# Effect of varying silica-limestone sand fines on the physical-mechanical performance of concrete

Tarek Djedid

*Laboratory of Exploitation and Valorisation of Saharan Energy Resources " LEVRES "*
*Department of Hydraulic and Civil Engineering, Faculty of Technology, University of El-Oued, 39000, Algeria.*
*tarek-djedid@univ-eloued.dz*

Mohammed Mani, Abdelkader Ouakouak

*Department of Hydraulic and Civil Engineering, Faculty of Technology, University of El-Oued, 39000, Algeria.*
*m.mani39@gmail.com, ouakouakk@yahoo.fr*

Abdelhamid Guettala

*Research Laboratory in Civil Engineering « LRGC », University Mohamed Khider Biskra, BP 145 RP, 07000 Biskra, Algeria.*
*guettalas@yahoo.fr*

**ABSTRACT.** The use of crushed limestone sand in the concrete industry will be quite possible and imperative for environmental reasons. Many researchers around the world have found that concrete based on 50% substitution of river sand by limestone sand gives better physico-mechanical characteristics. The main objective of this investigation is to search for an optimal percentage of silica-limestone fines resulting from the substitution of half in quantity of alluvial sand by crushed limestone sand in ordinary concrete. The proportions of fines that were tested in this work are 6%, 8%, 10%, 12% and 14%.
The obtained results revealed that concrete based on silica-limestone sand and containing 14% of the same type of fines strongly improves the different mechanical strengths and participates in the reduction of 10% and 13%, of the coefficient of capillary absorption and of the porosity accessible to water, respectively, compared to the control concrete. In addition, good statistical relationships between the studied parameters were also found.

**KEYWORDS.** Silica-limestone sand; Silica-limestone sand fines; Concrete; Physical-mechanical characteristics.

# INTRODUCTION

W orld consumption of natural sand is very excessive, due to the extensive use of concrete or mortar. In general, the demand for natural sand is quite high in Algeria and developing countries to satisfy the rapid growth of infrastructure [1, 2]. Thus, the production of concrete requires the consumption of a quantity of natural

construction sand, which is not sufficient to cover all the needs of the works.

Today, alluvial sand has become a very scarce material. Therefore, the search for an inexpensive and readily available alternative material is essential. Some alternative materials have already been used, e.g. fly ash, slag and silica fume are used in concrete mixtures as partial replacement of natural sand [3]. However, the scarcity of the desired quality is the main limitation of some of these substitute materials.

Due to the high percentage of fine particles, the use of crushed limestone sand in concrete production is limited to road pavement construction, which causes a major storage problem. Today, sustainable infrastructure growth requires an available alternative material that meets the technical requirements of fine aggregates [4]. Several countries such as France, Spain and Tunisia have experienced a shortage of natural sand and a large availability of crushed limestone sand which has led to a change in their standards to accept sand with 12% to 16% fines. In some cases, there are standards in force that reduce this rate to 7% such as ASTMC33 and 5% such as CSAA231, or even 4% such as DI4226, Uni163 and NB589-102. On the other hand, some standards admit a rate of fines of 16% such as BS822 and 12-18% such as NF P 18 – 541 [5].

Chris Hartwiger and Patrick O'Brien [6], found that artificial sand is extremely angular and has a wide particle distribution curve. Companies manufacturing sand should eliminate fine and very fine particles. Seven factors should be evaluated in the sand selection process. They are size, shape, crushing potential, chemical reaction, hardness, infiltration rate, colour and particle quality. Ghataora et al [7], used limestone quarry fines with a size of less than 4mm. They suggested that quarry fines could be pumped by hydro transport techniques using only water. The quarry fines could be processed into cement paste and pumped over long distances. Abou-Zeid and Fakhry [8], reported that the properties of hardened concrete indicated an increase in compressive strength in concrete mixtures containing fine particles, without admixture, while maintaining a constant water/cement ratio. When the W/C ratio is increased to maintain workability and slump, the compressive strength predictably decreases. Furthermore, at the same W/C ratio, mixes containing micro fine had higher flexural strength than concrete mixes without micro fine.

Concrete based on combined silica and limestone aggregates with appropriate percentages of fines contributes to the reduction of the overall volume of capillary pores and improve the physico-mechanical characteristics, which leads to prolonging the life of structures and strongly avoiding the signs of cracking and degradation under the effect of an external aggression. In this contribution we have focused on the influence of the alternation of the percentage of silico-calcareous fines on some physical-mechanical characteristics of the above-mentioned concrete. Various parameters were measured in this study including workability and fresh density, different mechanical strengths, measurement of the absorption coefficient, and evaluation of the percentage of open pores. The experimental data were statically analyzed by using the ANOVA test to better understand the relationship between the studied physical-mechanical parameters.

# MATERIALS

## Cement

The cement used in this work is a compound cement of type CEM II/B 42.5N with a strength class of 42.5 MPa produced by the LAFARGE cement plant (Matine), the physical-chemical, mineralogical and mechanical characteristics are given in Tab. 1.

## Aggregates

The sand used for the production of concrete is composed of a mixture of 50% natural crushed sand (limestone sand) with a grain size of 0/3 mm (Fig. 1b) from the Ben Brahim quarry in the area (Hassi Messaoud, Algeria) and 50% natural rolled sand from the area of (Tébessa, Algeria) with a grain size of 0/5 mm (Fig. 1a) (alluvial sand). The RS has a grain fraction of less than 0.08 mm is 4.35%. However, CS has a grain proportion of less than 0.08 mm is 20.92% (Fig. 1c and 2a). SEM observation of CS and RS clearly shows the angular rough texture shape of the former and the rounded shape of the latter (Fig. 3).

