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"Gheorghe Asachi" Technical University of Iasi, Romania

MARBLE FILLERS EFFECT ON THE MECHANICAL PERFORMANCE OF A RECYCLED AGGREGATE CONCRETE

Larbi Belagraa[1,2*], **Miloud Beddar**[2], **Abderrazak Bouzid**[1]

[1] *Laboratory of Materials and Electronic Systems [LMSE], Faculty of Sciences and Technology,*
Bordj Bou Arreridj University, El-annasser (34030), Algeria
[2] *Department of Civil Engineering, Laboratory of Materials and Mechanics of Structures, University of M'sila, Algeria*

Abstract

The aim of the present work is to investigate the effect of marble waste fillers incorporation on the mechanical properties of Recycled Aggregate Concrete (RAC). The RAC studied mixes were 0, 5, 8 and 10% (by weight of cement) of marble fillers respectively. Direct tests of compressive and flexural strength and non-destructive testing (NDT) (rebound hammer, ultrasonic) were performed. The optimal content of 5% marble fillers showed an improvement for both used test methods (compression, flexion and NDT). The increase of RAC compressive strength was about 15%, whereas the flexural strength reached 10% increase compared to control natural crushed aggregate concrete (CAC).

Key words: marble fillers, mechanical strength, natural aggregate, non-destructive testing (NDT), recycled aggregate concrete

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1. Introduction

The needs of the construction sector are still increasing for concrete. The shortage of the natural resources and the preservation of the environment could be a major challenge to be considered all over the world. The serious problem of waste disposal associated to the negative impact caused by Construction and Demolition (C&D) operation, (Robinson et al., 2004; Simion et al., 2013; Topcu and Sengel, 2004) creates a severe ecological and environment hazard (Chandra, 2004, 2005; Vasilescu et al., 2016). These factors have prompted the researchers in the civil engineering domain to focus their efforts on the demolition waste management, in order to conserve natural resources and to preserve the environment.

Recycling aggregate from construction and demolition(C&D) waste presents a major interest for users and researchers of concrete since this constituent can occupies more than 70% of concrete volume. Recycling of demolition waste was first carried out after the Second World War in Germany (Calvo et al., 2015; Khalaf and DeVenny, 2004). One of the ways to solve this ecological problem is the waste recycling in the concrete matrix. This new concrete should fulfill the requirements of lower cost and good quality in regards to the adequate resistance and durability. It is reported that the free water demand of a recycled aggregate (RA) mix is approximately 5% higher compared to a conventional concrete in order to achieve the same workability (Corinaldesi, 2010; Kikuchi et al., 1988; Limbachiya et al., 2012).

Some researchers suggest a limit of 30% of recycled aggregate in order to maintain 5% of absorption capacity of aggregate for structural concrete (Mukai and Koizumi, 1979). Furthermore the concretes using a recycled aggregate show reduced workability due to its higher absorption capacity. In general, the absorption capacity of recycled aggregate affects the workability of the mix (Nealen and Schenk, 1998). The shape and texture have also their effects on the workability of RAC

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[*] Author to whom all correspondence should be addressed: e-mail: lbelagraa@yahoo.fr; Phone +213 660 463 446 ; Fax +213 35 681454

depending on the type of crusher used (Rashwan and AbouRizk, 1997). So appropriate adjustment depending on the source and properties of the RA should be made to obtain the suitable water-cement ratio, required workability and the desired strength of RAC (PrEN 13242, 2002; Sarja, 1999). According to Topcu (1995) and Katz (2003), the density of RAC is lighter than normal concrete, regardless of the type of cement. This lower density is attributed to the specific gravity of the aggregate depending on the quality of the based used concrete.

In general, it is reported that density and absorption capacity of RA are affected by the adhered mortar. These properties must be known before the use of the recycled aggregate in concrete production in order to control properties of fresh and hardened concrete (de Juan and Gutiérrez, 2009; Hansen, 1992).

