontal shear displacement curve for RS mixed with various contents of CLS at normal stress: (a) 100 kPa, (b) 200kPa, and (c) 300 kPa

At low normal stresses (100 kPa), sands containing 10 and 20% of the CLS content exhibit greater dilation compared to RS, which is attributable to the theoretical capacity of sands containing irregular particle shape to form a lower minimum void ratio compared to sands with rounded particles, allowing particle rearrangement during shearing (Lu et al, 2019). In contrast, when the CLS content exceeds 30%, the dilation level is notably decreased, signifying the predominance of angular particle effects in constraining expansive movements through enhanced interlocking and prevention of particle rearrangement during shear resulting from the incorporation of angular particles (Cho et al, 2006).

Furthermore, the contraction phase in the samples containing 30 and 40% CLS is observed to intensify under 200 and 300 kPa of normal stresses, in particular.

This behaviour underscores the critical role of angular grains in constraining the interparticle rotation and promoting interlocking, thereby diminishing the potential for expansion (Bolton, 1986; Lu et al, 2019).

The interaction between particle shape, content and stress illustrates the importance of optimising the CLS content to balance expansion and contraction to improve mechanical performance, thus justifying the use of up to 30% CLS content in technical applications requiring high load-bearing capacity.

Effect of the LCSD content on the mechanical properties of the optimum reconstructed clean sands (RCS)

Based on the results obtained in the first stage, the mixture that developed the best resistance and friction angle is the reconstituted sand containing 30% of crushed sand.

Therefore, the investigation in the second stage will be based on studying the effect of limestone crushed sand dust (LCSD) on the mechanical properties of the optimum reconstructed clean sands (RCS). RCS is substituted by LCSD with various volumetric contents (from 0 to 35%) and sheared under different normal stresses of 100, 200, and 300 kPa at 50% of relative density.

Effect of the LCSD content on shear strength

Figure 8 represents the variation of shear strength versus horizontal shear displacement for reconstituted clean sand (RCS) mixed with various contents of LCSD. Clearly visible in the figures is that the shear strength of clean sand is significantly greater than that of the mixtures containing fine particles.

Furthermore, the shear strength of clean sand increases considerably with the advancement of horizontal displacement. Consequently, an increase in fine content leads to a gradual decrease in shear strength, especially during the initial stage of horizontal displacement (from 0 to 2 mm).

This reduction can be attributed to fine particles enhancing the contractiveness phase during the test, thereby filling the voids as well as reducing internal friction between the resulting sand particles (Arab et al, 2008; Belkhatir et al, 2010; Monkul et al, 2016; Monkul et al, 2017; Bouri et al, 2019; Aouali et al, 2019; Nougar et al, 2021).

