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INFLUENCE OF THE NATURE AND PARTICLE SIZE DISTRIBUTION OF ROLLED AND CRUSHED COARSE AGGREGATES ON THE PHYSICO-MECHANICAL PROPERTIES OF CONCRETE

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ABSTRACT

An experimental study is carried out on concrete composed of two different types of coarse aggregates: crushed coarse aggregates (CCA) and rolled coarse aggregates (RCA). Aggregate shape, texture, and grading have a significant effect on the properties of the fresh and hardened concrete. This experimental study investigates the possibility to make a concrete with a binary natural coarse aggregates (crushed and rolled coarse aggregates). The experimental program reported herein was carried out to evaluate engineering properties of natural aggregates (crushed and rolled gravels) and dune sand-concrete mixtures in both fresh and hardened states. These properties were then compared to traditional concrete mixtures made with crushed gravel and dune sand to expand the beneficial use of rolled gravel concrete and underline its potential applications. Two series of coarse aggregates mixtures using crushed limestone gravel and rolled gravel have been investigated during this study; the first mixture (serie A: the first preliminary mixture proportioning method consists in obtaining the optimum mixture from a binary mixture of two fractions 3/8 mm and 8/15 mm of crushed limestone coarse aggregates at different percentages (0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90%). The obtained optimal mixture consists of 40 % crushed coarse aggregates (3/8 mm fraction) and 60 % crushed coarse aggregates (8/15 mm fraction). This optimal mixture of crushed coarse aggregates gave a minimal porosity and a maximal compactness. From this result the second concrete mixture formulation was prepared with two fractions (3/8 mm and 8/15 mm) of crushed coarse aggregates and one fraction (3/8 mm) of rolled coarse aggregates (serie B : the crushed coarse aggregates of 3/8 mm fraction was substituted by 3/8 mm fraction rolled coarse aggregates at various percentages 0%, 8%, 16%, 20%, 24% and 40% by fixing constant the percentage of 8/15 mm fraction crushed coarse aggregates at 60 % in all concrete mixtures prepared). The

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concrete with 40% of 3/8 mm fraction rolled gravel and 60% fraction crushed gravel showed a better performance than the control concrete in terms of the physical and the mechanical properties. This study allowed to better understand the influence of chemico-physical characteristics of coarse aggregates on the mechanical behavior of concrete. The inclusion of 3/8 mm fraction rolled coarse aggregates at replacement level of 40% and 60% of 8/15 mm fraction crushed coarse aggregates resulted in a increase in the mechanical strength of the concrete. The results show that, the use of 3/8 mm fraction rolled river gravel in concrete effectively improved the mechanical properties.

Keywords: Crushed and rolled coarse aggregates; physico-mechanical properties; concrete.

1. INTRODUCTION

The fine and coarse aggregates are inert granular materials used for the manufacture of the mortar or concrete. For a good mortar mix, fine and coarse aggregates need to be clean, hard, strong and free of absorbed chemicals and other fine materials that could cause the deterioration of mortar and concrete. Properties of aggregates affect the durability and performance of mortar and concrete. The shape and texture of aggregates particles could lead to improvements in the strength of concrete due to better interlocking between particles [1-2].

The fine and coarse aggregates have a significant influence on both rheological and mechanical properties of mortars and concrete. Their specific gravity, particle size distribution and surface texture influence markedly the properties of mortars and concrete in the fresh state [3-4]. On the other hand, the mineralogical composition, toughness and degree of alteration of aggregates are generally found to affect the properties of mortars and concrete in the hardened state [5]. The aggregate characteristics of shape, texture, and grading influence workability and segregation of fresh concrete and affect strength, shrinkage, density, permeability, and durability of hardened concrete. The shape and surface texture of fine and coarse aggregates will affect the quality of the cement paste/aggregates interface [6-7].

The importance of using the type and quality of fine and coarse aggregates cannot be overemphasized. The fine and coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete’s freshly mixed and hardened properties, mixture proportions, and economy.

Aggregates quality strongly influences properties of fresh and hardened mortar and economy. Consequently, selection of aggregates is an important process. Although some variation in aggregate properties is expected, characteristics that are considered when selecting aggregate include: particle shape, surface texture, abrasion, unit weights, voids, absorption and surface moisture [8-12]. The workability of concrete changes significantly with grading. Mixtures with high void contents require more paste for a given level of workability. Minimizing the aggregates voids content should be to correct the concrete mixtures.

Natural river rolled gravel (uncrushed coarse aggregates) and manufactured crushed gravel (crushed coarse aggregates) are two types of coarse aggregates normally found. Uncrushed coarse aggregates (rolled gravel) are semi angular or rounded, but crushed coarse aggregates (crushed gravel) are angular. Concrete strength depends upon the above mentioned types of fine and coarse aggregates. Shape of the fine and coarse aggregates contributes to the strength value of mortar and concrete. Aggregate is one of the important constituents in concrete, which has effect in strength development.

The granulometric composition is an important indicator of the physical properties and structure of a natural or manufactured aggregates. Particle size distribution of fine aggregate plays a very important role on workability and segregation of fresh concrete. If aggregates voids are minimized, the amount of paste required for filling these voids is also minimized maintaining workability and mechanical strength. Consequently, optimal mixture proportioning will produce good-quality concrete with a minimum amount of cement [13-15].

The fine and coarse aggregates with varying chemical and mineralogical compositions produce mortars and concretes of diverse characteristics. A number of studies have dealt with the influence of both grading and particle shape of the fine aggregate in mortars and concrete [16,17].

In order to investigate the possibility of using rolled coarse aggregates in mortar, it was first necessary to investigate the physical properties of the aggregates themselves, as these properties will affect the properties of fresh and hardened mortar. The main fine and coarse aggregates properties influencing the mortar and concrete properties are : grading, strength, relative density, porosity and surface texture. By using rolled coarse aggregates as a partial replacement of crushed coarse aggregates in concrete is very beneficially. Two different types of coarse aggregates (crushed and rolled coarse aggregates) were used in this investigation.

The objectives of this study are to investigate the effect of use of the 3/8 mm fraction rolled coarse aggregates as replacement of the 3/8 mm fraction crushed coarse aggregates in various percentages (0%, 8%, 16%, 20%, 24% and 40%) by fixing constant the percentage of 8/15 mm fraction crushed coarse aggregates at 60 %) on concrete mixtures properties such as compressive strength, workability etc. and also the determine the optimum dosage of the 3/8 mm fraction rolled coarse aggregates in concrete having maximum compressive strength. The percentage of 8/15 mm fraction manufactured crushed aggregates was fixed constant at 60% in all concrete mixtures studied.