Regarding the compressive strength, RAC shows lower values compared to natural aggregate concrete (Khaldoun, 2007). However, the extent of reduction is related to the parameters such as the type of concrete used for making the recycled aggregate (high, medium or low strength), replacement ratio, water cement ratio and the moisture conditions of the recycled aggregate; the moisture content in RA induces more porosity, resulting in a decrease of compressive strength. Altogether previous studies have shown that employing supplementary cement blend admixture, such as silica fume helps improving the properties of RAC (Ajdukiewicz and Kliszczewicz, 2002; Banfil et al., 1991). Rao et al. (2007) reported that the strength of RAC and the control concrete are comparable at 100% replacement provided that W/C is higher than 0.55. In case of RAC, it will be necessary to add more cement in concrete with 100% of RA in order to achieve the same workability as CAC. Nevertheless, as the water cement ratio is reduced to 0.40 the strength of RAC was only about 75% of the reference concrete. According to this study the flexural strength presented a reduction in the range of 15 to 20% compared to concrete using crushed aggregate.

In the last few years, a particular interest is given for the use of marble fillers (MF) in the concrete matrix as marble manufacturing industry produces considerably amount of waste. Self-compacting concrete (SCC) technology has a great potential for this type of solid waste materials (Akbulut and Gurer, 2007; Alyamac and Ince, 2009; Uysal and Sumer, 2011). Topcu et al. (2009) reported that a positive effect was noticed of different marble powder contents up to 200 kg/m^3, which led to acceptable fresh properties of SCC in terms of workability. This has also improved hardened concrete properties. But dosages just above this amount cited resulted in a decrease of mechanical response.

It is revealed that SCC mixes containing marble fillers (MF) combined with 2 % super-plastizier pointed out a higher strength at a given water/cement ratio than the conventional concrete (Alyamac and Ince, 2009). Furthermore, marble powder proved to be very effective; in recent work on the subject of marble powder incorporation in SCC conducted by Belaidi et al. (2012), these mineral additions are reported to improve some properties of fresh concrete mainly the workability. However, the results indicated a decreased strength with the increase in natural pozzolana and marble dust content.

In this frame of ideas, the present work examines the effect of marble fillers incorporation on the properties of RAC. The study emphasizes that these waste materials can be successfully and economically utilized as additional inert filler in RAC formulation within similar performances compared to a conventional concrete.

2. Experimental work

2.1. Materials

The cement used was of type CPJ CEMII/A 42.5 delivered by the Algerian Cement Company [ACC] and widely used in the construction sector in Algeria. Blaine fineness of this cement is about 3910 g/cm^2. The fillers of marble are collected from local marble factories. It is a white powder having a density of 2.81; the specific area is around 3850 g/cm^2. The physical properties and chemical analysis of the cement and fillers are listed in Table 1.

Table 1. Physical and chemical compositions of cement and marble fillers

	Cement	***Fillers***
Specific density	3.08	2.81
Blaine fineness, cm^2/g	3910	3850
Loss of ignition, %	0.85	41.76
SiO_2, %	21.35	1.47
Al_2O_3, %	5.02	0.35
CaO, %	65.61	55.3
MgO, %	2.28	0.01
SO_3, %	0.79	0.03
Na_2O, %	0.10	0.12
K_2O, %	0.71	0.04
Fe_2O_3, %	3.61	0.147

The sand used in this study was a clean siliceous and fine sand of fraction 0/5 mm from Boussaada region (300 km southern of Algiers). Its characteristics are reported in Table 2. The specific gravity and fineness modulus of sand passing through 5 mm sieve are 2.56 and 2.03, respectively. Crushed limestone coarse aggregates fraction 8/16 passing sieve 19 mm were used at a 40 % proportion of the total coarse aggregate volume. Further to the 16/25 fraction passing the sieve 37.5 mm at the proportion of 60 % for control concrete mix. The same fractions and proportion were kept for RAC mixes prepared in this experimental investigation. The recycled aggregates were prepared from old pieces of crushed tested specimens (specimens were taken from conventional concrete 25÷30 MPa of compressive strength and having more than 28 days of age). In the laboratory of civil engineering a steel hammer was used in the due operation of concrete crushing and the main properties are reported in Table 2.