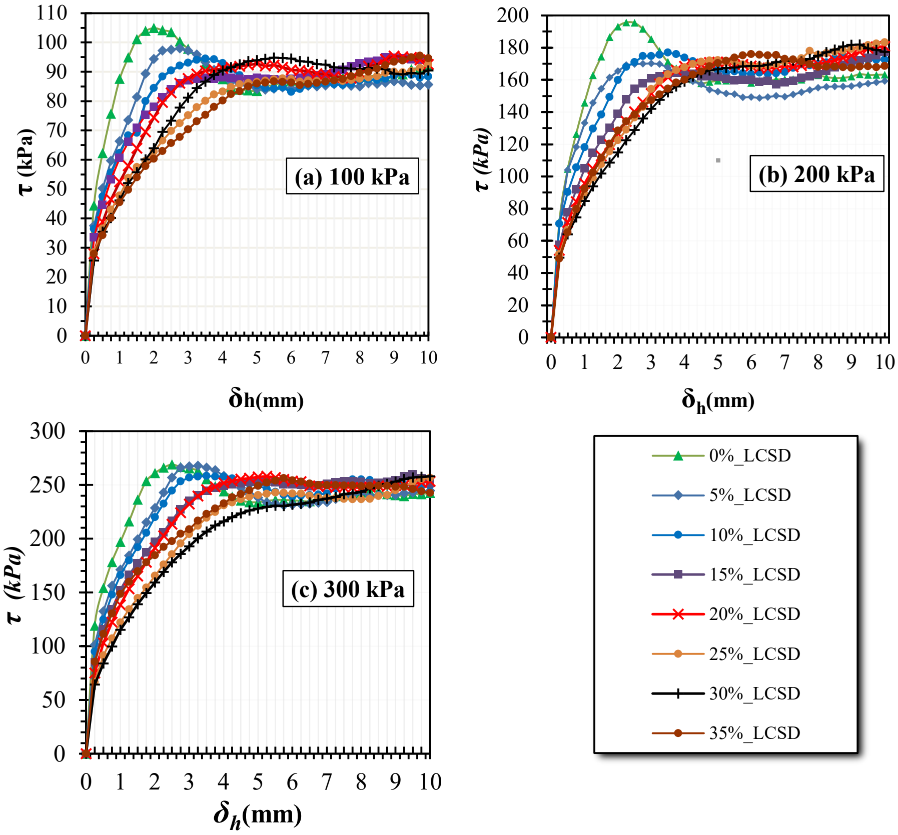

Figure 8 – Variation of shear strength versus horizontal shear displacement for reconstituted clean sand (RCS) mixed with various contents of LCSD, under normal stress: (a) 100 kPa, (b) 200 kPa, and (c) 300 kPa

In particular, the stabilisation of shear strength at large displacements was observed for higher proportions of LCSD (>15%), while lower proportions (≤15%) exhibited lower strength and less stability in comparison. High fines content enhances the phenomenon of "soil softening" or "stable cohesion", ultimately leading to relative stability after reaching maximum shear strength values (Ishihara, 1996; Lade & Yamamuro, 1997).

The effect of the LCSD content on the maximum shear resistance (τ_{Peak}) and the residual shear resistance (τ_{res}) under different normal stresses (100, 200, and 300 kPa) is shown in Figure 9. The maximum shear strength (τ_{Peak}) is linearly decreased with increasing the LCSD content under all levels of normal stress, as shown in Figure 9(a). The decrease is attributed to the effect of fines on reducing the interlocking between sand particles, which reduces the ability of the mixture to resist external loads (Shen et al, 2021; Ouici et al, 2024; Li et al, 2023).

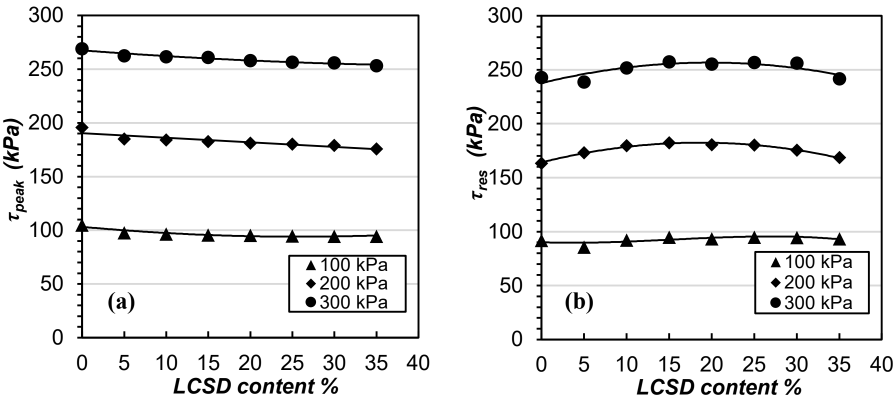

Figure 9 – Effect of the LCSD content on the peak and residual shear strength, under normal stresses of 100, 200, and 300 kPa

A different trend is shown in Figure 9(b) - as the LCSD content increases up to 15%, the residual shear strength (τ_{Res}) is improved. However, beyond this threshold, the residual shear strength is decreased gradually with an increase in the LCSD content. This performance at this range of substitution (less than 15%) can be attributed to the interlocking effect between fine and soil particles during shearing, which significantly enhances the overall structure and increases the residual shear strength (Shi et al, 2024).

Once the value exceeds 15%, the interparticle content becomes sufficient to destabilize the sand particles' cohesion.

