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Predicting Mechanical Properties of Concrete Using Equivalent Mortar: A Comparative Study

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ABSTRACT

Comprehending the mechanical characteristics of concrete is paramount for its efficient deployment in construction. This investigation endeavors to predict these properties utilizing equivalent mortar, furthering previous inquiries on the topic. Literature suggests a viable approach to create concrete through a method employing both natural and crushed aggregates. This technique considers the corresponding mortar, amalgamated with crushed (SC) and dune sand (SD), as a novel mortar. Implementing this method could curtail the consumption of natural resources while conserving the mechanical attributes in both fresh (flow) and hardened states (strength and durability). This approach aims to anticipate the mechanical performance of concretes formulated from equivalent mortar data. Five mixtures were constituted to discern the optimal blend from a binary amalgamation of crushed coarse aggregates (30% fraction 3/8 and 70% fraction of 8/15) sized 3.8mm and 8.15mm, alongside five mixed sand percentages: (30% SC+70% SD), (40% SC+60% SD), (50% SC+50% SD), (60% SC+40% SD), and (70% SC+30% SD). The application of super plasticizer was investigated, and the compressive strength function of coarse aggregate was ascertained at intervals of 7, 14, and 28 days. The mechanical strength was determined at the 28-day mark. The empirical study indicates that density attains its zenith when a 40% mortar is incorporated into the concrete matrix. Conversely, with a 50% SC composition within the mixed sand, the mechanical strengths achieve acceptable values with moderate CS dosages. Specification tests reveal that incorporating 50% to 70% mortar into the concrete matrix can yield high-quality concrete.

1. INTRODUCTION

Concrete, a vital material in infrastructure construction, exhibits performance characteristics heavily influenced by its component properties, particularly coarse aggregate. This study builds upon preceding research to explore the mechanical properties of concrete utilizing equivalent mortar, aiming to further elucidate the factors influencing concrete performance. Prior studies have emphasized the significance of coarse aggregate's characteristics, including its shape, size, surface condition, and type, in determining the performance of concrete [1].

Research conducted by Hossain et al. [2] examined the relationship between six different cement contents (ranging from 150 to 400kg/m^3 of concrete) and six nominal sizes of coarse aggregate (from 12.5 to 50.0mm). The results indicated that as the cement content of concrete was increased to 150kg/m^3, the strength of the concrete also increased. However, for concrete with a cement content exceeding 150kg/m^3, strength was found to increase with coarse aggregate size up to 25mm, but it decreased when the aggregate size exceeded 25mm.

In a separate study, Zitouni et al. [3] detailed the influence of coarse aggregate properties on the mechanical behavior of concrete. The findings suggested that the inclusion of RG (3/8mm) in concrete led to improved mechanical properties. Similarly, Maza et al. [4-5] reported an increase in the mechanical strength of mortar or concrete when augmented with 40% to 50% crushed sand (CS).

Abderrachid et al. [6] investigated the impact of gravel content on various properties of concrete, such as compressive strength, water-accessible porosity, depth of water penetration, and ultrasonic velocity. The study incorporated 15 types of concrete fabricated by varying the gravel-sand ratio (G/S) from 0 to 2.5, while maintaining the cement dosage at 150, 250, and 350kg/m^3. The results pointed out that the G/S ratio significantly influenced the mechanical strength and porous structure of concrete.

Recently, there has been a surge of interest in a novel type of concrete, referred to as "equivalent concrete," the properties of which are derived from its equivalent mortar. This approach aims to decrease the amount of concrete batches, thereby saving materials and time. Ghorbel et al. [7] examined the impact of formulation parameters on the performance of equivalent concrete mortars, which incorporated varying ratios of recycled sand. The study revealed that the properties of mortars containing recycled sand were inferior to those made with natural sand mortar.

Schwartzentruber and Catherine [8] proposed a new method for designing equivalent concrete mixtures (CEM) with an admixture. Using rheological and thermal results, the CEM method provides a means to select the most appropriate admixture based on effectiveness (proportion/cost ratio), capacity to maintain rheological properties over time, and delay of formwork removal.