The main goals of this experimental work were to investigate the followings:

– The possibility of using 3/8 mm fraction rolled (uncrushed) coarse aggregates in concrete mixes as replacement of the 3/8 mm fraction crushed coarse aggregates in order to correct the particle size distribution and modified the porosity of various coarse aggregates (round river gravel and angular manufactured gravel) used in concrete.
– The impact of 3/8 mm fraction rolled coarse aggregates on the physical properties of binary coarse aggregates prepared (i.e., density, porosity, particle size distribution and water absorption) and mechanical response (compressive strength) of the concretes made with binary coarse aggregates mixtures.

2. RESEARCH MATERIALS AND METHODOLOGY

The experimental test program was designed to achieve the research objectives of the study. The program consists of two phases; phase I: the first preliminary mixture proportioning method consists in obtaining the optimum mixture from a binary mixture of two fractions 3/8 mm and 8/15 mm of crushed limestone coarse aggregates at different percentages (0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90%). Phase II, the second concrete mixture method consists in analyzing the effect of use of 3/8 mm fraction rolled coarse aggregates (rounded natural river gravel) as replacement of 3/8 mm fraction crushed coarse aggregates (crushed manufactured gravel) in various percentages (0%, 8%, 16%, 20%, 24% and 40%) by fixing constant the percentage of 8/15 mm fraction crushed coarse aggregates at 60 %) on concrete properties such as compressive strength, workability, etc. and also the determine the optimum dosage of 3/8 mm fraction rolled gravel concrete having maximum mechanical strength. The percentage of 8/15 mm fraction manufactured crushed aggregates was fixed constant at 60% in all concrete mixtures studied.

2.1 Materials

The used fine aggregates (dune sand) and coarse aggregates (rolled and crushed gravels) in the current study were provided from locally available sources in Algeria. The concrete mixtures were prepared at the laboratory of the Civil Engineering Department, M'sila University (Algeria), using the following materials:

2.1.1 Dune sand (natural fine aggregates)

The natural fine aggregates used were dune sand with particles ranging from 0.08 mm to 3 mm in size. The fineness modulus, M_f, was calculated as 2.47. This natural sand was taken from Boussâada, Algeria. The absolute density and porosity were 2.54g/cm^3 and 39.48%, respectively. The physical characteristics are summarized in Table 1.

Table 1: Physical properties of dune sand

Properties	Specific weight (g/cm^3)	Water absorption (%)	Sand equivalent (sight/test)	Porosity (%)	Fineness modulus
Dune sand	2,54	1.66	72/76	39.48	2.47

The mineralogical composition (mineral phases) of the dune sand was investigated by the X-ray diffraction (XRD). Mineralogy was determined by X-ray diffraction (XRD) analysis using a diffractometer. The crystalline mineral phases identified for the dune sand (Fig. 1) is mainly composed of quartz (SiO_2), calcite ($CaCO_3$) and anorthite ($CaSi_2Al_2O_8$). It has a small but evident band ranging from 20° and 30°, indicating the presence of amorphous materials. The chemical composition of siliceous sand is shown in Table 2. Silicate is predominant in termes of chemical composition that also indicates the presence of lime, alumina, iron and magnesia in small quantities.

Table 2: Chemical composition (%, by weight) of fine aggregates (dune sand) used

Compounds	% (by weight)
Lime	02.94
Silica	88.25
Alumina	00.71
Iron oxide	00.96
Potassium oxide	00.30
Sodium oxide	00.01
Sulfite	00.08
Magnesia	00.17

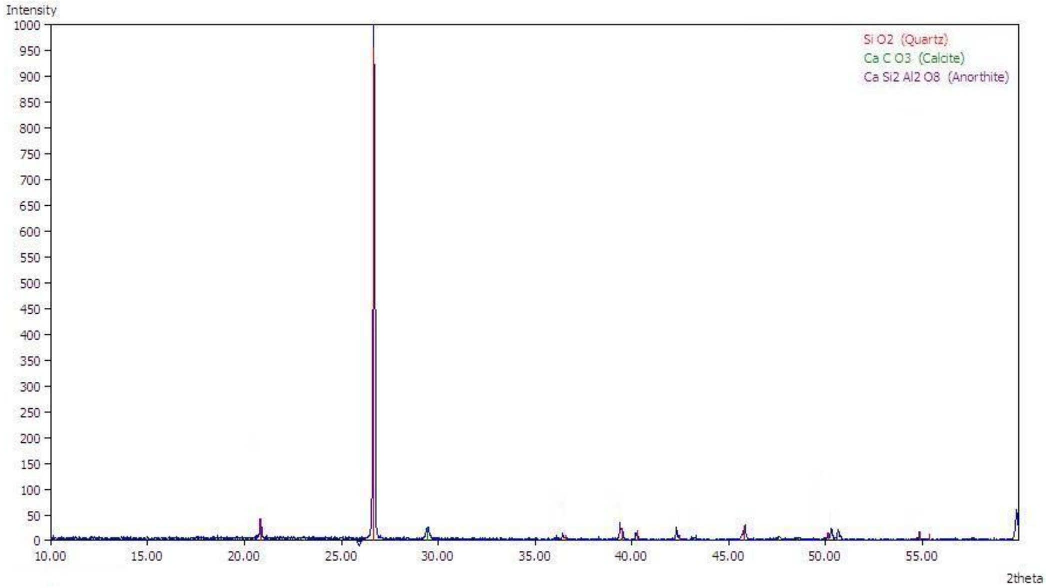

Figure 1. XRD of dune sand

The thermal analysis (TG/DTG) curves for dune sand are presented in Fig. 2. A finely ground sample was introduced into a furnace where the temperature was increased from 0°C to 1000°C with a rate of 10°C/min. The loss in mass was equal to 4%. The curve shows two main endothermic peaks:

- Endothermic peak (P1) at 100°C indicates the evaporation of water.
- Endothermic peak (P2) at 640°C corresponds to the decomposition of carbonates ($CaCO_3$).

