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Performance study of eco-concrete based on waste demolition as recycled aggregates

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Abstract: Aggregates are considered as essential constituents in the composition of the ordinary concrete or special concretes. The use of recycled aggregates is of great interest from the economic and environmental point of view. This study concerns the use of aggregates issued from the waste of crushing of the old concrete as a substitution for natural aggregates. An experimental program plan includes the study of on the behavior of recycled aggregate concretes (RAC) at replacement of 0 %, 30 %, 50 %, 70 % and 100 % of recycled aggregates respectively.

The objective of the present research work is to study the substitution effect of recycled aggregates (RA) on the physical and mechanical characteristics of a local recycled concrete. The non-destructive test methods NDT (Rebound hammer and ultrasonic velocity) were adopted to assess the mechanical response. The correlation of these tests had been considered for the different properties of tests to see wither; they are reliable to characterize a local recycled concrete, in this particular case of study.

The results obtained showed that that there is a negative impact of replacement ratio of recycled aggregate on the physical and mechanical properties mainly higher air content, lower density, greater absorption and decrease in strength in comparison with reference crushed aggregate concrete (CAC). Further, low correlation coefficients were registered to predict the due compressive strength in this case regarding the effect of aggregate type..

Keywords: Recycled aggregate concrete; mechanical and physical properties; the NDT methods; correlations.

Introduction

Concrete is the most widely used construction materials throughout the world, that is why the consumption of aggregate, whitish constitute approximately 70% of the volume of a concrete, is rapidly increasing. During the last decades, the sector of construction knew a growing trend in construction and demolition (CD) activities and result a huge waste producer [1,2],

Further to accidental causes for example earthquakes, exploitation and ageing of the

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structures. The direct consequence, thousands of the tons of the waste of demolition of construction (DC), (the glass, the wood, the steel, the brick and the concrete etc.) was generated. The management of the collected debris and waste causes real problems at the environmental level [3,4]

Some authors [5-11] have concluded that the use of recycled aggregate from concrete demolition has a remarkable influence on concrete in the fresh state hardened state. For mechanical properties, Xiao et al studied the Variability of stress-strain relationship for recycled aggregate concrete and reported that the recycled aggregate concrete presented a similar failure pattern with that of natural aggregate concrete [5]. However, in self-competing concrete reductions in compressive strength of 13% are with 40% replacement of aggregate by recycled aggregate reported by Aslani et all[6]. Concerning Durability properties Porosity of concrete mixes with recycled aggregate increases with the level of substitution [12]. The use Recycled Aggregate in reinforced Concrete accelerates the steel corrosion process because the electrical resistivity decreases and the porosity increases [13]. This reduction is mechanical and durability properties mainly due to the old adhered mortar which decreases the mechanical behaviour of concrete compared to the conventional concrete. In the other hand recycled aggregates present higher porosity which leads significant water absorption during mixing [14]

In terms of the fresh-state properties Yong & Teo showed that this water absorption leads to a loss workability. pre-saturated of recycled aggregate is recommended by the authors in their study [15-17]to improve workability and the mechanical strength. Multiple recycling of concrete present also a very important research topic brings the attention of authors [18].

The partial or the total substitution of these aggregates instead of natural one could be the right economic solution for the formulation of a concrete meeting the requirements of quality and durability. Thus, at present the subject of great interest for the specialists of construction [19].

in This study we use the recycled aggregates resulting from former old concrete specimens coming from construction site projects. The percentages adopted in this experimental program for recycled aggregate replacement varies from 0, 30, 50, 70 and 100 %. The objective of the present work is the preparation of recycled aggregate concrete having the performances similar to a conventional concrete. The behaviour of the new product of concrete incorporating a percentage going of 0 until 100 % of collected aggregates was the object of this research project. In addition, the NDT test methods were used to assess the compressive strength of the due concrete. A correlation study to predict the compressive strength in this particular case was considered.

Experimental program

Materials

The studied concrete is a concrete based on recycled aggregates and a cement type CPJ CEM II/B 42.5 MPa delivered from Lafarge cement plant of Hammam Dalaa (wilaya of M'Sila, 250 km East of Algiers). Aggregates were crushed at a maximal size of 16 mm using hand hammer in the laboratory of the department of civil engineering. The source of these recycled aggregates is an ancient local concrete tested specimen (25-30 MPa strength). The siliceous sand of dune (0/5) was used for this program experimental program constitute the fine granular fraction; with a fineness modulus Mf of 1.94 and the sand equivalent modulus ESV equal to 65%. The table 1 presents the physical and mechanical properties of the aggregates used in this experimental study.