The current study extends the earlier work by Maza et al. [4], which utilized quarry waste as fine aggregate and compared the results to samples prepared with dune sand. This research aims to enhance our understanding of the factors influencing concrete performance, specifically focusing on the role of aggregate properties. This knowledge will be crucial in advancing concrete technology and improving the performance and sustainability of infrastructure projects.

2. MAZA'S PREVIOUS WORK ABOUT THE EQUIVALENT MORTAR

2.1 Materials and methods

The objective of this work is:

- In order to get rid of industrial waste and reduce the environmental impact, the idea of using SC in mortar mixtures came as a partial replacement for fine aggregate;
- The second objective is to find out the effect of this solid waste (SC) on the physical properties of mortars prepared by binary sand and their mechanical responses.

Dune sand (SD): is characterized by particle size 0.08mm to 3mm and 1.77 of fineness modulus (Mf).

Crushed fine aggregate (SC): It is produced from the aggregate residues during the rock crushing process.

Mixture of sand: the quarry waste replacement by SD (from 0 percent to 70 percent by volume).

The particle size of CS and DS presented Figures 1 and 2. The mixtures (Figure 2) are called by the following names: M0 (0% SC+100% SD), M30 (30% SC+70% SD), M40 (40% SC+60% SD), M50 (50% SC+50% SD), M60 (60% SC+40% SD) and M70 (70% SC+30% SD).

Cements: type CEM II/A 42.5 was used in this experimental with a uperplasticiser high reducer water Medaflow 30.

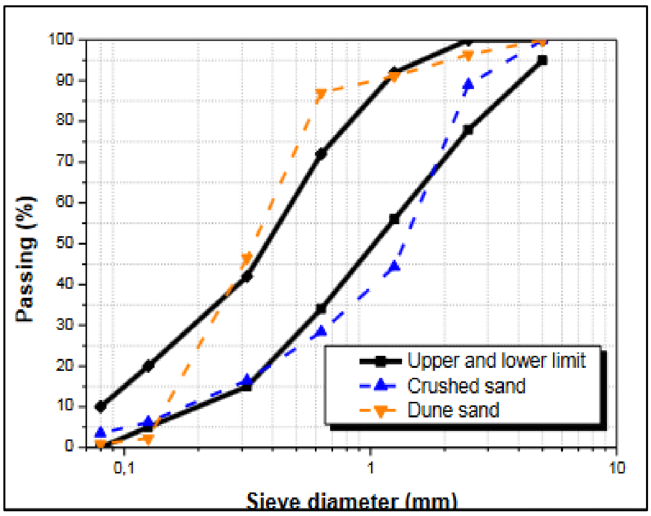


Figure 1. Granular distribution of SC and SD [4]

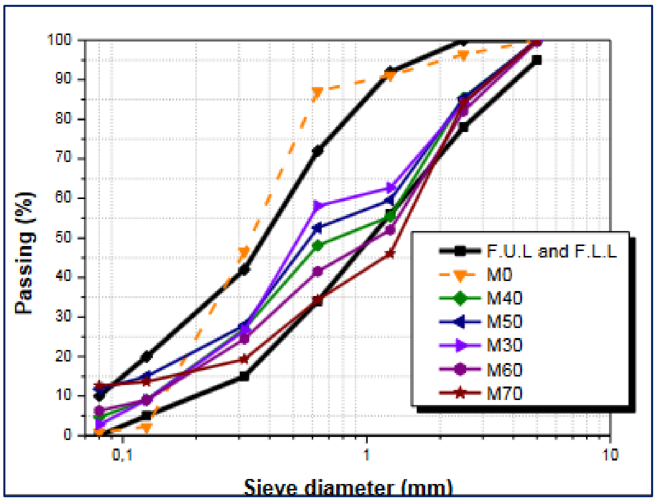


Figure 2. Grain size distribution of the mixed sand [4]

2.2 Results obtained

The results obtained in this stydy (Figures 3, 4 and 5) confirmed that the integration (30%, 40% and 50%) of CS in DS improves the mechanical strengths of mortars (M30, M40 and M50).