The grain size distribution of natural aggregate (dune sand) used is presented in Fig. 3. The sieve analysis was obtained according to AFNOR standard NE EN 933-1 [18]. From the sieve analysis result, the studied sample of the fine aggregates used (DS) is compared to fine upper limit (F.U.L.) and fine lower limit (F.L.L.).

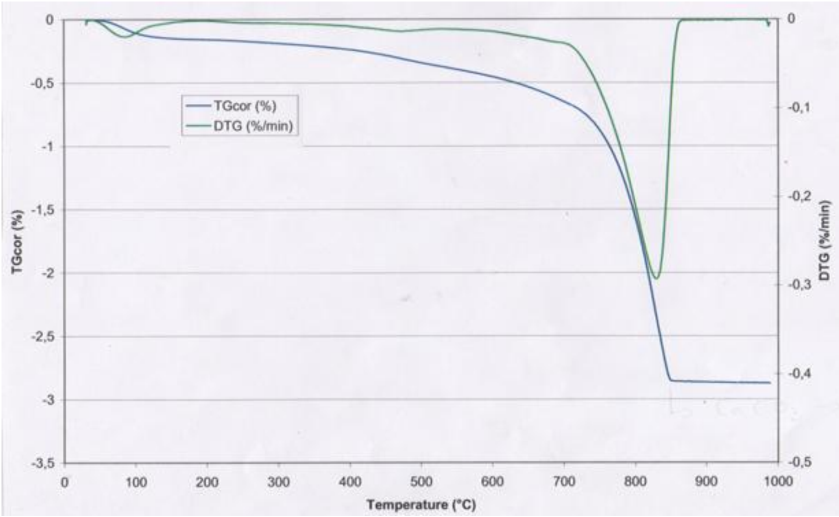

Figure 2. The thermogravimetry (TG) and the derivative thermogravimetry (DTG) curves of dune sand

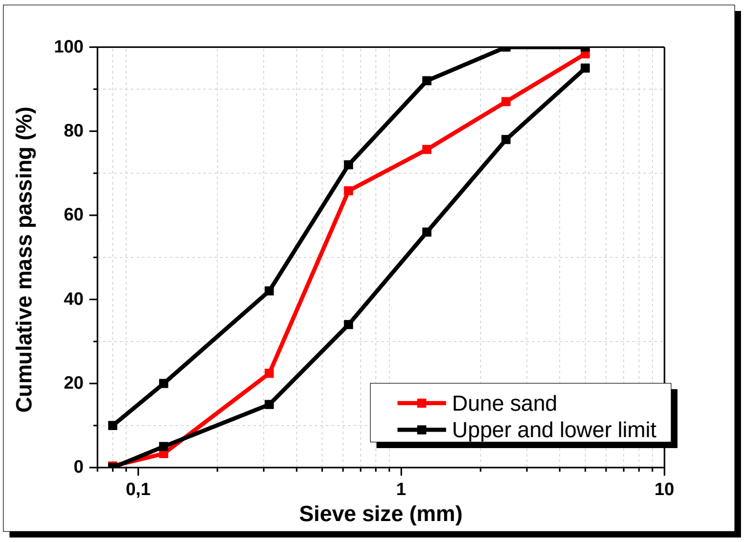

Figure 3. Particle size distribution curve of the dune sand studied

2.1.2 Crushed and rolled (uncrushed) coarse aggregates (natural river gravel and crushed manufactured gravel)

Natural river rolled and crushed manufactured gravels were used in the concrete mixes. In this study, two size fractions of crushed limestone coarse aggregates (3/8 mm and 8/15 mm) and one size fraction of rolled coarse aggregates (3/8 mm) were used. Crushed quarry waste (calcareous gravel) is obtained as a by-product during the production of coarse aggregates through the crushing process of rocks in rubble crusher units. In this study the manufactured limestone coarse aggregates used is crushed gravel generated by the quarry. The crushed coarse aggregates are angular and irregular in shape. The surface of the particles is rough with uniform colour. The silico-calcareous particles of the rolled coarse aggregates have a rounded shape and a smooth surface texture. The rolled silico-calcareous coarse aggregates was extracted from Oued Maîter River with grading of 3/8 mm. The natural river gravel particles have a rounded or flattened shape and a rough surface texture. Samples of the natural fine aggregates (siliceous dune sand) and natural coarse aggregates (calcareous crushed and silico-calcareous rolled gravels) utilized in this study are shown in Figs. 4, 5 and 6. The granulometric composition is an important indicator of the physical properties and structure of a coarse aggregates used is this study. The grading and grading limits are usually expressed as the percentage of material passing each sieve. There are several reasons for specifying grading limits and nominal maximum aggregate size; they affect relative aggregate proportions as well as cement and water requirements, workability, economy, porosity, shrinkage, and durability of mortar and concrete. Variations in grading can seriously affect the uniformity of mortar and concrete from batch to batch. The sieve analysis curves of 3/8 mm fraction rolled coarse aggregates and 3/8 mm and 8/15 mm fractions crushed coarse aggregates are shown in Fig. 7 and their physical properties and chemical compositions are summarized in Tables 3 and 4. Porosity of fine and coarse aggregates was calculated from the absolute density and bulk density values using the formula:

$$P(\%) = (1 - \frac{\rho}{\gamma}).100 \quad (1)$$

where P is the porosity as the content of pores and voids in the specimens (wt.%), γ is the absolute density (g/cm^3) and ρ is the bulk gravity (g/cm^3).

Based on the analysis of the results obtained concerning the physical properties of natural river rolled gravel and manufactured crushed gravel (Table 3):

Rolled gravel (3/8 mm fraction) has a low porosity and water absorption compared to the crushed gravel, this is primarily with its rounded or flattened shape and a rough surface texture.

Crushed gravel (3/8 mm and 8/15 mm fractions) has a high porosity and water absorption compared to the rolled gravel, this may be attributed to its angular and irregular shape and the surface of the particles is smooth.

Table 3: Physical properties of manufactured coarse aggregates (crushed gravel) and natural river coarse aggregate (rolled gravel)

Physical properties	$CG_{3/8}$	$CG_{8/15}$	$RG_{3/8}$
Apparent density (g/cm^3)	1.32	1.38	1.52
Porosity (%)	51.60	51.42	47.41
Water absorption (%)	1.60	1.33	0.94
Abrasion resistance (L.A)	22.36	22.36	23.08

$CG_{3/8}$: crushed gravel (3/8 mm), $CG_{8/15}$: crushed gravel (8/15 mm) and $RG_{3/8}$: rolled gravel (3/8 mm).