In this work five different sand mixtures have been considered, which contain the following percentages of fines: 6%, 8%, 10%, 12% and 14% (Fig. 2b). In this context, the amount of silica-limestone fines was removed to obtain a mixture without fines, then replacing the proposed rates of this sand with fines (< 80 µm) of the same amount.

Two types of gravels are used in this investigation from the same mineralogical source as CS, one with a grain size of 3/8 (named $G_1$), and the other with a grain size of 8/16 (named $G_2$).

All characteristics of alluvial sand and limestone as well as the two types of gravel are presented in Tab. 2.

The particle size distribution of each aggregate is shown in Fig. 2.

| Chemical composition (% wt) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CaO | Al$_2$O$_3$ | SiO$_2$ | Fe$_2$O$_3$ | Na$_2$O | SO$_3$ | K$_2$O | Cl$^-$ | MgO | IR | Loss on ignition | Free CaO |
| 61.90 | 4.15 | 15.80 | 2.31 | 0.06 | 2.80 | 0.69 | 0.023 | 2.39 | 0.7-2 | 9.59 | 1 |
| Mineralogical composition (%) | | | | | | | | | | | |
| C$_3$S | | C$_2$S | | | C$_3$A | | | C$_4$AF | | | |
| 58 | | 16 | | | 7 | | | 12 | | | |
| Physical and mechanical properties | | | | | | | | | | | |
| Specific gravity (g/cm³) | | | | | | | | | | | 3.22 |
| Blaine specific surface area (cm²/g) | | | | | | | | | | | 3750 – 5250 |
| Initial set (min) | | | | | | | | | | | 150 |
| Final set (min) | | | | | | | | | | | 188 |
| Consistency of cement paste (%) | | | | | | | | | | | 28 |
| Strength class (MPa) | | | | | | | | | | | 42.5 |

Table 1: Physico-chemical, mineralogical and mechanical characteristics of cement.

| Type | Sand | | Gravel | |
|---|---|---|---|---|
| | RS | CS | CG | |
| | | | 3/8 | 8/16 |
| Apparent volumetric mass (g/cm³) | 1.638 | 1.506 | 1.308 | 1.381 |
| Absolute volumetric mass (g/m³) | 2.628 | 2.55 | 2.620 | 2.654 |
| Fineness modulus | 2.33 | 1.735 | - | - |
| Sand equivalent (%) | 80.69 | 80.87 | - | - |
| Aggregate cleanness (%) | - | - | 98.98 | 99.13 |
| Water absorption after 24 h (%) | 2.13 | 4.1 | 2.5 | 1.21 |
| Flatness coefficient (%) | - | - | 30 | 17.13 |
| Los Angeles testing (%) | - | - | 27.60 | 26.52 |
| Insoluble (%) | 99 | 38 | - | - |
| SO$_4^{-2}$ content (%) | 0.69 | 0.62 | - | - |
| CaCO$_3$ content (%) | 0 | 58.07 | - | - |

Table 2: Physico-chemical characteristics of studied aggregates.



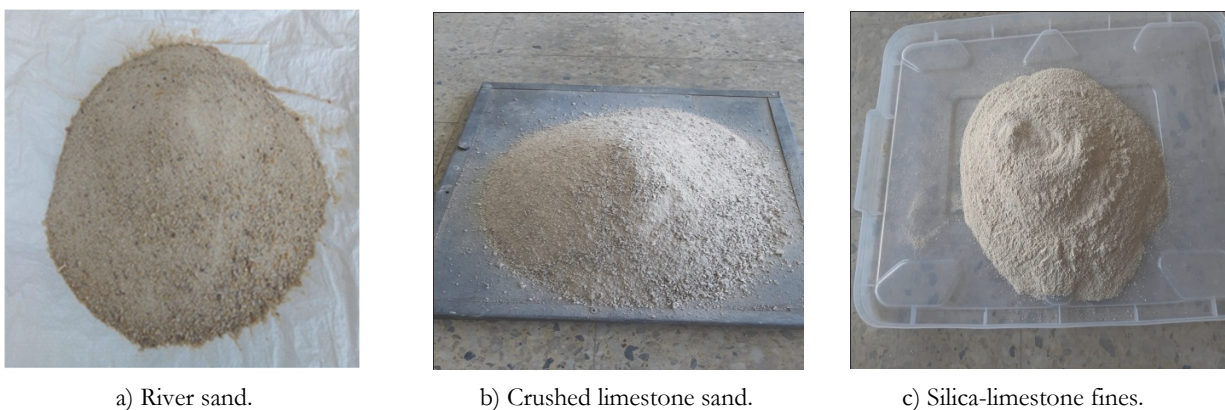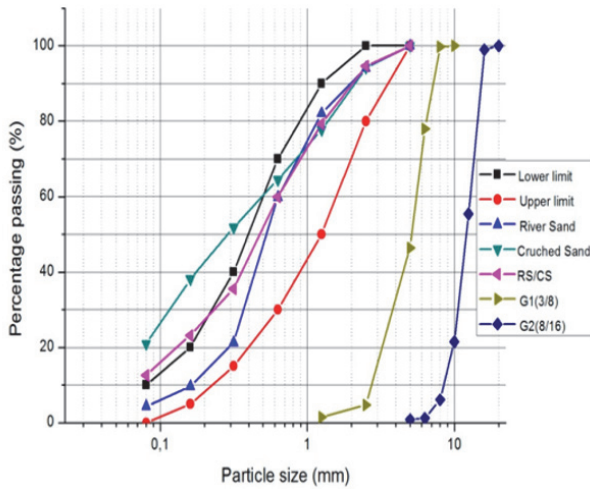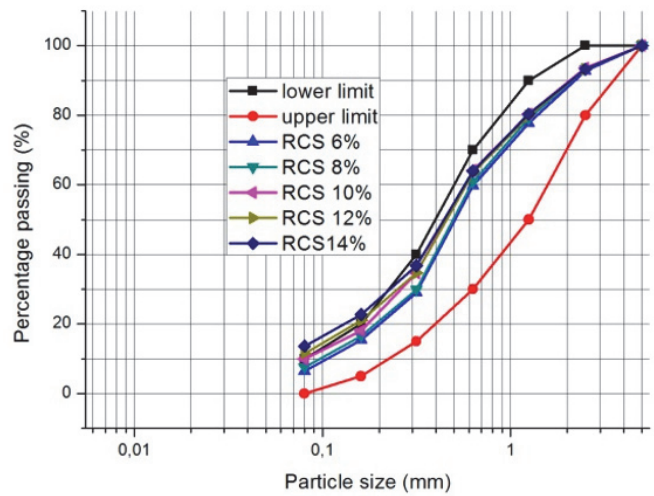a) River sand.　　　　　　b) Crushed limestone sand.　　　　　　c) Silica-limestone fines.