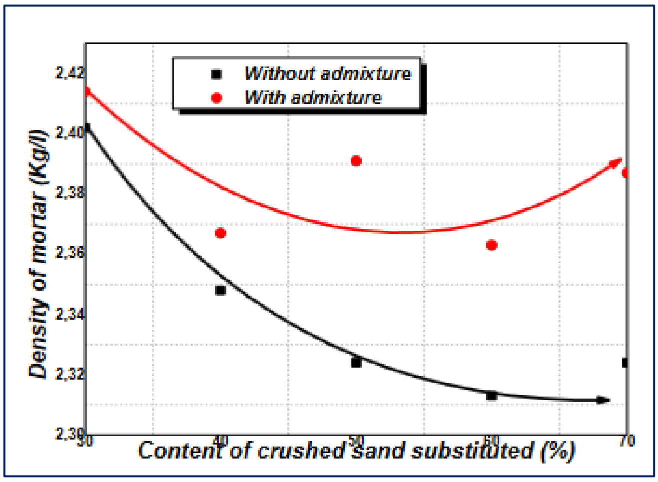


Figure 3. Density of mortars according to % of CS [4]

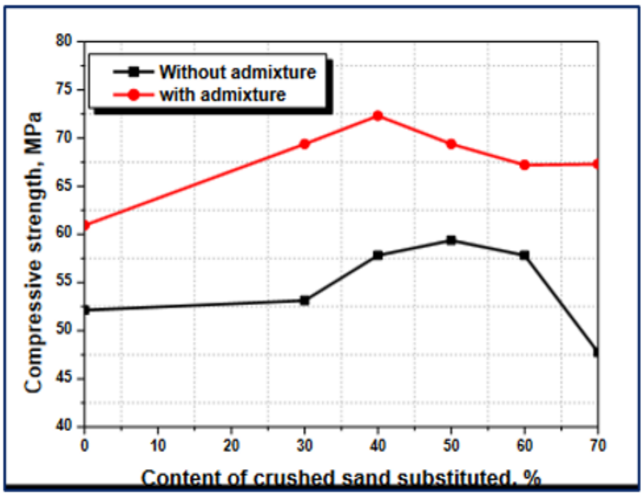


Figure 4. Compressive strength of mortars at 28 days according to the % of SC replaced [4]

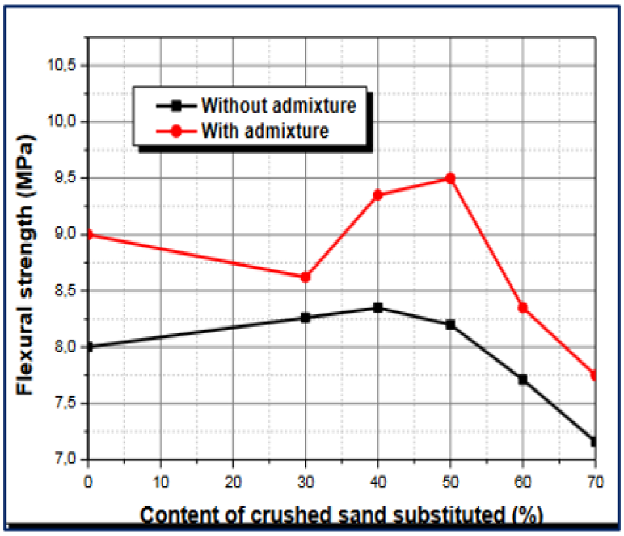


Figure 5. Variation of tensile strength of mortars at 28 days as a function of the quantity of SC substituted [4]

3. MAZA'S COMPLEMENTARY WORK ON EQUIVALENT CONCRETE

In this part of the work we have used the same materials as in the first part 1 [4] in the formation of various concretes. The experimental study carried out on concretes of different compositions (different % of mortars and % of gravel) through the analysis of density, fluidity (reduction of mixing water), compressive strength depending on the percentage of crushed sand, the porosity of the mixed sand and the percentage of mortar used in the concrete matrix.

The granulometric study is performed according to the European standard NF EN 933-1 [9].

3.1 Composition of concrete

The concrete matrix is made up of the mortar plus gravel, then using the composition of the mortar meadows defined in the mortar part, i.e., with C/S≈0.9 we prepare five concretes with each of the mixed sands (SC, S3, S4, S5, SD) as defined in Table 1. Five series of binary fine aggregate mixtures were prepared were:

- SC: Crush Sand;
- SD: Dune Sand;
- S3: 50% SD+50% SC;
- S4: 60% SC+40% SD;
- S5: 70% SC+30% SD.