Table 1: Physical and mechanical properties of aggregates.

	Bulk density γ Kg/m³	Specific density ϱ Kg/m³	Los Angeles L_A (%)	Adsorption A (%)
0/5	1558	2514	--	17.65
3/8 CA*	1338	2593	21	02.25
8/15 CA*	1419	2564	20.74	01.42
3/8 RA**	1148	2369	--	09.65
8/15 RA**	1239	2486	29.90	06.50

* CA, crushed aggregate.

** RA, recycled aggregate.

Mixtures and tests

The formulations of studied concretes were established by the method of the absolute volumes, the spending (expenses) in materials is presented in the table 2.

Table 2: Composition of concrete mixtures (Kg/m³).

Mixe	Cement	Water (l)	W/C	Sand	CA 3/8	CA 8/15	RA 3/8	RA 8/15
CAC	405	233	0.57	447	482	723	/	/
RAC_{30}		236	0.58		338	506	145	217
RAC_{50}		238	0.59		241	362	241	362
RAC_{70}		247	0.61		145	217	338	506
RAC_{100}		278	0.69		/	/	482	723

Results and Discussion

In the following, we proceed to the analysis, the interpretation and the presentation of the results obtained in this study. The properties such as the density, the air content, water cement ration W/C, the absorption and the compressive-tensile strengths were studied.

3.1. Fresh state

Table 3: Properties of different concrete types at fresh state (recycled, crushed).

Type of concrete	ϱ (kg/m³)	W/C (effective)	Air content (%)
CAC	2399	0.57	1.95
RAC_{30}	2359	0.58	2.05
RAC_{50}	2338	0.59	2.60
RAC_{70}	2315	0.61	2.60
RAC_{100}	2267	0.69	3.20

3.1.1. Bulk density

Figure 1, shows that the density of recycled aggregate concrete is lower in comparison with the reference concrete (CAC) for all replacements 30, 50, 70 and 100 % replacement. The registered maximal value is obtained with CAC; this concrete gives a higher density value compared with all RAC mixtures, 2400 Kg/m³.

The reduction of the concrete density for RAC_{100} at 100 % replacement reached approximately 5 % compared to the witness concrete CAC. This decrease could be attributed to the nature of the aggregates; in particular the recycled aggregates with a higher porosity and upper air content, in comparison with the crushed aggregates being dense and compact.

According to previous studies the density of RAC at the fresh state is significantly lighter, 2120 Kg/m³ compared with a concrete with natural aggregates (CAC), 2400 Kg/m³ [20-21]

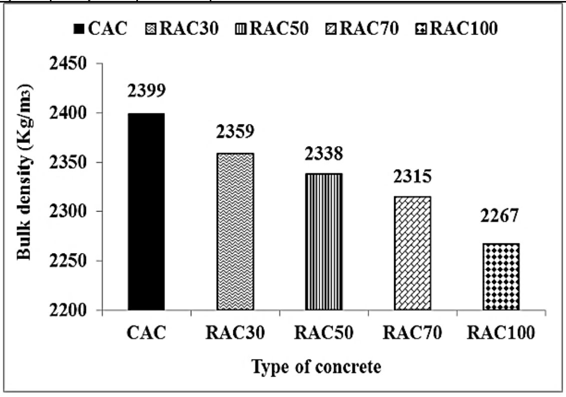

Fig 1. Density for the different concrete types.

3.1.2. Air content

The use of recycled aggregates in the concrete leads to an increase of the air content, as presented in figure2, which shows the variation of the air content in the different mixtures according to the various percentages of recycled aggregate.

The increase of the air content of RAC at 100 replacements is greater about 4 % compared to CAC. This type of concrete based on RA is less dense and with higher porosity with regard to the other tested mixtures at partial substitution, 2.05, 2.60, 2.60 and 3.20, respectively.

According to antecedent research studies the air content of the recycled concrete at the fresh state is slightly superior (4 – 5.5 %) relatively to the concrete based on natural aggregate [21]. This is in accordance with the obtained results in the present study.

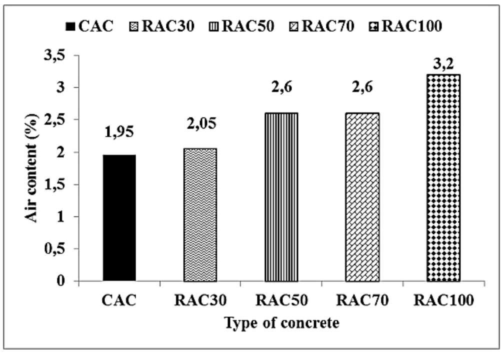

Fig 2. Air content for the different types of concrete.