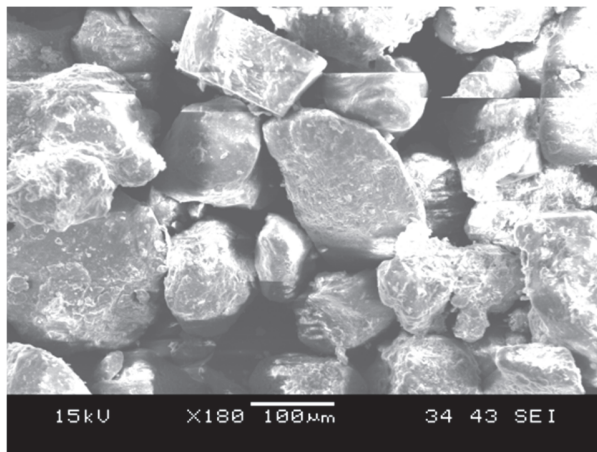Figure 1: Photos illustrate the sands and fines studied.

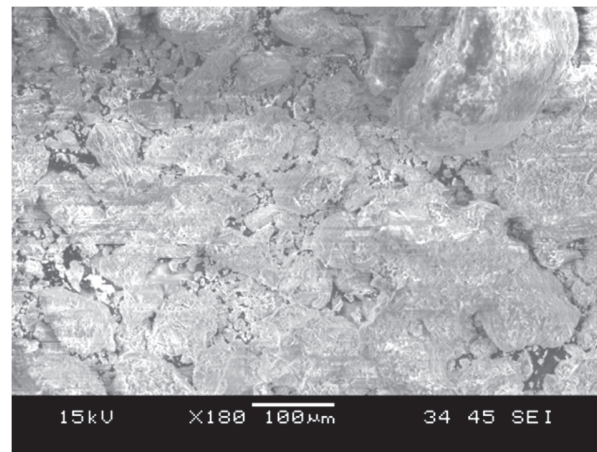a) Grading curves of the studied aggregates.

b) Grading curves of different crushed limestone sands.

Figure 2: Particle size analysis of studied aggregates.



a) River sand.

b) Crushed limestone sand.

Figure 3: SEM images of the used sands (a: river sand, b: crushed limestone sand).

*Adjuvant*

The admixture used in this work is a super plasticizer with a high water-reducing capacity in liquid form, light brown in colour, it allows the production of very high quality concrete and mortar. It is supplied by the company GRANITEX and marketed under the name: MEDAFLOW 145, with a density of 1.065 ± 0.015, a pH of between 5 and 6, and a chloride content < 1g/l, and a dry extract of 30±1.5% in accordance with the standards NF EN 934-2 [9] and NA 774 [10]. The percentage permitted by the manufacturer is (0.3 - 2.0)% by weight of cement. The optimal dosage must be determined on site according to the type of concrete and the desired effects.

*Concrete formulation and test methods*

The method followed in the making of the concrete is the Dreux Gorisse graphical method [11]. The dosage of cement and super plasticizer are fixed, 400 Kg/m³ and 2% of the cement weight respectively. The same desired strength class of concrete C 30/37 MPa was chosen for all formulations studied.

Tab. 3 summarizes the quantities of the used materials for the studied concretes.

The slump test was carried out according to EN 12350-2 [12]. It consists of determining the slump of a concrete cone under its own weight. The concrete is introduced into the mould in 3 layers of equal height, which are placed by means of a pitting rod operated 25 times per layer. After leveling by rolling the pricking rod over the top edge of the mould, the

mould is removed by carefully lifting it. Concrete slumps more or less depending on its consistency. The measurement must be carried out at the highest point of the concrete and within one minute of demoulding.