Table 4: Chemical composition (%, by weight) of coarse aggregates (crushed gravel and rolled gravel) used

Compounds	% (by weight)	
	Crushed gravel	Rolled gravel
Lime	50.66	45.97
Silica	04.40	15.13
Alumina	01.39	00.65
Iron oxide	01.13	00.93
Potassium oxide	00.11	00.17
Sodium oxide	00.02	00.03
Sulfite	00.43	00.01
Magnesia	00.75	00.23

Figure 4. Sample of dune sand

Figure 5. Sample of crushed coarse aggregates

Figure 6. Sample of rolled coarse aggregates

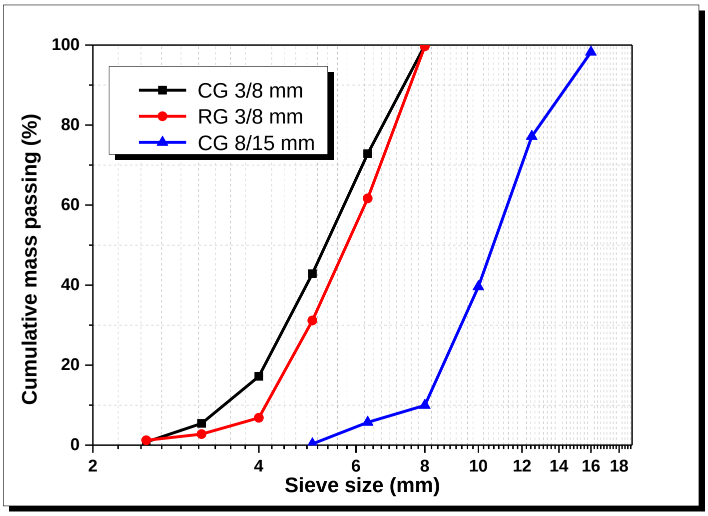

Figure 7. Particle size distribution curve of the rolled and crushed coarse aggregates studied

2.1.3 Cement

The Portland cement type CEM II/A 42.5 from Hammam Dalâa local factory was used in this experimental study. The absolute density, bulk density and porosity were 3.1 g/cm^3, 1.9 g/cm^3 and 41.93%, respectively. The Blaine specific surface area (fineness) was 3800 cm^2/g. The finenesses (specific surface area) of the cement studied was determined by Air Permeability Apparatus and the chemical composition have been determined by the testing method "X-ray Fluorescence Spectrometry (XRF)". Chemical and mineralogical compositions of the cement used are shown in Table 5.

Table 5: Chemical analysis of the cement and the Bogue composition

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	C_3S	C_2S	C_3A	C_4AF
22.10	04.57	03.95	66.34	01.60	00.54	65.70	16.85	5.42	12.03

2.1.4 Mixing water

Water is an important ingredient of Mortar as it actually participates in the chemical reaction with cement. Since it helps to from the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. Potable tap water was used for mortar mixing all through the study and contains none harmful impurity.

2.2 Binary gravel (coarse aggregates) mixtures

The natural river rolled gravel and manufactured crushed gravel used in this study were $RG_{3/8}$ (3/8 mm fraction rolled gravel), $CG_{3/8}$ and $CG_{8/15}$ (3/8 mm and 8/15 mm fractions crushed gravel). Two series of mixtures were prepared. The first preliminary serie mixture proportioning method consists in obtaining the optimum mixture from a binary mixture of two fractions 3/8 mm and 8/15 mm of crushed limestone coarse aggregates at different percentages (0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90%). The second concrete mixture method consists in analyzing the effect of use of 3/8 mm fraction rolled coarse aggregates (rounded natural river gravel) as replacement of 3/8 mm fraction crushed coarse aggregates (crushed manufactured gravel) in various percentages (0%, 8%, 16%, 20%, 24% and 40%) by fixing constant the percentage of 8/15 mm fraction crushed coarse aggregates at 60 %) on concrete properties such as compressive strength, workability, etc. and also the determine the optimum dosage of 3/8 mm fraction rolled gravel concrete having maximum mechanical strength.

The characteristics of binary crushed gravel mixtures are given in Table 6 and designated as: $CG_{10/90}$ (10%$CG_{3/8}$ + 90% $CG_{8/15}$), $CG_{20/80}$ (20%$CG_{3/8}$ + 80% $CG_{8/15}$), $CG_{30/70}$ (30%$CG_{3/8}$ + 70% $CG_{8/15}$), $CG_{40/60}$ (40%$CG_{3/8}$ + 60% $CG_{8/15}$), $CG_{50/50}$ (50%$CG_{3/8}$ + 50% $CG_{8/15}$), $CG_{60/40}$ (60%$CG_{3/8}$ + 40% $CG_{8/15}$), $CG_{70/30}$ (70%$CG_{3/8}$ + 30% $CG_{8/15}$), $CG_{80/20}$ (80%$CG_{3/8}$ + 20% $CG_{8/15}$) and $CG_{90/10}$ (90%$CG_{3/8}$ + 10% $CG_{8/15}$). The sieve analysis of binary crushed gravel mixtures is shown in Fig. 8 and their physical properties are summarized in Table 7.

The first preliminary method to blend crushed manufactured coarse aggregates (3/8 mm and 8/15 mm crushed gravel) improves the physical properties of prepared crushed coarse aggregates mix. The obtained optimal mixture consists of 40 % crushed coarse aggregates (3/8 mm fraction) and 60 % crushed coarse aggregates (8/15 mm fraction). This optimal mixture of crushed coarse aggregates gave a minimal porosity and a maximal compactness of mixed crushed gravel. Fig. 9 shows the variation of the porosity of mixed crushed gravel for various percentages of crushed gravel (3/8 mm fraction) substituted.