3.1.3. W/C ratio

The use of the recycled aggregates in the concrete matrix leads to an increase of the quantity of mixing water need of batches as shown in figures 3. The variation of the ratio (W/C) according to the recycled aggregates percentages is much appreciated. The difference is around 18 % between a recycled concrete RAC100 and that of CAC with natural aggregate the water ratio is equal to 0.57 and 0.69 respectively.

It is the effect of recycled aggregates type mixtures with an important porosity, and higher absorption that needs much more water demand.

According previous research studies, for the similar workability as the ordinary concrete, the quantity of water added for the recycled case of the aggregates is approximately of the order of 3-5 % higher, thus the W/C ratio increases as noticed for all RAC mixtures and mainly at 100 % substitution as concluded in the present work [22].

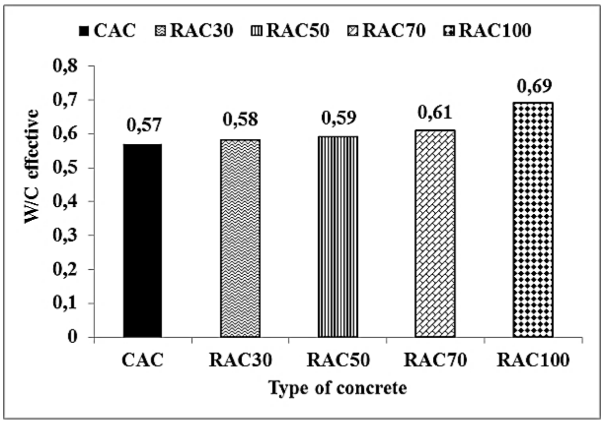

Fig 3. W/C ratio as a function of the percentage of replacement of recycled aggregate.

Hard state

Density

From figure 4, it can be noted that the density of recycled aggregate concretes at the age of 28 days is lower in comparison with the witness concrete; the registered optimal value is obtained for this type (around 2400 Km/m³).

The reduction of the density of RAC mixtures at 100 % (RAC) of the order of 6 % compared to CAC ; this is due mainly to the nature of recycled with higher porosity and lower density.

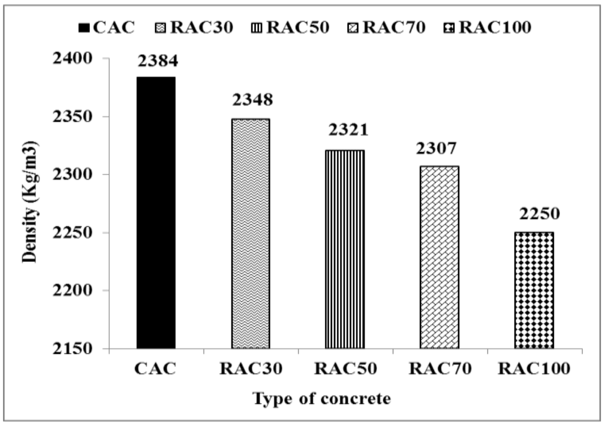

Fig 4. Density for the different types of concrete at 28 days of age.

1.1.1. Absorption rate

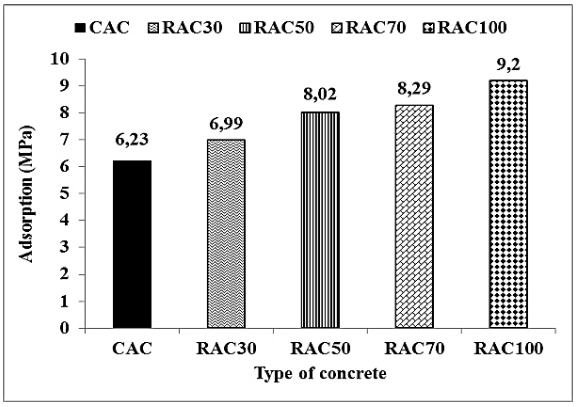

Fig 5. Absorption rate for the different types of concretes.