2.2. Specimens

The concrete mix proportions used were for a concrete grade 350 with a design target-strength at 28 days of 35 MPa. The concrete mixes have been prepared and the different constituents determined according to the method of absolute volume (Neville, 1986). The following percentages of fillers 0, 5, 8, and 10 % were chosen. A total of sixty cubes specimens (100x100x100 mm^3) were cast. For each batch a set of twelve specimens as for recycled aggregate fraction of the size of 8/16 and 16/25 were used at a proportion of 40% and 60%, respectively. RAC specimens were cast at different percentages of fillers.

The mix of CAC of 12 specimens based on CA was prepared with similar aggregate proportion at size (8/16 and 16/25) and without fillers as control reference mix. Tests of the specimens at the ages of 7, 14, 21 and 28 days using a compressive testing machine were carried out. Non- destructive methods were used to evaluate the mechanical response of concrete. More, the program includes an additional set of prismatic specimens (100x100x400mm^3) per batch for all mixes for flexural strength assessment of either, RAC and control concrete; these were tested at the age of 28 days. The utilized proportions of CAC and RAC, as well as the fresh properties are presented in Table 3.

2.3. Testing

The slump test method was used to assess the workability for both control and recycled concrete mixes. A workability of about 50 mm was maintained for all mixes during the experimental program, so that the effective water cement ratio could be determined for all batches.

Compression tests were carried out on 100 mm side cubic specimens. The ultimate compression load for each concrete cube was recorded at 7, 14, 21 and 28 days age. Before preceding the testing operation, the specimens were air dried and cleaned with a cloth in the laboratory to be weighed in order to assess the density of concrete. For Rebound hammer test, the specimens were placed in the center of the hydraulic machine press; a continuous load was applied and maintained within the range of 10 to 20 KN. The rebound hammer test was carried out on five different points spaced at about 2.54 cm intervals on both opposite faces of the cubic specimens and the average result of ten reading recorded was taken. The rebound hammer number S is evaluated as Eq. (1):

$$S= {}_{i=1}\sum^{n} {}_{Si/N} \qquad (1)$$

with: N - number of tests carried out on both faces of the cube; Si - the recorded value of rebound hammer.

Regarding the ultrasonic method, the pulse velocity test was carried out on the two opposite faces of the specimens using direct transmission. The transit time t in µs was recorded and the velocity V measured consequently. The ultrasonic strength is given as below (Eq. 2):

$$R_u=K.\rho.V^4/g \text{ (bars)} \qquad (2)$$

where K: is the coefficient of calibration, ρ: the concrete density expressed in (kg/m^3), g: the earth gravity (m/s^2) and V: the velocity expressed in (km/s).

2.3.1. Aggregates tests

The aggregates were characterized based on the following tests (and standards):

Table 2. Properties of the sand, natural crushed aggregates (CA) and recycled aggregates (RA) used

Materials	***Specific weight(ρ_s)(Kg/l)***	***Density (ρ) (Kg/l)***	***Compactness (Solid content)(C)*(%)***	***Porosity (P)**(%)***	***Sand modulus(E_s) (%)***
Sand	2.56	1.60/1.70	64.42/70.76	36.58/29.24	73.40
Crushed agg (CA) 8/16	2.54	1.33	50.97	49.06	------
Crushed agg (CA)16/25	2.57	1.31	51.85	48.16	------
Recycled agg (RA) 8/16	2.40	1.24	48.97	51.03	------
Recycled agg (RA)16/25	2.34	1.12	49.93	50.07	------

*[C =1-P], ** P= $[\mathbf{1}- {}^{\rho}/_{\rho s}]$

Table 3. The concrete mixture proportions and fresh concrete properties

Designated mixture (35-Design strength)	***Effective W/C ratio***	***Constituents, Kg/m^3 (Kg)***						***Plastic concrete Slump (mm)***
		Water	***Fine Aggregates***	***Coarse Aggregates***		***Fillers***	***Cement***	
			Sand 0/5	***16/25 (60%)***	***8/16 (40%)***			
CAC$_0$*	0.59	204	560	697	465	0	346	50
RAC$_0$*	0.64	208	560	690	465	0	346	50
RAC$_5$*	0.63	207	560	690	465	17	329	50
RAC$_8$*	0.71	226	560	697	465	28	319	50
RAC$_{10}$*	0.70	218	560	697	465	35	312	50

**The indice indicating the MF introduced ratio*

- Particle size distribution - NA EN 933-1 (2000) and NA EN 933-2 (1999);
- Density and water absorption - NA EN 1097-6 (2003);
- Density and voids ratio - NA EN 1097-3 (2005);
- Determination of strength, Method of testing cement -NA EN 196-1- part-1- (2003).