Table 6: Composition of the crushed gravel mixes ($CG_{3/8}$/$CG_{8/15}$)

Mix notation	$CG_{3/8}$	$CG_{8/15}$
$CG_{10/90}$	10	90
$CG_{20/80}$	20	80
$CG_{30/70}$	30	70
$CG_{40/60}$	40	60
$CG_{50/50}$	50	50
$CG_{60/40}$	60	40
$CG_{70/30}$	70	30
$CG_{80/20}$	80	20
$CG_{90/10}$	90	10

Table 7: Physical properties of the mixed crushed coarse aggregates (3/8 mm and 8/15 mm fractions crushed gravel)

Physical properties	$CG_{10/90}$	$CG_{20/80}$	$CG_{30/70}$	$CG_{40/60}$	$CG_{50/50}$	$CG_{60/40}$	$CG_{70/30}$	$CG_{80/20}$	$CG_{90/10}$
Apparent density (g/cm^3)	1.326	1.362	1.371	1.376	1.367	1.347	1.347	1.341	1.319
Porosity (%)	50.52	49.18	48.84	**48.66**	48.99	49.74	49.74	49.96	50.78

Table 8: Composition of the rolled and crushed gravels (3/8 mm fraction) and the crushed gravel (8/15 mm fraction) concrete mixes

Mix notation $M_{(RG\ 3/8)/(CG\ 3/8)/(CG8/15)}$	$RG_{3/8}$ Rolled gravel (3/8 mm)	$CG_{3/8}$ Crushed gravel (3/8 mm)	$CG_{8/15}$ Crushed gravel (8/15 mm)
$M_{0/40/60}$	0	40	60
$M_{8/32/60}$	8	32	60
$M_{16/24/60}$	16	24	60
$M_{20/20/60}$	20	20	60
$M_{24/16/60}$	24	16	60
$M_{40/0/60}$	40	0	60

From this result the second concrete mixture was prepared with two fractions (3/8 mm and 8/15 mm) of crushed coarse aggregates and one fraction (3/8 mm) of rolled coarse aggregates. The second concrete mixture method consists in analyzing the effect of use of 3/8 mm fraction rolled coarse aggregates (rounded natural river gravel) as replacement of 3/8 mm fraction crushed coarse aggregates (crushed manufactured gravel) in various percentages (0%, 8%, 16%, 20%, 24% and 40%) by fixing constant the percentage of 8/15 mm fraction crushed coarse aggregates at 60 %). The percentage of 8/15 mm fraction manufactured crushed aggregates was fixed constant at 60% in all concrete mixtures studied.

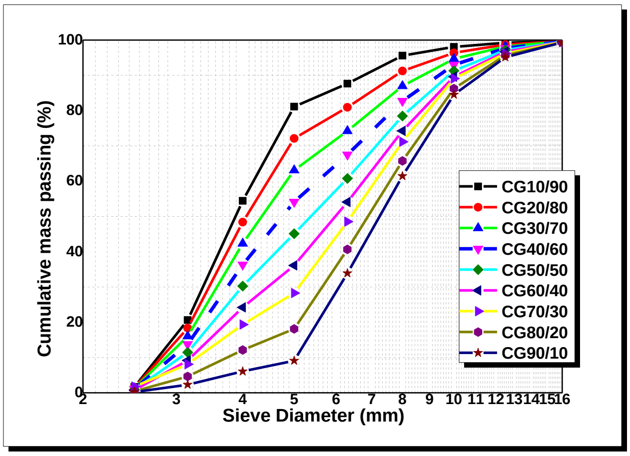

Figure 8. Grain size distribution of the mixed crushed coarse aggregates (3/8 mm and 8/15 mm fractions) tested

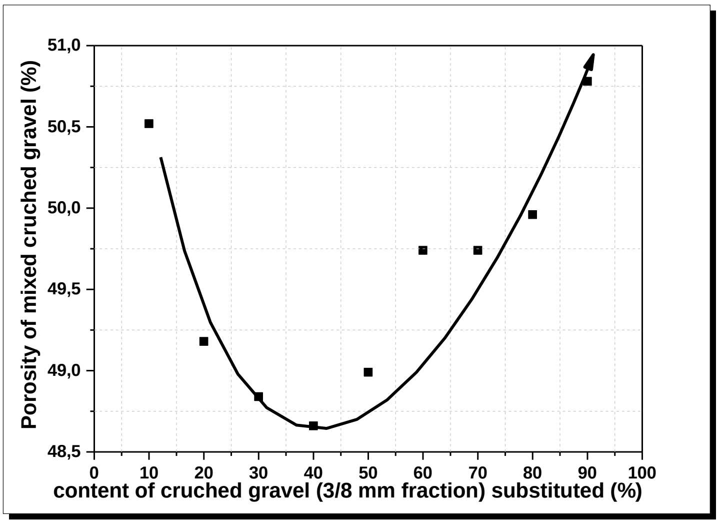

Figure 9. Variation of the porosity of mixed for various percentages of crushed gravel (3/8 mm fraction) substituted

The properties of binary rolled and crushed gravels concrete mixtures are given in Table 8 and designated as: $M_{0/40/60}$ ($0\%RG_{3/8} + 40\%CG_{3/8} + 60\%CG_{8/15}$), $M_{8/32/60}$ ($8\%RG_{3/8} + 32\%CG_{3/8} + 60\%CG_{8/15}$), $M_{16/24/60}$ ($16\%RG_{3/8} + 24\%CG_{3/8} + 60\%CG_{8/15}$), $M_{20/20/60}$ ($20\%RG_{3/8} + 20\%CG_{3/8} + 60\%CG_{8/15}$), $M_{24/16/60}$ ($24\%RG_{3/8} + 16\%CG_{3/8} + 60\%CG_{8/15}$) and $M_{40/0/60}$ ($40\%RG_{3/8} + 0\%CG_{3/8} + 60\%CG_{8/15}$). The sieve analysis of binary rolled and crushed gravels concrete mixtures is shown in Fig. 10.

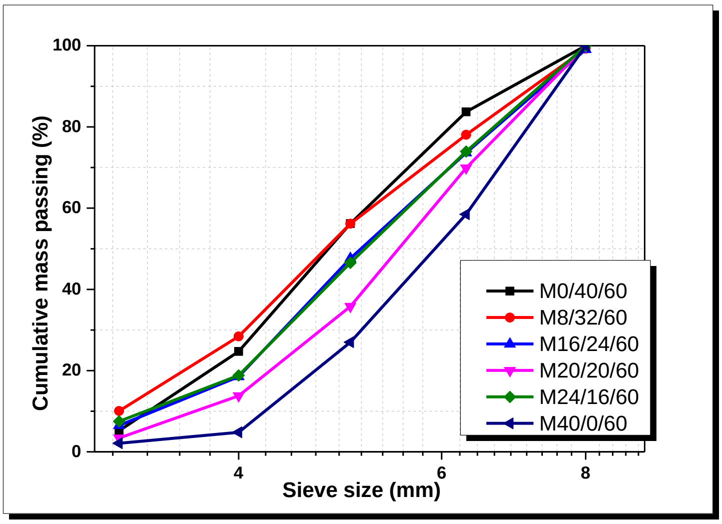

Figure 10. Grain size distribution of the mixed crushed and rolled gravels (3/8 mm fraction) keeping the 8/15 mm fraction of crushed gravel constant

2.3 Tests

The following fresh and hardened properties of mortar were selected for testing:

Slump test (Properties of fresh concrete).