This study reflects a dual effect of the LCSD content on shear strength - fine particles improve the residual shear strength within a certain range, while their increase leads to a negative effect on the maximum and residual shear strength when the critical percentage is exceeded (15%).

Effect of the LCSD content on the friction angle

The influence of the limestone sand dust content (LCSD) on the maximum friction angle (φ_{Peak}) and the residual friction angle (φ_{Res}) of reconstituted clean sand (RCS) is shown in Figure 10. The test results show that the maximum friction angle gradually decreased as the LCSD content increased, indicating the effect of fine particles in reducing the interaction between coarse grains; this result agrees with those of (Bouri et al, 2019; Monkul & Ozden, 2007; Najjar et al, 2015) concluding that the addition of fines to granular materials decreases the friction angle. This decrease is attributed to fine particles by the voids filling effect, limiting the structural cohesion and reducing the friction angle (Been & Jefferies, 1985). In addition, the results showed an almost linear relationship between the LCSD content and the maximum friction angle.

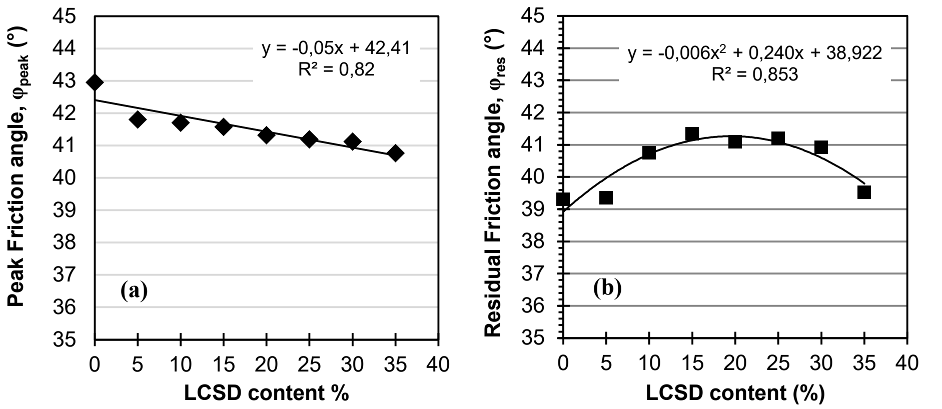

Figure 10 – Effect of the LCSD content on: (a) peaks friction angle (φ_{Peak}) and (b) residual friction angle (φ_{Res})

On the other hand, the residual friction angle (φ_{res}) shows a clear improvement as the LCSD content increases until reaching 15%; at this threshold, the interstices between sand grains are completely filled by fine particles, without significantly altering the interaction between the coarse grains, thereby enhancing the residual friction characteristics (Thevanayagam et al, 2002). However, when the substitution exceeds 15%, the residual friction angle begins to diminish due to the increased content of fine particles, leading to the failure of structural cohesion and the reduction of the positive effect of these particles (Vallejo, 2001).

Effect of the LCSD content on the volume change behaviour

The effect of the LCSD content on the volume change behaviour of the reconstituted clean sand specimens, incorporating different LCSD ratios ranging from 0 to 35% by sand volume, under normal stresses of 100, 200, and 300 kPa, is shown in Figure 11.

The analysis reveals a typical volumetric deformation of medium-density samples, where three primary phases are observed. Firstly, there is the initial contraction phase, where the specimens begin to contract as the shearing process begins due to the rearrangement of sand grains and the void filling by fine particles (Xiao et al, 2017). Moreover, the results illustrate that increases in normal stress lead to a greater initial contraction behaviour of the specimens.