2.3.2. Fresh concrete tests

Concrete in its fresh state was subjected to the following tests (and standards):

- Density - NA EN 12350-6 (2002);
- Slump test (Abrams cone) - NA EN 12350-2 (2009).

2.3.3. Hardened concrete tests

Concrete in its hardened state was subjected to the following tests (and standards):

- Density at 28 days - NA EN 1097-3 (2003);
- Compressive strength at 7, 14, 21 and 28 days - NA EN 12390-3 (2009);
- Splitting tensile strength at 28 days - NA EN 12390-6 (2003);
- Rebound hammer strength at 28 days - NA EN 12398-6 (2003);
- Ultrasonic strength at 28 days - NA EN 13296-6 (2003).

3. Results and discussion

3.1. Density

The density presented in Fig. 1 displays a slight decrease in hardened specimens RAC values compared to crushed concrete aggregate (CAC). This may be related to the recycled aggregate type which is characterized by its higher absorption and porosity compared to natural aggregate. This is more evident for RAC$_8$ and RAC$_{10}$ with dosages of 8, 10% of marble fillers incorporated, respectively.

Katz (2003) noticed and regardless of the type of cement that the air content of RAC is slightly higher (around 4% to 5.5%) in comparison with control concrete CAC. The increase of air content is attributed to the higher porosity of recycled aggregate type. Whereas the concrete density made with natural crushed aggregate is in the range of 2400 kg /m^3, the RAC is lighter; its density is about 2318 kg/m^3. The difference in density values is related to both factors of compacily and water demand variations among mixes. Khatib (2005) reported that at 28 days age of testing; the density of a concrete based on (RA) obtained from old concrete had given an average density of 2320 kg/m^3 compared to control mix with 2427 kg/m^3. Thus, the additional air amount leads to a lower density of RAC.

The air content of the matrix is directly affected by the higher porosity of the RA which is attributed to the residue of mortars adhering to the original aggregate; resulting in a lower density of the RAC. Furthermore, the lower density is the result of specific gravity of the aggregates which is revealed to the type of concrete used for producing the recycled aggregates (Katz, 2003; Khaldoun, 2007; Topcu, 1995).

This is in a good agreement with the results obtained in the present research work for all dosages of fillers with RAC mixes, where the values of the density are 2393 kg/m^3 for crushed aggregate concrete compared to lower results of RAC at 10% fillers addition (2340 kg/m^3).

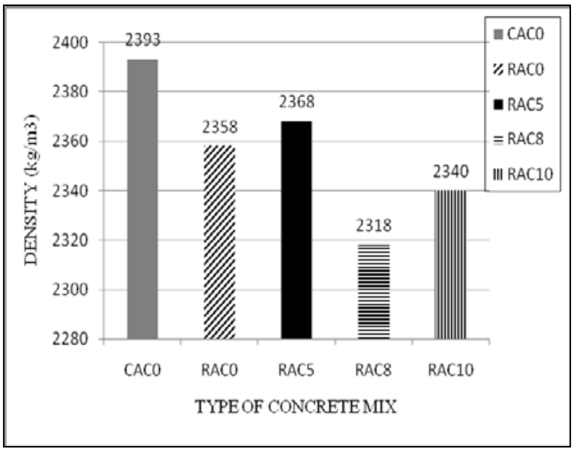

Fig. 1. The density versus type of concrete mix at 28 days for prismatic specimens

3.2. Compressive strength

According to Fig. 2, the behavior of RAC shows the same trend of strength development for all dosages of fillers at 7, 14, 21and 28 days. One can notice that for a dosage of 5% marble fillers incorporated, the recycled concrete gives a better compressive strength compared to normal concrete with crushed stone aggregate CAC. For filler contents over 8%, the recycled concrete showed similar comparative values to ordinary concrete (RAC$_8$=34.76, RAC$_{10}$=30.10, CAC$_0$= 32.25 MPa) at 28 days age.