Testing of dry density (Hardened concrete).

Testing of compressive strength (Hardened mortar at age 7, 14 and 28 days).

2.4 Slump test (properties of fresh concrete)

The slump test is a method of testing the workability of the fresh concrete. A standard metal slump cone is to be filled with 4 layers of concrete, each layer is to be thoroughly compacted with a steel rod. The last layer which fills the cone to the top is to be trowelled flat. The cone is then removed and the height reduction (slump) of the concrete is measured. The slump test is used for evaluation of rheological behavior of a mixture. All concrete mixes was used to maintain a constant slump of 6 ± 1 cm. Workability is a property of fresh mortar and it is measured by the slump test and is described as a measure consistency.

2.5 Mechanical tests

The concrete samples were subjected to compressive mechanical tests. Mechanical strength was determined at 7, 14 and 28 days. Six concrete mixes were prepared by using crushed and rolled coarse aggregates. All the concrete specimens were cast in three layers into 100 x 100 x 100 mm cubic steel molds; each layer consolidated using a vibrating table. The main objective of this paper is the experimental characterization of the performance of concrete made with binary natural coarse aggregates (crushed and rolled gravels) at fresh and hardened states.

3. RESULTS AND DISCUSSION

3.1 Effect of 3/8 mm fraction rolled (uncrushed) gravel on the water cement ratio

The results of the reduction of water cement ratio for various percentages of 3/8 mm fraction rolled gravel substituted of fresh concrete are presented in Fig. 11. The concrete made with binary gravel (natural river gravel and crushed manufactured gravel) presents a low water-cement ratio in comparison with the control concrete ($M_{0/40/60}$). The difference observed between the water-cement ratio of various concretes tested, depends of the content of the 3/8 mm fraction rolled coarse aggregates (rolled gravel) incorporated in the crushed manufactured gravel (difference of the water absorption and the porosity between the different coarse aggregates studied). The Substituted 3/8 mm fraction rolled coarse aggregates presents a low water absorption and porosity compared to the crushed manufactured coarse aggregates, this is mainly due at the variation of the physical properties for each type of coarse aggregates. The test results show that water cement ratio and water absorption values of binary gravel concrete mixtures increased with the decrease in level of 3/8 mm fraction crushed coarse aggregate replacement by 3/8 mm fraction rolled gravel. The water-cement ratio of the concrete mixture ($M_{40/0/60}$) made with 40% of 3/8 mm fraction rolled gravel and 60% of 8/15 mm fraction crushed gravel was reduced by 22.8% in comparison to the control concrete ($M_{0/40/60}$) made with 40% of 3/8 mm fraction and 60% of

8/15 mm fraction crushed gravel. The Fig. 11 shows that increasing the percentage of 3/8 mm fraction rolled gravel for all mortars studied is generated by an decrease in the mixing amount of water. This is due primarily to cohesion force between the particles of rounded shape and a smooth surface texture of the rolled gravel (low water absorption). The incorporation of 3/8 mm fraction rolled gravel allows a significant reduction of mixing water for all concretes despite the high percentages of 3/8 mm fraction rolled gravel used. Hence, it is concluded that increasing the use of a high percentage of 3/8 mm fraction rolled gravel leads to an decrease of the concrete mixing water.

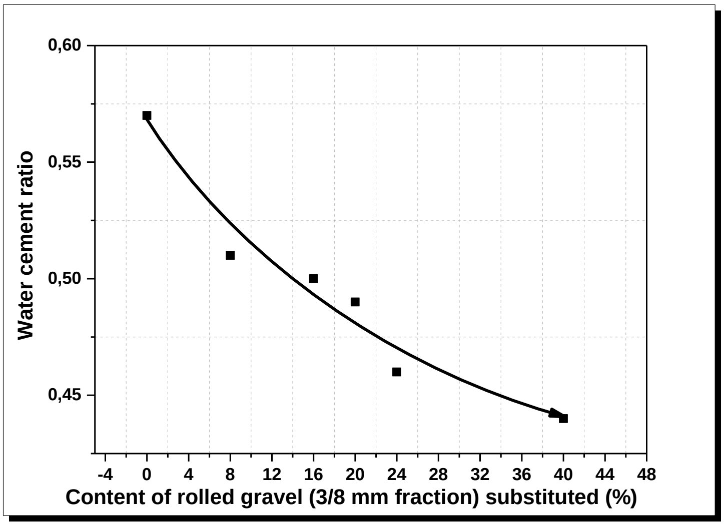

Figure 11. Reduction of water cement ratio for various percentages of rolled coarse aggregates (3/8 mm fraction) substituted

3.2 Effect of 3/8 mm fraction rolled (uncrushed) gravel on the mix density of hardened concrete

The density tests for binary gravel (natural river rolled gravel and manufactured crushed gravel) concrete mixture are shown in Fig. 12. The density at 28 days increases with increasing the 3/8 mm fraction natural river rolled coarse aggregate (rolled gravel) in concrete mixture. The use of 3/8 mm fraction rolled coarse aggregate for each curing age increase the densities of all mixtures with increasing the 3/8 mm fraction rolled coarse aggregate, because the variation of density of natural river rolled gravel (rounded shape and a smooth surface texture) is higher than that of manufactured crushed gravel. The incorporation of 3/8 mm fraction rolled gravel allows the improvement of the dry density that is mainly due to the water reduction then the concrete becomes more compact. The dry density of hardened concrete as follow:

$$\rho(Kg/l) = \frac{M}{V} \tag{2}$$

where, M, weight of specimen (kg); V, volume of specimen (l).

On the other hand, the difference in the density of concrete mixes are mainly due to the difference in specific gravity of the used rolled coarse aggregates (rolled gravel). Consequently, the density of rolled gravel is higher than that of crushed gravel.