The physical properties of the aggregate mixture were improved by combining natural and crushed sand.

In our study, the Russ method called "method of absolute volumes" for extract the proportions of sand, cement and water in the mortar used. This method is based on the following principle: The sum of the absolute volumes of all the materials composing 1m^3 of fresh concrete is equal to 1000 liters. That is to say, the porosity of fresh concrete is considered zero.

Table 1. Designation of concrete

Denomination	B1	B2	Bt	B3	B4
Mortar	30	40	50	60	70
Gravel	70	60	50	40	30

To reduce the mixing water of the concrete, a water-reducing admixture is introduced with a dosage of 1% by weight of cement in order to further improve the performance of this last. To clearly show the improvement in the physical and mechanical characteristics of the concrete with admixture, the control concrete is made without admixture.

According to NF EN 12390-4, the prismatic test specimens (70×70×140) mm^3 were used for the determination of the compressive strength at 28days [10]. The test specimens for testing of water porosity are dried in a stove at a temperature of 100°C to constant weight and then returned to room temperature in a desiccator. The porosity to water has been calculated conforms to recommendations of AFREM group [11].

3.2 Results and discussion

3.2.1 Density

The density is measured just after demoulding and before each crushing of the cubic specimens of 10cm×10cm×10cm, the analysis of the experimental results is presented as follows.

(1) Variation of the density according to the % of mortar composing the concrete

According to the results obtained and shown in Figure 6 below, it can be seen that the density of the concretes reaches a maximum value at a dosage of 40% mortar and then displays a slight drop by increasing the proportion of mortar in the concrete matrix [12, 13].

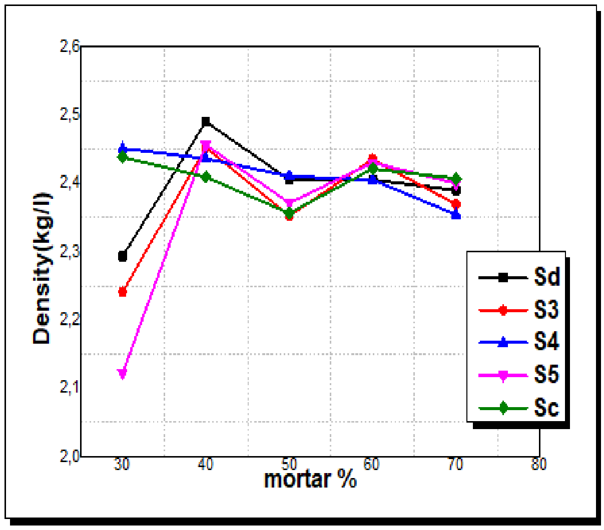


Figure 6. Density of the concretes according to the % of mortar

(2) Variation of the density according to the % of crushed sand

In Figure 7 we note a slight drop in density by increasing the % of crushed sand in the concrete matrix with the exception of concrete B1 (30% mortar) whose density reaches a maximum with sand mixed which contains 60% crushed sand [14, 15].

(3) Variation of the density of the concretes according to the porosity of the mixed sand

A slight decrease in the density of the concretes is noted when the porosity increases except for concrete B1 which shows a sudden saw tooth which is shown in Figure 8.