The fresh concrete is compacted with a bar in a rigid, watertight container of known volume and mass, as specified in EN 12350-6 [13].

The amount of mixture is divided into two layers and should be subjected to at least 25 strokes per layer. To eliminate trapped air pockets, after each layer has been compacted, the walls of the container are tapped intelligently with the mallet until the large air bubbles no longer appear on the surface and the depressions left by the compaction rod or bar are eliminated. Finally the density is calculated from the formula: $D = (m_2-m_1)/v$, where $m_1$ is the mass of the container, in kilograms; $m_2$ is the mass of the container plus the mass of the concrete sample in the container, in kilograms; V is the volume of the container, in cubic metres.

The uniaxial compression test is performed according to EN 12390-3 [14]. The ends of the test specimens are ground by surfacing with a grinding machine. The specimen is placed and centred on a 2000 kN UTEST hydraulic press and subjected to a loading rate of $0.6$ $kN.s^{-1}$ until failure.

The splitting tensile test is performed according to EN 12390-6 [15], and consists of applying a compressive stress along the generatrix of a cylindrical specimen over a narrow area. The resulting orthogonal tensile stresses cause the specimen to break in tension. For each of these tests and for each concrete formulation, three 10 x 10 x 10 cm cubic specimens for compression and three other 11 x 22 cm cylindrical specimens for splitting tensile are also tested.

The flexural strength was carried out on 7x7x28 cm prismatic concrete specimens in accordance with EN 12390-5 [16]. This test is carried out with a universal CBR press with a capacity of 50 kN and a speed of 1.27mm/min, delivered with a dynamometric ring and a comparator and a support specially designed for bending (three-point bending). These tests are performed at 7, 28 and 60 days.

The capillary absorption test was inspired by the recommendations of the French Association of Civil Engineering [17]. Concrete samples with cubic shapes of 70 mm on each side were sawn from 70 x 70 x 280 mm prismatic specimens.

The evaluation of the porosity of the concrete was carried out according to ASTM C642 [18], with 10 x 10 x 10 cm specimens.

| Designation | Percentage of aggregates | | | Materials dosage in kg/m³. | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sand | G₁ 3/8 | G₂ 8/16 | Sand | G₁ 3/8 | G₂ 8/16 | Cement | Water |
| C0 | 32.2 | 9.5 | 58.3 | 576.24 | 169.49 | 1053.63 | 400 | 160 |
| C6 | 32 | 9 | 59 | 556.33 | 158.21 | 1050.33 | 400 | 160 |
| C8 | 31 | 9.6 | 59.4 | 548.70 | 168.77 | 1057.81 | 400 | 160 |
| C10 | 31.1 | 9 | 59.9 | 550.89 | 158.21 | 1066.67 | 400 | 160 |
| C12 | 31.1 | 8.9 | 60 | 551.94 | 156.45 | 1068.45 | 400 | 160 |
| C14 | 31 | 8.9 | 60.1 | 550.99 | 156.45 | 1070.23 | 400 | 160 |

Table 3: Quantities of materials in the production of concrete.

# RESULTS AND DISCUSSIONS

*Effect of varying silica-limestone sand fines on properties of fresh concrete*

The details of the different studied concretes, as well as the workability results obtained during this investigation (Fig. 4) show us that when the fines content of the silica-limestone sand of irregular particles (limestone) is increased, the workability is reduced. Due to the large void space in crushed sand, water requirements are also important [19, 20]. Pedro Quiroga et al [21] stated that when the fines are > 15%, the slump decreases by 60%, also requires high range water reducing admixtures. Therefore, fines should be limited to 15%, and to increase the slump, it is necessary to use an appropriate particle size classification. A good continuity of the grading curve is necessary to obtain a workable concrete [11].

In our case, the fineness modulus of the concretes C0, C6, C8, C10, C12 and C14 was 2.33, 2.25, 2.20, 2.09, 2.07 and 2.02, respectively. When the fineness modulus of different formulations decreased, the slump values also decreased.

From results of the fresh density of silica-limestone sand concrete (Fig. 5), an increase in density can be seen when the fines content was increased. The control concrete gained the highest density, which is originally due to the high absolute density of the silica grains compared to the crushed limestone grains (Tab. 2). On the other hand, the fines give the fresh concrete a certain cohesion and water-holding capacity that allows the maintenance of homogeneity, opposing bleeding and segregation [22].
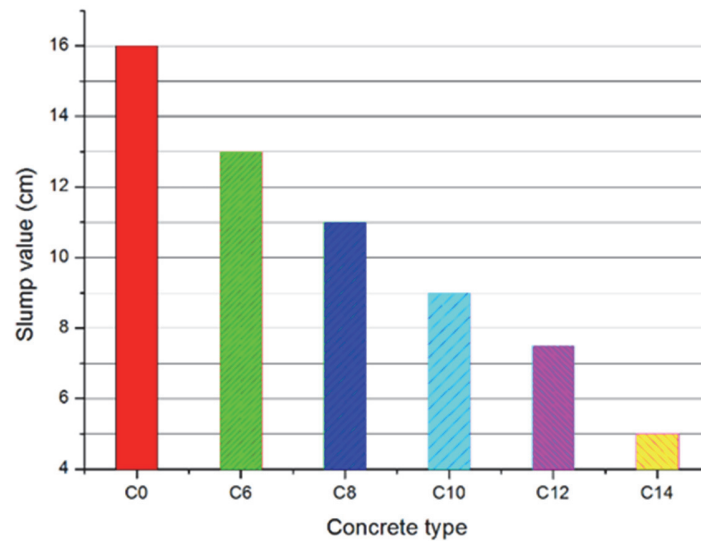