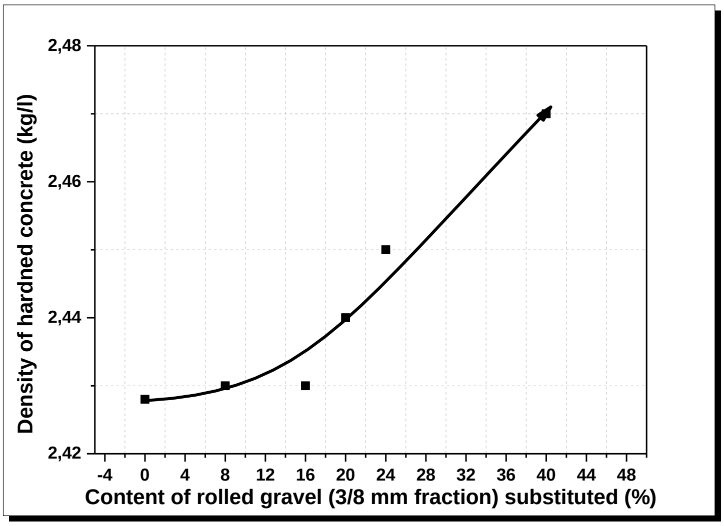

Figure 12. Variation of the density of hardened concrete for various percentages of rolled gravel (3/8 mm fraction) substituted

3.3 Effect of 3/8 mm fraction rolled gravel (uncrushed) substituted on the compressive strength

The results of the compressive strength of the concretes made with binary coarse aggregates at 28 days are plotted in Fig. 13. Each presented value is the average of three measurements. The replacement of 3/8 mm fraction manufactured crushed gravel by natural river rolled gravel results in a increase in compressive strength of the mortars made with binary gravel ($M_{8/32/60}$, $M_{16/24/60}$, $M_{20/20/60}$, $M_{24/16/60}$ and $M_{40/0/60}$) compared to the control mortar ($M_{0/40/60}$). The use of 3/8 mm rolled gravel increases the mechanical strength of the mortar, depending on the percentage of 3/8 mm fraction coarse aggregates used. The increase in the mechanical strength of the mortars may be attributed to the chemical composition, type, grain size distribution and structure of the natural river rolled coarse aggregates (rolled gravel). The results obtained specify in a clear way that the incorporation of 3/8 mm fraction rolled gravel (8%, 16%, 20%, 24% and 40% of rolled gravel) in the 3/8 mm fraction crushed gravel improves the compressive strength of the concretes tested to base of the binary gravel mixtures. This can be to explain by the fact why nature (chemical composition) and the grain-size distribution are the principal parameters which influence the increase in the mechanical behavior of the concrete tested. The strength gain of the concrete tested was superior for the concrete containing binary gravel ($M_{40/0/60}$) for the compressive strength to that of the control mixture ($M_{0/40/60}$). This, can be to explain by the fact why nature (chemical composition) and the grain-size distribution are the principal parameters which influence the increase in the mechanical behavior of the concrete tested. Indeed, the improvement of the mechanical strength is due to the correction of the physical properties (improved grading, low porosity, high compactness, etc....) of the concrete containing binary gravel (rolled and crushed coarse aggregates). Finally, one concluded that the concrete made with binary gravel (40% of 3/8 mm fraction rolled gravel and 60% of 8/15 mm fraction crushed gravel) we notice an improvement of the compressive strength of concrete. We notice that the use of the 3/8 mm fraction rolled gravel improves the mechanical strength of the concrete ($M_{40/0/60}$) of more than 29 %. The results revealed that, the concrete mixes containing rolled coarse aggregates reaches the highest compressive strength values exceeding over the control mixture ($M_{0/40/60}$) requirement by 29% after 28 days. Similar finding was also reported by other investigations [18].

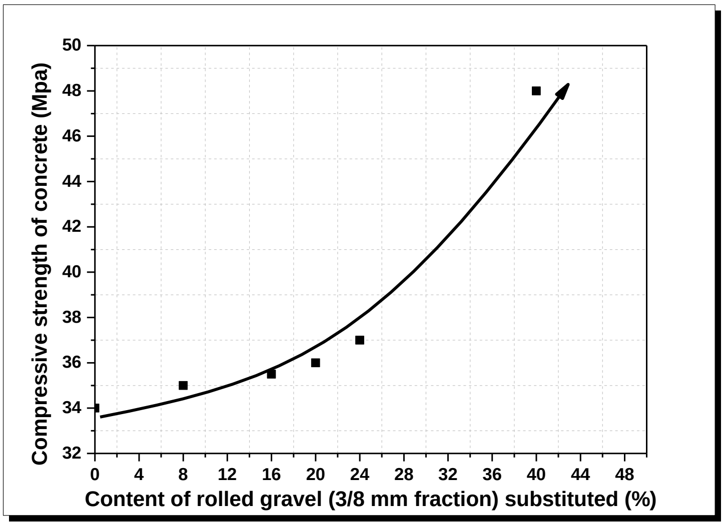

Figure 13. Variation of compressive strength of concrete at 28 days as a function of the quantity of rolled coarse aggregates (3/8 mm fraction) substituted

3.4 Effect of the porosity of mixed rolled (uncrushed) and crushed gravels on the mechanical strength

Fig. 14 show the relationship between porosity of mixed rolled and crushed gravels and compressive strength of concrete studied. It shows that the increase of porosity of mixed rolled and crushed gravels influences considerably the mechanical strength of concrete tested. In general, an increase in porosity of binary gravel (mixed rolled and crushed coarse aggregates) results in a decrease in the compressive strength of concrete. Porosity and texture of coarse aggregate have an important effect on workability of fresh concrete and have an effect on mechanical strength of hardened concrete. In fact, the effects of shape and texture of coarse aggregate are much more important than the effects of concrete characteristics. Porosity of binary gravel also effects the mechanical strength and water absorption of concrete, and it will affecting the behavior of both freshly mixed and hardened concrete. The mechanical strength of concrete also may depend on the porosity, water absorption, and pore structure of the coarse aggregates. From the result of porosity of binary gravel, it can be concluded that the sample incorporation with different percentage rolled gravel replacement has lower percentage of porosity of the binary gravel mixtures ($M_{8/32/60}$, $M_{16/24/60}$, $M_{20/20/60}$, $M_{24/16/60}$ and $M_{40/0/60}$) compared with the control mixture ($M_{0/40/60}$). The porosity of binary rolled and crushed gravel decreased with an increase in the replacement of 8%, 16%, 20%, 24% and 40% of 3/8 mm fraction rolled gravel. This is due to the lower volume of voids inside the binary gravel. Similar finding was also reported by other investigations.