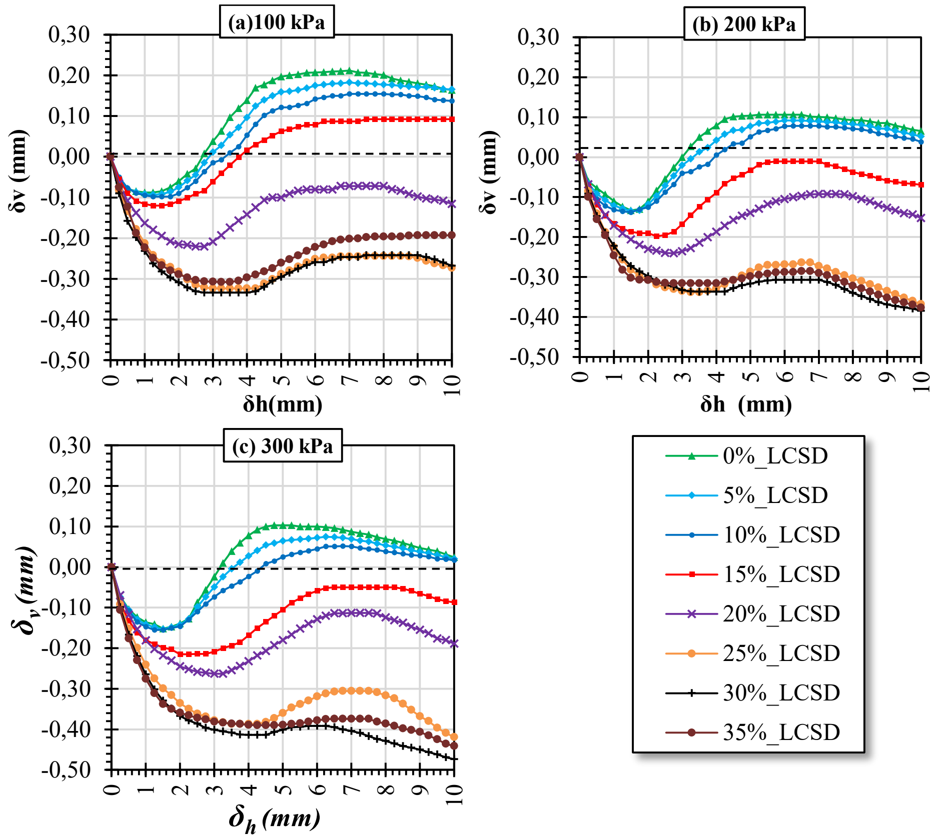

Figure 11 – Vertical displacement / horizontal shear displacement curve for RCS mixed with various contents of LCSD, at normal stress: (a)100 kPa, (b)200 kPa and (c)300 kPa

The second stage is expansion: the samples begin to expand significantly at low pressures compared to high pressures and with the increase in the LCSD content, especially within the range of 0 to 15%, the expansion becomes more pronounced. Meanwhile, at an amount exceeding or equal to 20%, the expansion gradually decreases due to the effect of fine content in increasing the sphericity and roundness of the samples (Nguyen et al, 2021). The final phase is indicative of the secondary contraction under normal stresses of 200 and 300 kPa.

Subsequent to the expansion phase, the samples begin to contract once more under a high LCSD content. The fine particles start to create internal saturation of the voids, thereby reducing the void ratio. Consequently, the interlocking increases, weakening the significance of the expansion (Liu et al, 2023).
Moreover, when the fine content (FC) is low (FC ≤ 10%), the values of the volume change are very similar to each other, indicating that the influence of the LCSD content on volumetric deformation is negligible. In this case, coarse particles dominate the mechanical properties of the soil, while fine particles occupy the voids between them. Nevertheless, a substantial decrease in the volume change values is observed when the FC is greater than or equal to 15%. This decline can be ascribed to fine particles starting to fill the voids between coarse particles. Consequently, the porosity and compressibility of the soil are reduced, thus limiting the volume change that occurs under loading condition (Gong et al, 2019). The distribution of fine particles in the soil plays a critical role in the phenomenon of contraction and expansion during the shearing process. The increase in the percentage of fines in the soil leads to an enhancement in its contraction, concurrent with a reduction in its expansion, resulting from an increase in internal friction between the grains (Been & Jefferies, 1985; Schanz et al, 1999). Furthermore, the results of (Thevanayagam et al, 2002) indicate that the optimum percentage of fines, varying between 15 to 20%, improves the behaviour of mixed sands through the filling void without disturbing the fundamental interaction of sand grains. These results confirm that the optimum LCSD ratio obtained in this study to balance contraction and expansion is estimated at 15% of LSCD substitution.