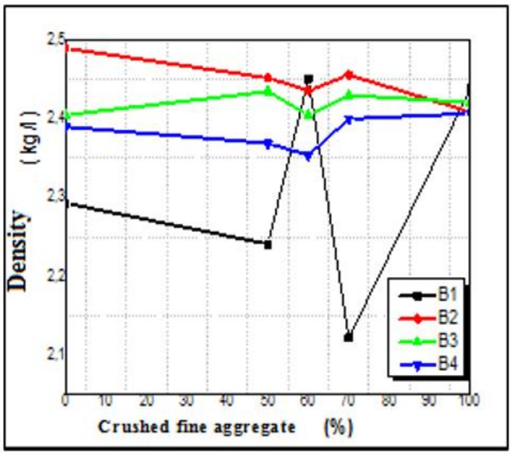


Figure 7. Density of the concretes according to the % of crushed sand

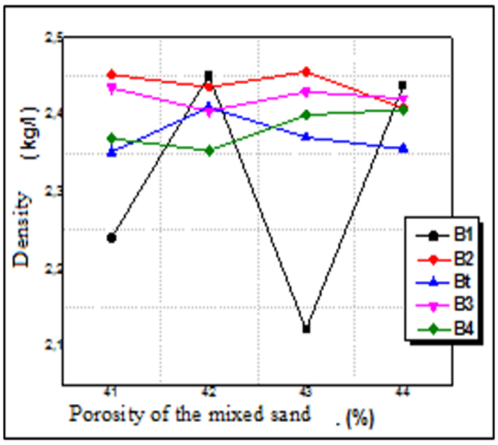


Figure 8. Density of the concretes according to the porosity of the mixed sand

(4) Fluidity and reduction of mixing water

We recall that the fluidity or the workability is the quality of a concrete which allows its workability while preserving its homogeneity. On a practical level, this translates into ease of implementation in formwork; coating of the steels and obtaining an acceptable raw facing whether in the vertical or horizontal plane [16].

For a more or less constant fluidity at the cone of Abrams f≈5 to 7cm has been noticed. The influence of the percentage of crushed sand entering the composition of the mortar and the percentage of the mortar composing the matrix of the concrete as well as the use of adjuvant on the measured fluidity, leads us to examine and analyze the reduction of water observed, since the fluidity is kept more or less constant. The results shown in Figures 9 and 10.

(5) Compressive strength of concrete

Mechanical resistance is expressed by the power of concrete to resist destruction under the action of stresses due to different compressive loads. The variation in compressive strength is studied as a function of the percentage of crushed sand in the mixed sand and as a function of the percentage of mortar which makes up the matrix of the concrete. After demolding the 10cm×10cm×10cm cubic specimens are kept in a water tank, they are subjected to the crushed test at 7, 14 and 28 days by a hydraulic press, the results obtained are represented in Figures 11 and 12.

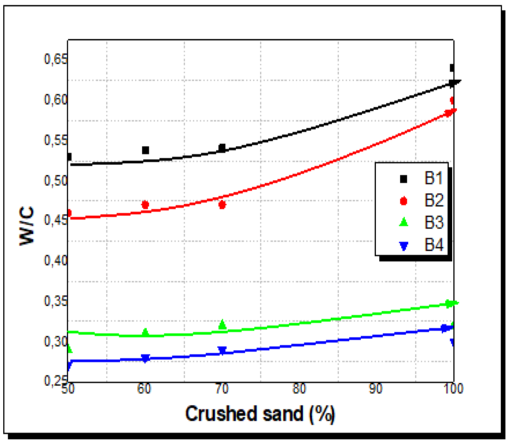


Figure 9. W/C ratio according to the % of crushed sand

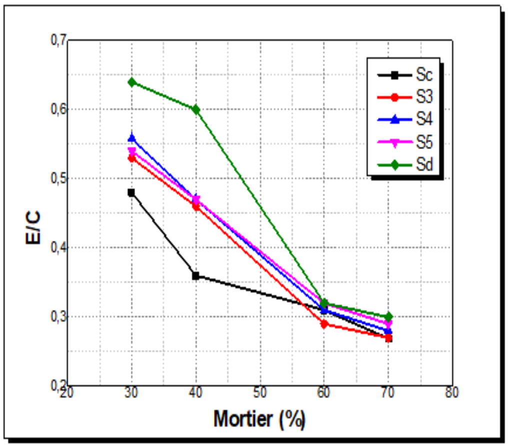


Figure 10. W/C ratio according to the % of mortar

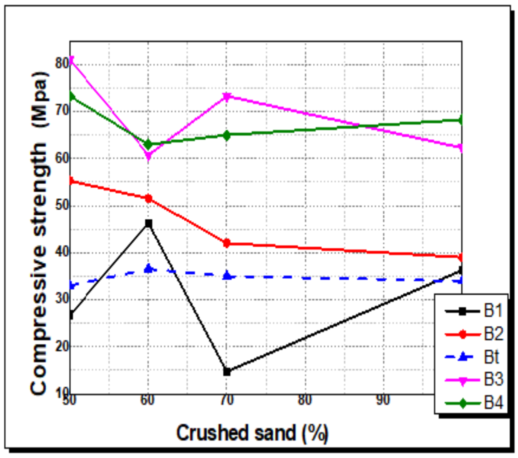


Figure 11. Variation of the compressive strength at 28 days according to the % of crushed sand

(6) Effect of crushed sand on the compressive strength of concrete

Analyzing the results shown in Figure 11, it is generally noted that when more than 50% crushed sand is added, the strength of the concrete shows a fairly slight drop and the optimum resistance is obtained at 50% crushed sand addition for concretes B2, B3 and B4 except by exception the concrete composed of 30% mortar displays a maximum resistance to an addition of 60% crushed sand [17].