From figure 5, it can be observed that the rate of absorption of water increases according to the percentage of the recycled aggregates. The reference concrete gives the lowest rate of absorption of 6.23 % in comparison with the other types of RAC mixtures. Further, it can be noticed that the recycled aggregates affects negatively the rate of absorption for RAC mixes, because without any replacement (0 %) for CAC the rate of absorption has a lower value compared to RAC at 100 % recycled aggregates substitution 6.23 % and 9.20 %, respectively.

Thus the recycled aggregates increase the rate of absorption up to 32 %, resulting in a concrete matrix; permeable, less resistant for aggressive agents and even more porous with low compactness; by the fact that there are micro cracks in the matrix of the concrete.

Various studies on the absorption of water of the recycled concrete reported a slightly superior rate for RAC mixes at total replacement (2 - 12 %) compared with a concrete based on natural aggregate [23].

Compressive strength

Generally, the values obtained for the compressive strength (Rc) are lower for concretes with recycled aggregates in comparison with the reference concrete.

It can be noted from figure 6, that the decrease of the compressive strength of RAC (100 % replacement) is about 19 % compared to CAC.

The concrete with 30 % recycled aggregates RAC_{30} gives a compressive strength (Rc) at 28 days nearly the same as the normal concrete with values (30.12 and 32.23 MPa), respectively.

It is marked that the substitution of natural aggregate by recycled aggregate has a great effect on the development of the resistance (Rc). This can be attributed to the nature of the aggregates, in particular the recycled aggregates which have a high porosity, an important air content and less compactness in comparison with the crushed aggregates, which is dense and compact.

Previous studies carried out on the compressive strength for concrete with recycled aggregate is reported to be 10 to 30 % lower compared with a reference concrete [24].

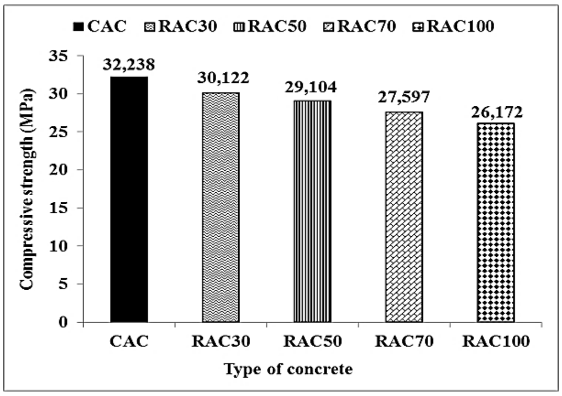

Fig 6. Compressive strength as a function of percentage of recycled aggregate replacement at 28 days.

Tensile strength (fending test)

Generally, the tensile strength by fending (Rt) is lower for a concrete with 30 % replacement of recycled aggregates (RAC_{30}) in comparison with the reference concrete, however for the other misters the maximal value was obtained for RAC_{100} at 100 % replacement.

This give a slight increase of the resistance about 2 % compared to the reference concrete CAC.

Studies made on the subject reported that the (Rt) of some recycled concrete is slightly superior (15 to 20 %) compared with a concrete with natural aggregate 100 % [22]. Other research study, where we determined the direct tensile strength of the concrete, it was noticed that this difference is about 10 % for RCA when compared to conventional concrete [25].

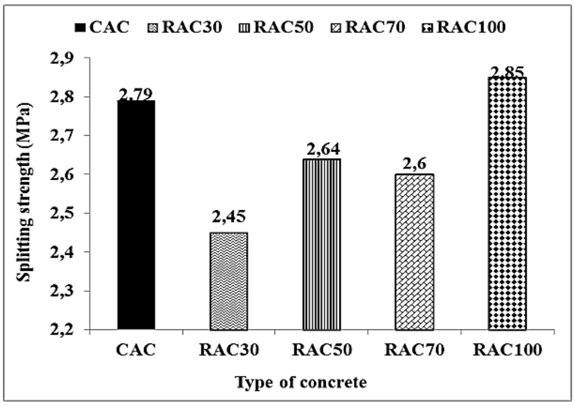

Fig 7. Tensile strength (Rt) for different types concretes at 28 days of age.

1.1.2. Dynamic elastic Modulus

According to the figure 8, it can be noticed, that the module of elasticity of RAC mixtures is lower in comparison with the normal concrete. The maximal value is obtained with CAC mix reaching 29134 MPa when the lowest is for 100 % replacement 23492 MPa.

The reduction is about 20 % with regard to the normal concrete. This RAC concrete is less dense and more porous compared to the other types of tested concretes.

According to previous studies made on the module of elasticity of the recycled concrete is slightly superior (15 in 25 %) compared with a concrete with natural aggregate [4].