Conclusion

This experimental study investigates the effect of crushed limestone sand (CLS) and limestone crushed sand dust (LCSD) on the mechanical behaviour of river sand (RS). Based on the obtained results, the following conclusions can be drawn:

– The substitution of RS with 30% CLS resulted in an enhancement of the peak shear strength by 18, 28, and 17% under normal stresses of 100, 200, and 300 kPa, respectively. Furthermore, the friction angle is improved to 43° (representing a 12% improvement).
– At low normal stresses (100 kPa), sands with 10% and 20% CLS showed greater dilation compared to river sands. However, as the content of CLS is increased to 30% or more, the dilation is reduced,

and the contraction is increased, especially under higher normal stresses of 200 and 300 kPa.

– The findings demonstrate a gradual decrease in the peak shear strength values, exhibiting a linear relationship with the increasing LCSD content. Moreover, the residual shear strength increased by 12%, 14%, and 9.5% at 100, 200, and 300 kPa normal stresses, respectively, up to 15% LCSD content.
– The incorporation of up to 15% LCSD content enhanced the residual shear strength without compromising the peak shear strength; beyond this threshold, a decline in residual shear strength is observed.
– The optimum amount of the LCSD content is considered to be 15%.The peak friction angle (φ_{peak}) regularly decreased as the LCSD content increased.
– The residual friction angle (φ_{res}) achieved the optimum value for 15% of LCSD substitution.
– The substitution of sand with 15% to 20% LCSD resulted in enhanced dilation under low stresses and balanced contraction under high normal stresses.

The mechanical behaviour of river sands from the M'zi River was significantly improved when substituted with crushed limestone sand at a percentage of 30%, with the incorporation of fines from the same limestone rock estimated at 15%. The waste from the aggregate production quarries in the Montgorno region (Medea, Algeria) contains a limestone fines content ranging between 15 and 20%, which allows it to be used directly without any treatment. These findings are highly promising for the field of sustainable development, as they demonstrate the potential to enhance soil properties and valorise quarry by-products.

The results presented in this paper are part of a research project focusing on the valorisation and reuse of construction and road wastes and industrial by-products.

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Efecto de la arena y el polvo de caliza triturados sobre el comportamiento mecánico de mezclas de arena de río: un estudio experimental

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CAMPO: materiales
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: El presente estudio tiene como objetivo investigar el efecto de la arena caliza triturada (CLS) y el polvo de arena caliza triturada (LCSD) sobre el comportamiento físico y mecánico de la arena de río reconstituida (RS) utilizando el método de sustitución volumétrica.

Métodos: El estudio implicó la realización de pruebas de corte directo en dos series de sustitución para evaluar el efecto de la arena CLS con incrementos incrementales de 0, 10, 20, 30 y 40%, y del polvo LCSD que varía de 0 a 35% en pasos del 5% sobre el comportamiento mecánico de *la arena de río reconstituida. Todas las muestras se preparan con una densidad relativa del 50% y se prueban bajo tres tensiones normales diferentes de 100, 200 y 300 kPa, respectivamente.*

Resultados: Los resultados muestran que la sustitución de arena de río por CLS hasta un 30% mejora sus propiedades mecánicas; la resistencia máxima al corte alcanzó un valor máximo del 29% bajo 200 kPa de tensión normal. La sustitución de arena de río por LSCD conduce a una disminución de las propiedades mecánicas. Sin embargo, un análisis más profundo de los resultados obtenidos revela una mejora en los parámetros residuales, con hasta un 15% de sustitución.

Conclusión: Tras un análisis riguroso de los resultados obtenidos, se determinó que la arena reconstituida a partir de una combinación de 30% de CLS y 15% de LCSD ofrece un rendimiento óptimo en términos de propiedades mecánicas mejoradas. Esta solución se alinea significativamente con la estrategia de desarrollo sostenible del gobierno argelino que promueve la mejora de las características y la preservación de los recursos naturales, al tiempo que cumple con los estrictos requisitos del sector geotécnico.