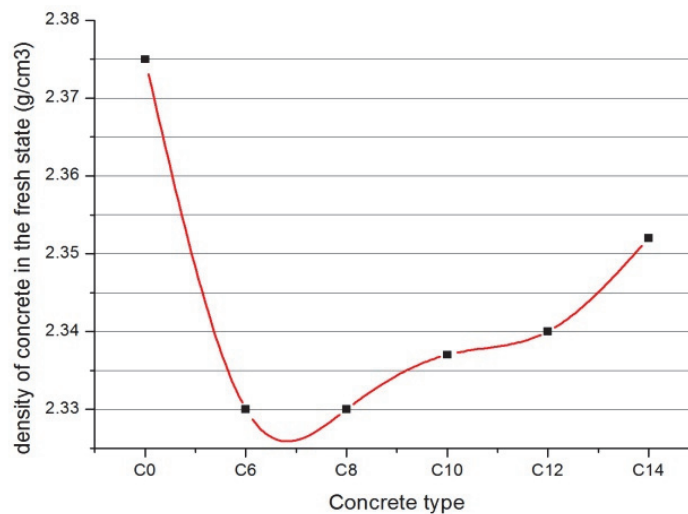Figure 4: Slump rate as a function of concrete type.



Figure 5: Values of fresh density as a function of concrete type.

*Effect of varying silica-limestone sand fines on mechanical strength*

The curves of the compressive strength as a function of the percentage of fines in silica-limestone sand concrete show the same pattern, regardless of the age of the different types of mixes studied, as shown in (Fig. 6). It was also found that the compressive strength increases with increasing the percentage of silica-limestone fines and reached its maximum at around 14% fines.

At all times, the strength increases with increasing fines content, reaching a maximum at around 14% fines. Concretes based on an equivalent percentage of natural river sand and crushed limestone sand and containing 10, 12 and 14% fines, their compressive strengths improved by 51%, 56% and 62% at 28 days and by 37%, 45% and 52% at 60 days compared to the control concrete. In addition, the strengths of the same concretes, which contain 6% and 8%, were improved compared to the reference concrete. Several authors agreed with this finding. Ahn [23] reported that for a fixed W/C

ratio, the artificial aggregate concrete had a higher compressive strength than the control concrete. The same author and others [24, 25] confirmed that good quality concrete can be made with fine particle contents of up to 17% without admixture, compared to concrete made from natural sand. Another claim was reported by Nisnevich et al [26], who revealed that lightweight concrete containing rejects from thermal power plants and quarry stone with fines. They concluded that the strength was multiplied by 2 or more when the crushed sand was close to 50%.

The flexural strength of concrete with fine limestone and river aggregates is better than that of river sand. The evolution of the curves is similar to that obtained in compression case. The fines of the fine sand-lime aggregate concrete oppose the tensile stress by bending in the lower layer of the specimens, which increases the flexural strength. In this stage, it can be noted that the flexural strength is proportional to the increase in the percentage of fines. The growth rate of C6, C8, C10, C12 and C14 compared to C0 (control) is 2%, 5%, 12%, 15%, 20%, respectively, at 28 days and 6%, 8%, 18%, 25%, 27% at 60 days (Fig. 7). The flexural strength of sand-lime concretes (50/50)% containing 14% fines as a substitute for sand-lime fine aggregates gains the optimum value. Ahn et al [24, 25] stated that concrete with high fines generally had higher unit weight, higher flexural strength, improved abrasion resistance and lower permeability. Çelik and Marar [27] used limestone fines (<75 µm) to replace sand in concrete in proportions of up to 30%, while considering the mechanical properties, the dust content up to 10% improved the compressive strength and flexural strength of concrete. Topçu et al., [28] reported that the compressive strength and flexural strength were increased when sand was replaced by limestone with a grain size less than 2 mm. Shanumugapriya et al., [3] showed that the flexural strength of high performance concrete increased with increasing percentage of silica fume in the cement. For concrete containing 50% artificial sand, the strength is optimal. However, the rate of increase in flexural strength is 13.2% at 28 days of age for concrete with 50% artificial sand and 5% silica fume.
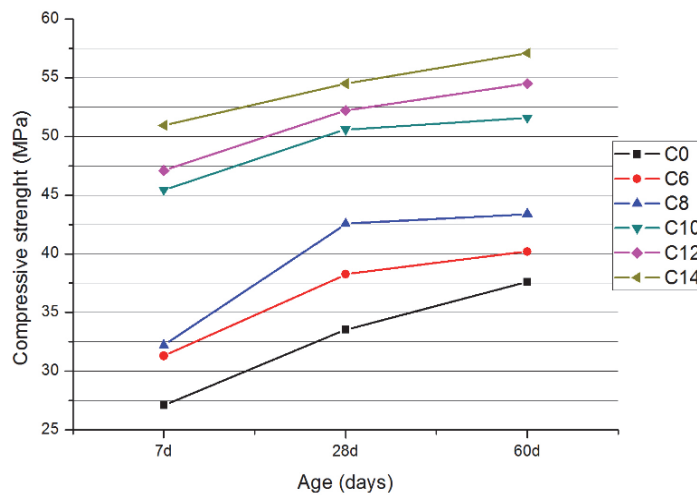