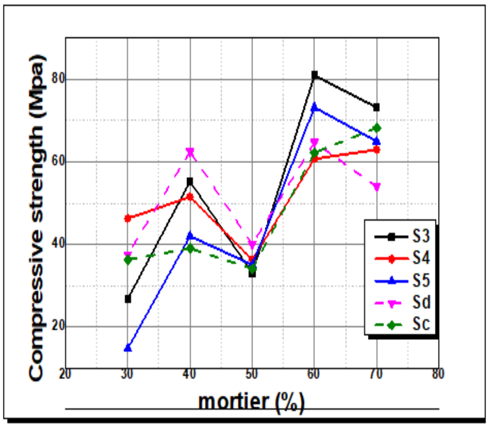


Figure 12. Variation of the compressive strength of concrete at 28 days according to the % of mortar

(7) Effect of mortar on concrete compressive strength

According to the results obtained and shown in Figure 12, it can be seen that increasing the percentage of mortar in the concrete matrix (30% to 60%) brings a clear improvement in the strength of the concrete, exceeding 60% of mortar in the concrete matrix there is a net decrease in resistance because the concrete becomes less compact and therefore less resistant and we can see this compactness of the matrix in Figure 14(d) which shows the distribution of the constituents of the concrete matrix, on the other hand, at 40% and 60% of mortar constituting the matrix of the concrete one notes a better compactness of the concrete which is well illustrated on the Figures 14(b) and 14(c) of the appreciable resistances are obtained with 60% of mortar for all the concretes. We note in Figure 12 that for a percentage of mortar equal to 50% the compressive strength of the concrete is low for any mixed sand used because these concretes are without adjuvant [17, 18].

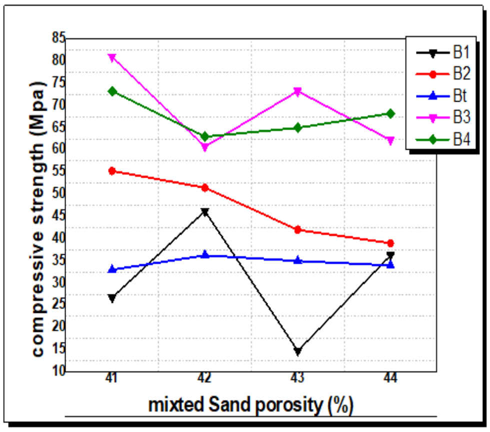
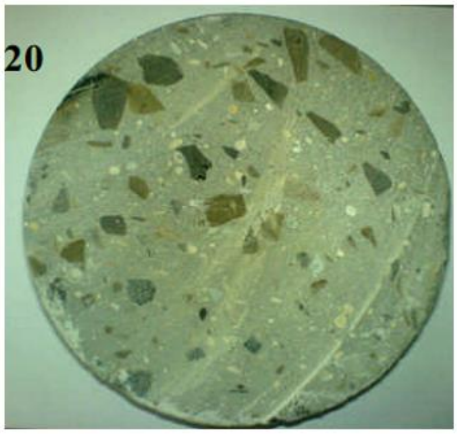


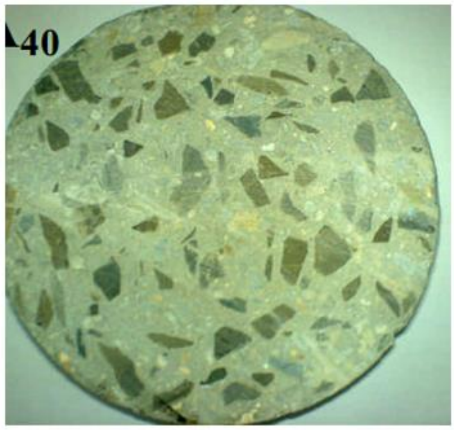
Figure 13. Effect of mixed sand porosity on the compressive strength at 28 days of the concrete