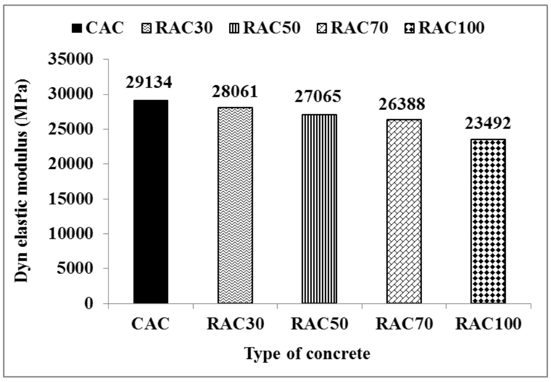

Fig 8. Elastic modulus as a faction of concrete types at 28 days

Correlations of mechanical properties

3.3.1. Compressive strength (Rc) and ultrasonic velocity (V)

The figure 9 shows the correlation between the compressive strength (Rc) and ultrasonic velocity (V). A wide dispersal was noticed with a coefficient of correlation R^2 equal to 0.5941.

The correlation is linear and it's in the form:

$$Rc=a(V)+b \quad (1)$$

Previous researches on concretes based on CAC [26,27] proposed a linear correlation between the mechanical strength and ultrasonic velocity.

The correlation proposed in the present study:

$$Rc = 21.024\,(V) - 55.433 \quad (2)$$

$$R^2 = 0.5941$$

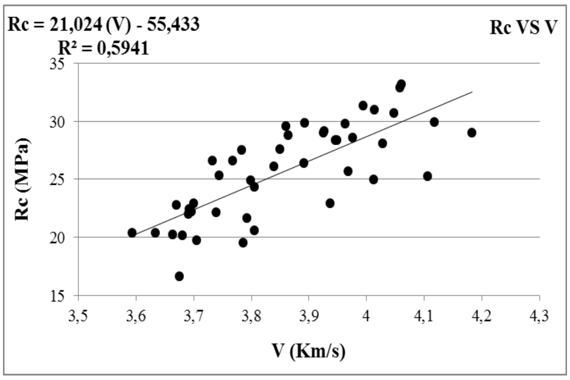

Fig 9. Correlation between compressive strength (Rc) and the ultrasonic velocity (V).

3.3.2. Correlation between compressive strength (Rc) and Rebound hammer number (RH)

The figure 10 presents the relation between the (Rc) and the rebound hammer number (RH).

A wide dispersion was also noticed with a coefficient of very low correlation the obtained correlation is of linear type.

The research works [27-29] led on the correlation between the compressive and the rebound hammer number (RH) presented a relation of linear type, the European standard EN 13791 give an expression of this relation of the form ;

$$Rc = -34.5 + 1.73(RH) \text{ with: } 24 \leq RH \leq 50 \quad (3)$$

The correlation proposed from the present study is:

$$Rc=0.3591(RH)+16.103 \quad (4)$$

$$R^2 = 0.0884$$

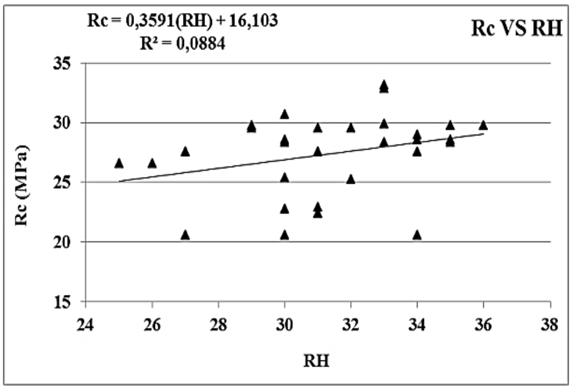

Fig 10. Correlation of compressive strength (Rc) and rebound hammer number (RH).

3.3.3. Combined method, (Rc), (V) and (RH)

Figure11, shows the correlation between compressive strength (Rc), ultrasonic velocity (V) and rebound hammer number (RH). Several researchers proved that the composition of the concrete, the techniques of the implementation and the petrorological and shape properties of the aggregates influence significantly non-destructive test results, to limit the errors and for the reliability of these tests for better assessment of the compressive strength, we combine two or several methods [26].