Figure 6: Compressive strength curves of different formulations over time.
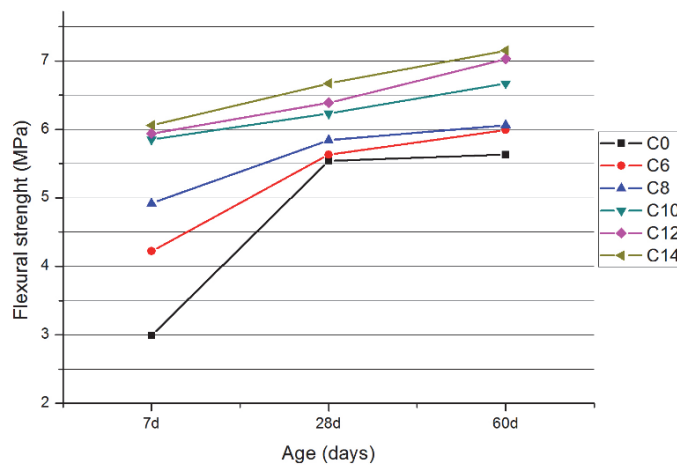


Figure 7: Curves showing the evolution of the flexural strength of different formulations over time.

Fig. 8 explains the evolution of the splitting tensile strength. The incorporation of silica-limestone fines in the concrete mix of 50% silica sand and 50% limestone sand improves the splitting tensile strength, especially at a replacement rate of 12% and 14% of the silica-limestone sand by fines of the same nature as the sand. C12 and C14 concrete remain advantageous for all mechanical strengths. C12 obtained the best result with an order of superiority of 20% and 26% at 28 and 60 days of age, respectively. A convergence was noticed between our results and the results conducted by Joudi et al., [29], who proved that the incorporation of limestone fines at a rate of 12% can improve the tensile strength of concrete compared to concrete without limestone fines. Another study conducted by Alshahwany [30] focused on the influence of calcareous fines in sand on the tensile strength of concrete. The rates of calcareous fillers substituted for sand used in this study were 0, 10, 20, 30, 40 and 50% with a water/cement ratio of 0.57. They concluded that the tensile strength is optimal for a sand substitution rate of 20% fines.
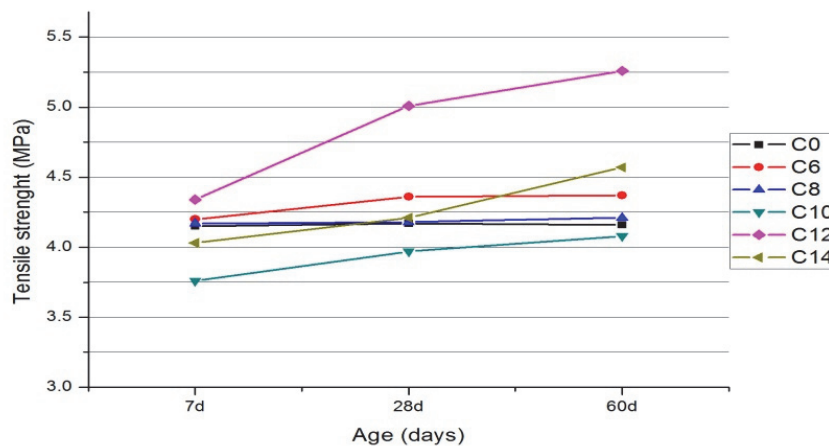


Figure 8: Splitting tensile strength curves of different formulations over time.

*Effect of varying silica-limestone sand fines on physical properties of concrete*
The results of the capillary absorption after 72h are presented in Fig. 9. The values of the different curves are decreasing according to the proposed time frames. The reference concrete gained the best value in the first two time frames. While the water absorption of silica-limestone concrete is low for a 14% replacement rate of silica-limestone sand by silica-limestone fines, and the C12 concrete has almost the same absorption coefficient as the control concrete at 60 days. The C14 concrete has a 10% lower absorption coefficient than the C0 (control) concrete after two months of immersion in drinking water. This significant reduction probably proves that the improvement of the microstructure resulting from the effect of calcareous fillers, leading to a fine and discontinuous pore structure [31].

It should also be noted that fines absorb the most water during the first period of life. Whereas in later ages the absorption capacity stabilizes and the fines play an effective clogging role, which decreases the absorption rate and increases the mechanical strengths. This is in agreement with the results obtained by Menadi et al., [32], who stated that ordinary portland cement concrete showed a higher absorption rate than that obtained by a limestone portland cement concrete containing 15% limestone by weight.

It is obvious that the water-accessible porosity is considered as one of the indicators of durability. The evaluation of the porosity of different formulations is done according to the ASTM C 642 standard [18].