(8) Effect of mixed sand porosity on concrete compressive strength

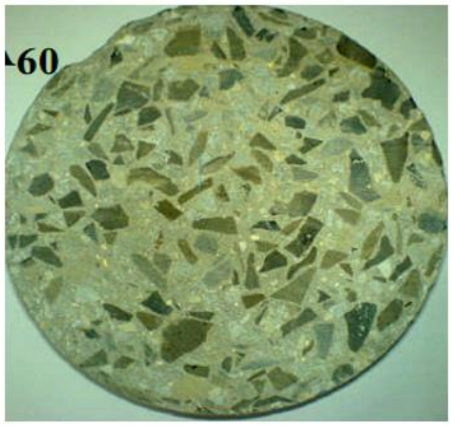
Analyzing the results obtained and shown in Figure 13, it can be seen that for a porosity of the mixed sand of 41% the maximum strength is reached for all the concretes except for the exception of the concrete with 70% gravel the porosity of the concrete matrix prime on the porosity of the mixed sand and this is very clear on Figure 14(d) more than in Figure 14(a) [19-21].



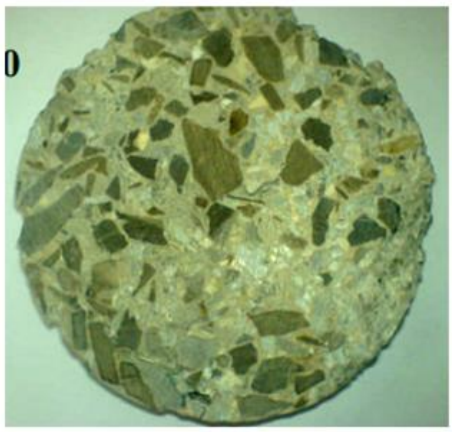
(a) 70% mortar, 30% gravel



(b) 60% mortar, 40% gravel



(c) 40% mortar, 60% gravel



(d) 30% mortar, 70% gravel

Figure 14. Compactness of the matrix

4. CONCLUSION

The use of crushed sand (waste in large quantities from the crushing of stones) allows us to contribute to increasing the storage areas at the crushing plants and to contribute to the fight against environmental pollution and to recover this waste. The experimental study on the physico-mechanical behavior of mortar and concrete based on mixed sand (sand dune+calcareous crushing sand) shows that the addition of crushed sand to dune sand for the manufacture of mortars and concretes is strongly recommended, especially if they are associated with adjuvants, which allows us to advance certain conclusions:

- The density of the concrete decreases slightly as the % of CS increases;
- The density reaches its maximum value when 40% mortar is used in the concrete matrix;
- A slight decrease in the density is recorded when the porosity of the mixed sand increases;
- The increase in the percentage of CS is caused by an increase in the amount of mixing water;
- The increase in the percentage of mortar in the concrete matrix is accompanied by a reduction in the mixing water;
- The use of 50% CS in the composition of the mixed sand makes it possible to obtain an appreciable improvement in the compressive strength of the concrete; it reaches a value of 70 to 80 Mpa for the B3 and B4 concretes;
- The use of 50% to 70% mortar in the concrete matrix makes it possible to produce quality concrete;
- The use of a thinning admixture allows a significant reduction of mixing water which allows the reduction of the porosity of the concrete which makes it possible to obtain very resistant concretes;
- The equivalent mortar allows us to predict the mechanical characteristics of concrete;
- Saving in the material and the time.

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NOMENCLATURE

CEM II/A 42.5	Portland cement type II/A 42.5
W/C	Water/cement ratio
C/S	Sand/sand ratio
SC	Crushed sand
SD	Dune sand
S3	50% SD+50% SC
S4	60% SC+40% SD
S5	70% SC+30% SD
M0	(0% Crushed sand+100% Dune sand)
M30	(30% Crushed sand+70% Dune sand)
M40	(40% Crushed sand+60% Dune sand)
M50	(50% Crushed sand+50% Dune sand)
M60	(60% Crushed sand+40% Dune sand)
M70	(70% Crushed sand+30% Dune sand)