Fig. 15 shows a photograph of the concrete section cut. This photo image shows clearly the good continuity of granular rearrangement of rolled and crushed coarse aggregates associated with cement matrix/aggregate interface of concrete ($M_{40/0/60}$) at 28 days.

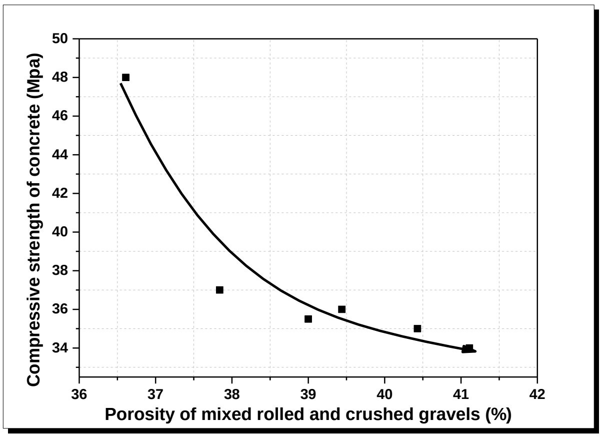

Figure 14. Variation of compressive strength of concrete at 28 days as a function of the porosity of mixed rolled and crushed gravels

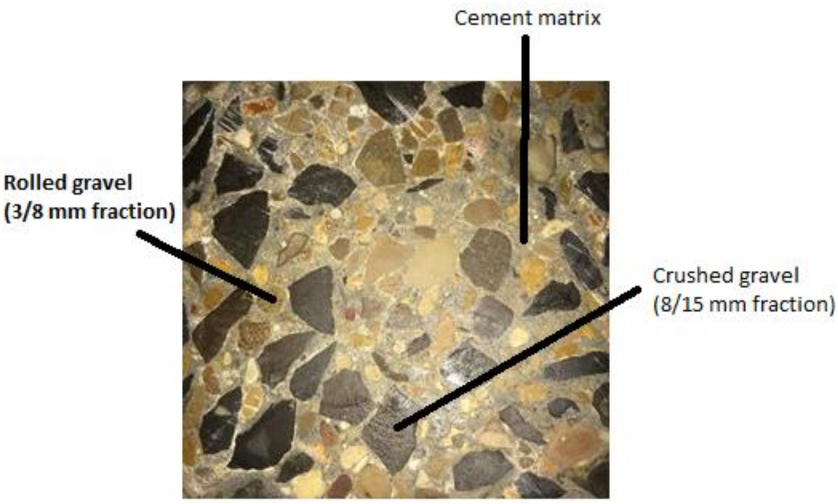

Figure 15. Photo image of concrete at 28 days

4. CONCLUSIONS

The results obtained specify in a clear way that the incorporation of 3/8 mm fraction rolled gravel (8%, 16%, 20%, 24% and 40%) in the crushed gravel improves the compressive strength of the concretes tested to base of the binary gravel mixtures ($M_{8/32/60}$, $M_{16/24/60}$, $M_{20/20/60}$, $M_{24/16/60}$ and $M_{40/0/60}$).

The improvement of the mechanical strength is due to the correction of the physical properties (improved grading, low porosity, high compactness, etc....) of the mortar containing binary gravel for the mixtures ($M_{8/32/60}$, $M_{16/24/60}$, $M_{20/20/60}$, $M_{24/16/60}$ and $M_{40/0/60}$) for the compressive strength.

This study shows the importance of this method to made concrete with binary gravel (natural river rolled gravel and manufactured crushed gravel) in order to correct the physical properties of coarse aggregates. Using a mixture of rolled and crushed gravels in various proportions, allows to obtain a high strength concrete.

The main objective of this experimental work is to investigate the possibility of using local materials (natural river rolled gravel and manufactured crushed gravel) as coarse aggregate in concrete mixtures. It aims at the study of the effect of use of 3/8 mm fraction rolled gravel as replacement of 3/8 mm fraction crushed gravel in various percentages (0%, 8%, 16%, 20%, 24% and 40%) on the physico-mechanical properties of concrete made with binary natural coarse aggregates (RG and CG). Starting from the test results, it can be concluded:

- Adding 3/8 mm fraction rolled gravel (RG) improves the physical properties of binary gravel (grading, low porosity, high compactness, etc …);
- It also improves its mechanical strength (compressive strength);

The best values of mechanical strength were obtained by using an optimum content of 3/8 mm fraction rolled gravel which were about 40% of 3/8 mm fraction rolled gravel and 60% of 8/15 mm fraction crushed gravel. It could be noted, finally, that it is possible to formulate concrete with binary gravel having good physico-mechanical properties by using rolled coarse aggregates. The rate of the strength gain increased as the percentage of rolled gravel replacement increase more than 8 percent in concrete. The test results indicated that rheological and mechanical properties of concrete would be better with rolled gravel (RG) replacing crushed gravel (CG). The rolled (uncrushed) gravel may be used as a substitute to crushed gravel. The natural river rolled gravel found to have good gradation and nice finish which is lacking in manufactured crushed gravel and this has been resulted in good cohesive cement concrete. From the laboratory test of compressive strength determination it was explored that concrete mixture made with 40% of 3/8 mm fraction uncrushed (rolled) coarse aggregates and 60% of 8/15 mm fraction crushed coarse aggregates ($M_{40/0/60}$) provide more strength (29% at 28 days) compared with the control mixture ($M_{0/40/60}$).

From the laboratory study, it was found that the rolled gravel (uncrushed coarse aggregates) need lower w/c ratio than crushed gravel (crushed coarse aggregates) and rolled gravel (uncrushed coarse aggregates) cater higher strength in concrete made with binary gravel (rolled and crushed gravels). Again rolled (uncrushed) coarse aggregates are cheaper than crushed coarse aggregates in Algeria. So from the study, it can be concluded that the use of uncrushed coarse aggregates (rolled gravel) are appropriate in concrete mixture for better performance in terms of strength and economy. The concrete with binary gravel (natural river rolled gravel and manufactured crushed gravel) can be recommended for construction work.

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