Palabras claves: arena de río, arena caliza triturada, polvo de arena caliza triturada, sustitución, resistencia al corte, desarrollo sostenible.

Влияние дробленого известнякового песка и пыли на физико-механические свойства речного песка: экспериментальное исследование

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РУБРИКА ГРНТИ: 81.09.00 Материаловедение
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Целью настоящего исследования является изучение влияния дробленого известнякового песка и известняковой пыли на физические и механические свойства восстановленного речного песка с использованием метода объемного замещения.

Методы: Исследование включало проведение испытаний на прямой сдвиг с использованием двух серий заменителей для оценки влияния дробленого известнякового песка с постепенным увеличением содержания на 0, 10, 20, 30 и 40% и известняковой пыли в диапазоне от 0 до 35% с шагом в 5% на механические свойства восстановленного речного песка. Все образцы были подготовлены с относительной плотностью 50% и испытаны под тремя различными нормальными напряжениями 100, 200 и 300 кПа.

Результаты: Результаты показывают, что замена речного песка на дробленый известняковый песок на 30% улучшает его механические свойства; максимальная прочность на сдвиг при этом достигла максимального значения в 29% при нормальном напряжении 200 кПа. В то время как замена речного песка на известняковую пыль приводит к снижению механических свойств. Однако более тщательный анализ полученных результатов показывает улучшение остаточных параметров, достигающее 15% при замене.

Вывод: После тщательного анализа полученных результатов установлено, что песок, восстановленный из комбинации 30% дробленого известнякового песка и 15% известняковой пыли, обладает оптимальными эксплуатационными характеристиками с точки зрения улучшенных механических свойств. Это решение в значительной степени соответствует стратегии устойчивого развития правительства Алжира, направленной на улучшение характеристик и сохранение природных ресурсов при одновременном соблюдении жестких требований геотехнического сектора.

Ключевые слова: речной песок, дробленый известняковый песок, известняковая дробленая песчаная пыль, замещение, прочность на сдвиг, устойчивое развитие.

Утицај издробљеног кречњачког песка и праха на механичко понашање мешавина речног песка: експериментална студија

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ОБЛАСТ: материјали
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Циљ ове студије јесте да испита утицај издробљеног кречњачког песка (crushed limestone sand –CLS) и кречњачког праха (limestone crushed sand dust – LCSD) на физичко и механичко понашање реконституисаног речног песка помоћу методе волуметријске супституције.

Методе: У студији су изведени тестови директног смицања на две серије супституције како би се проценио ефекат песка CLS са повећањима у инкрементима од 0, 10, 20, 30, и 40%, као и ефекат праха LCSD од 0 до 35% у корацима од 5% на механичко понашање реконституисаног речног песка. Сви узорци су припремљени са 50% релативне густине и тестирани под три различита нормална напона, тј. под напонима од 100, 200 и 300 kPa.

Резултати: Резултати показују да замена речног песка издробљеним кречњачким песком повећава његова механичка својства до 30%. Чврстоћа смицања достигла је максималну вредност од 29% под нормалним напоном од 200 kPa. Замена речног песка прахом издробљеног кречњачког песка доводи до смањивања механичких својстава. Међутим, детаљнија анализа добијених резултата открива побољшање у резидуалним параметрима до 15% супституције.

Закључак: Након ригорозне анализе добијених резултата, утврђено је да песак реконституисан комбинацијом 30% издробљеног кречњачког песка и 15% кречњачког праха нуди оптималне перформансе када је реч о побољшаним механичким својствима. Ово решење у великој мери одговара одрживом развоју стратегије алжирске владе јер промовише побољшане карактеристике и очување природних ресурса, док у исто време испуњава строге захтеве геотеханичког сектора.

Кључне речи: речни песак, издробљени кречњачки песак, прах издробљеног кречњачког песка, супституција, чврстоћа смицања, одрживи развој.

Paper received on: 20.01.2025.
Manuscript corrections submitted on: 26.03.2025.
Paper accepted for publishing on: 27.03.2025.