Fig. 10 shows the percentages of open porosity of the studied mixtures after 60 days of immersion in drinking water. It can be observed that result of the control sample based on fine aggregates completely siliceous tends to approximately the same value as C12. While C14 sample acquired the minimum pore size. The favorable effect of the fine silica-limestone aggregates can be seen here, which plug the gaps between the paste and the aggregates, creating a very dense interfacial transition zone and shortening the spaces occupied by the harmful neo-components. The curve in Fig. 10 marked an inflection point towards the value of C6 and beyond this value the porosity decreased. The C14 composition minimized the percentage of pores by about 13% compared to the control concrete. This result is similar to the findings of Benachour [33], who stated that the density of the mortar reaches its maximum and the porosity is at its minimum for limestone filler content of 15%. Whereas, for a rate higher than 15%, a progressive fall in density and an increase in porosity to a double value were observed. He also pointed out that for high filler contents and given that their specific surface area is large, new pores are created, resulting in an increase in porosity and a decrease in density. The explanations

given confirm that fillers first fill the voids around the sand grains to the optimum. On the other hand, with a large amount of fillers, the voids are completely filled with additions and the fillers take the place of the sand grains, resulting in a decrease in the proportion of sand, and consequently in the density of the mixture.
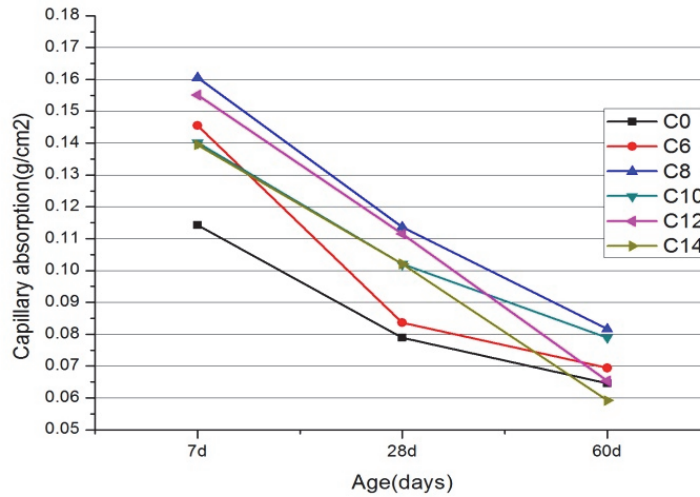


Figure 9: Capillary absorption values of different formulations after 72h over time.
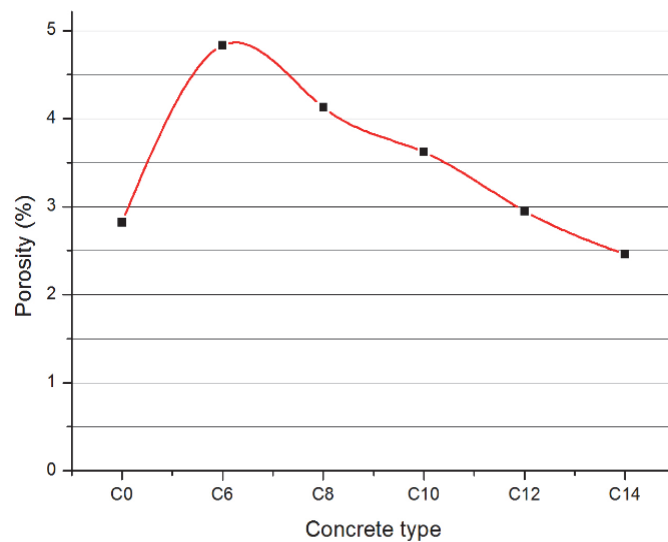


Figure 10: Pore size for different formulations after 60 days of immersion in drinking water.

*Mathematical approaches between the factors studied*

In order to make predictive approximations, the analysis of variance (by ANOVA) was performed which gives a pseudo-exact estimate of the influence of silica-limestone sand fines on the behavior of sand-based concrete of equal percentage of silica and limestone. The mathematical models offered a preliminary insight that helps the engineer to take decisional measures before making an experimental diagnosis.

The calculated slump values were correlated with the fresh densities on the one hand and with the results of the water accessible porosity on the other hand. There is an inverse relationship between subsidence and the corresponding fresh density, and a proportional one between subsidence and porosity. These dependencies have excellent correlation coefficients ($R^2$) equal to 0.975, 0.983 respectively, as shown in Fig. 11. Moreover, a concordant equation of opposition linked the porosity of these different types of concrete at the age of 60 days with the fresh density measured during the making (Fig.12), which has an $R^2$ of 0.909.

From the point of view of the agreement between the mechanical resistance to compression and to bending, we found that the curve shown in Fig. 13 represents an increasing function of the third degree; the values converge towards a correlation coefficient equal to 0.926. These interpretations led us to say that when increasing the substitution rate of

silica-limestone sand by fines of the same nature, the slump starts to reduce and the compressive strength gradually increases. Moreover, at the time when the life of the specimens kept in drinking water and subjected to the conditions of temperature and humidity of laboratory increases, the correlated figures between these last factors were triggered to approach and the correlation coefficient tends towards 1. Fig. 14 proves this situation and accurately clarifies the progressive increase of $R^2$ over time.
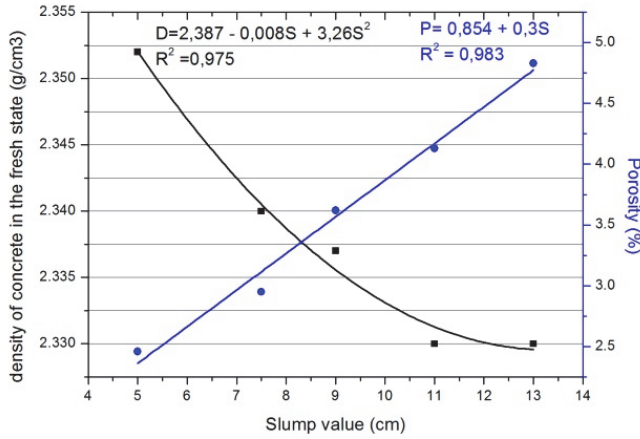