The dispersal of the values is wide, the coefficient of correlation R^2equal to 0.4941, previous research works propose polynomial correlations [26].as well as correlation linear form;

$$Rc = a(V) + b\,(RH) + c \quad (5)$$

The correlation proposed from the present study has the form;

$$Rc = 15.46\,(V) + 0.02326\,(RH) - 33.44 \quad (6)$$

$$R^2 = 0.4941$$

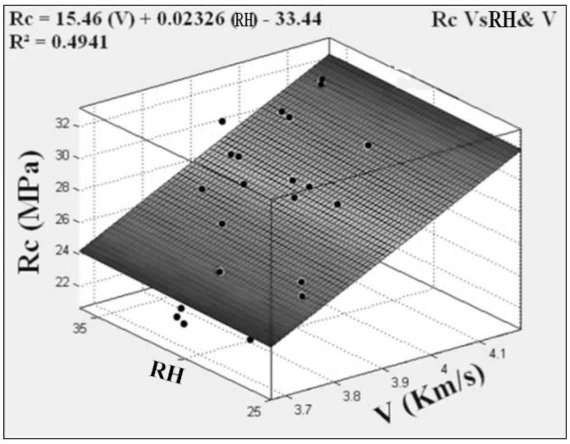

Fig11. Correlation between compressive strength (Rc), ultrasonic velocity (V) and rebound hammer number (RH)

3.3.4. Correlation between (Rc) and the elastic modulus (Ed)

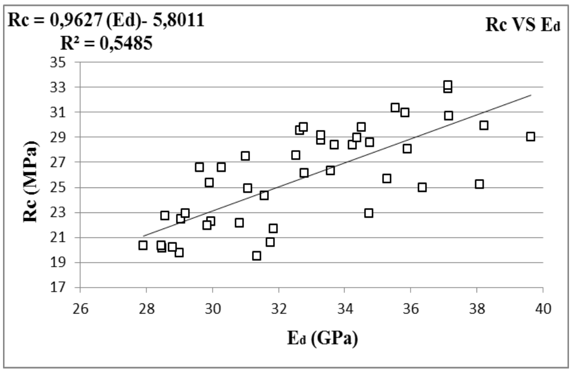

Fig 12. Correlation between compressive strength (Rc) and the dynamic elastic modulus (Ed).

A proportional relation between the elastic dynamic modulus and the mechanical resistance, a linear type was noticed, the coefficient of correlation is around 0.5485.

The correlation proposed from the present study is;

$$Rc = 0.9627\,(Ed) - 5.08011 \quad (7)$$

$$R^2 = 0.5485$$

3.4 Correlations of physical properties

3.4.1. Correlation between (Rc) and (γ)

According to figure 13 a low correlation was noticed between (Rc) and the density (γ) of the concrete. It is justified by the low coefficient of correlation (R^2 = 0.2958), the relation between (Rc) and (γ).

The correlation proposed from the experimental results is of linear type;

$$Rc = 45.044\,(\gamma) - 78.52 \quad (8)$$

$$R^2 = 0.2958$$

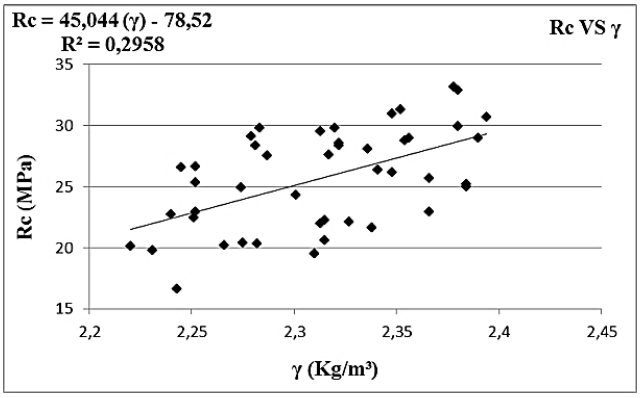

Fig 13. Correlation between the compressive strength and the density.

Conclusions

According to the results of this study on recycled concretes the following conclusions can be drawn:

- The increase of substitution ratio of the recycled aggregates recycled fraction in concretes causes a considerable decrease of the density at the fresh and hardened state. Also, it increases the air content and the rate of absorption. As a consequence, this influences negatively the compressive strength (Rc) of recycled concretes compared to the normal concrete.
- The 100% replacement requires more additional mixing water demand of 16 % with regard to the reference concrete at 0 %

substitution.

The majority of the correlations are low; hence the results obtained let us to suggest that concretes with the recycled aggregates require a particular study. This differs from common correlations known for that of conventional one. Bearing in mind these specific characteristics density, rate of absorption and the substitution percentage for this study case.

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