Figure 11: Relationship between fresh density and porosity of different formulations with slump.
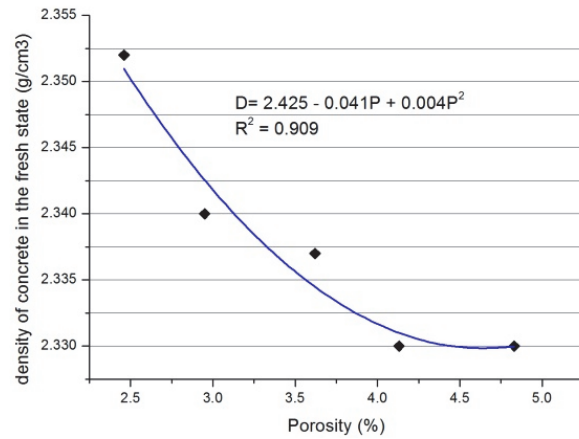


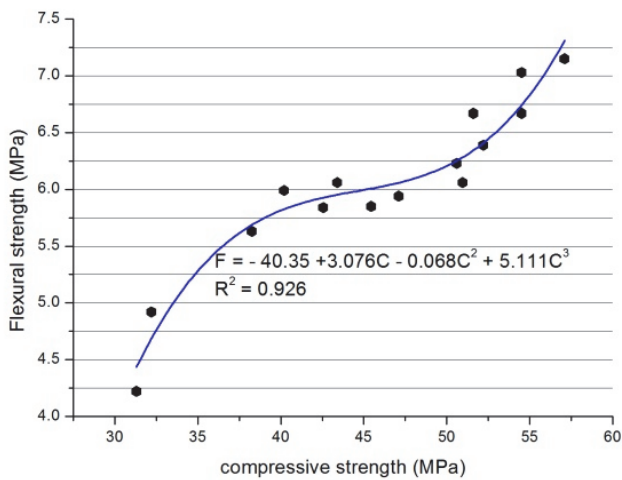Figure 12: Relationship between fresh density and porosity of different formulations.



Figure 13: Relationship between compressive and flexural strength of different formulations over time.
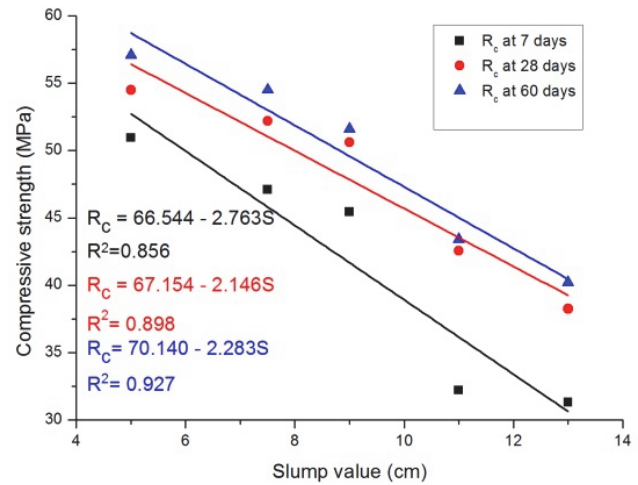


Figure 14: Relationship between compressive strength and slump at any proposed time.

## CONCLUSION

After this experimental study on the effect of the variation of silica and limestone fines in ordinary concrete containing silica-limestone grains, the following points can be summarized:
- The gradual increase in the substitution rate of silica and limestone sand by the fines of the same nature in the concrete resulted in a decrease in slump and an increase in fresh density.
- The reduction in fineness modulus of different sand formulations by the variation in fines in a silica-limestone sand based concrete produced a decrease in the slump.
- The increase in the proportion of silica-limestone fines in ordinary concrete improves the compressive strength and flexural strength.

- A similar evolution of the compressive and flexural strength was noticed in the concrete when silica-limestone sand was replaced by silica-limestone fines in all the measurement periods, and the C14 concrete obtained the optimal results compared to the other formulations.
- The C12 concrete acquired the best splitting tensile strength, followed by the C14 formulation.
- The effectiveness of fines was only observed at the first moments of measurement in the capillary absorption test in the silica-limestone sand concrete. After 60 days, the C14 concrete showed a low capillary absorption value.
- A minimum value of the water-accessible porosity is recorded in the silica-limestone sand concrete with 14% fines.
- Statistical approaches were inspired by the analysis of variance (ANOVA), linking the main properties of fresh and hardened concrete in order to participate and enrich the databases of silica-limestone sand and fines based concrete.
- The combination of river sand and limestone helps to minimize the excessive consumption of natural sand and to protect the environment.

## NOMENCLATURE

RS    : River Sand
CS    : Crushed Sand
CG    : Crushed gravel
CBR : Californian Buring ratio
RCS  : River Crushed Sand
C0    : Control concrete
Ci, i = 6, 8, 10, 12, 14 :   Concrete based on silica-limestone sand with i % fines.

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