Thus, the best RAC performance can be achieved with the incorporation of an optimal dosage around 5% with an increase of about 14 % (CAC$_0$ / RAC$_5$, 32.25/36.87 MPa) when compared with CAC (Table 5). This fact is only due to the contribution of the fillers effect, regardless of the W/C ratio which is considered within a slight variation (for CAC$_0$, W/C = 0.59 and for RAC$_5$ W/C = 0.63). Alyamac and Ince (2009) reported that SCC mixes containing marble powder pointed out a higher strength at given water cement ratio than conventional concrete. It is revealed that SCC mixes with MF showed values of strength 25 % higher than the reference concrete. The good compactly is obtained of the concrete matrix when, the marble fillers effect can be advantageous in filling voids; this contributes favorably to a better concrete mechanical performance. However, at the age of 28 days, the higher dosages up to 10% fillers presented a lower compressive strength for the RAC$_{10}$ compared to CAC mixes.

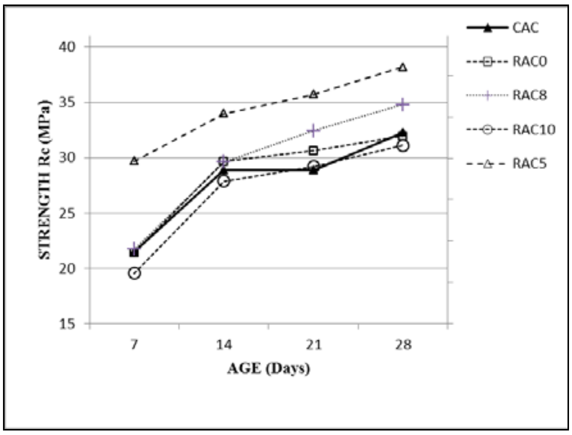

Fig. 2. Compressive strength development R_c for RAC and CAC mixes

The reduction in strength noticed is about 12 %, when RAC_8 showed always similar performance compared to conventional concrete at 7, 14, 21 and 28 days of age. These results are in agreement with previous studies (Belaidi et al., 2012).

3.2.1. Improvement ratio [Ci]

The improving coefficient of strength [Ci] is calculated in order to better assess of the improvement of strength. It is calculated according to the formula below (Eq. 3):

$$[C_i]= R_c(RAC)/R_c(CAC) \qquad (3)$$

where: $R_c(RAC)$ is the strength of recycled concrete at 28 days; $R_c\ (CAC)$ is the strength of control concrete at 28 days.

According to Fig. 3, there is a *[Ci]* increase for the percentage of 5% marble fillers incorporation with $[C_i]$ of 1.14. Also, RAC_8 presented greater value with *[Ci]* of 1.07 (Table 5). One can conclude that the 5% fillers shows the highest improvement (Almayac, 2009); whereas RAC_0 and RAC_{10} mixes show no improvement compared to control concrete (CAC_0). This demonstrates the good resistance of RAC_5 compared to ordinary concrete (*CAC*).

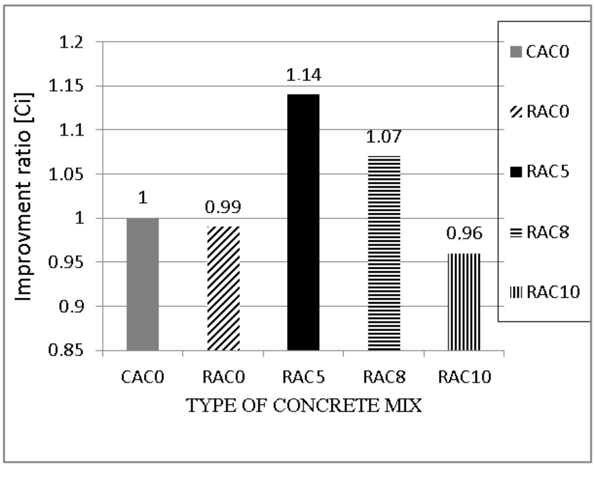

Fig. 3. Improvement ratio [Ci] versus type of concrete mix at 28 days for cubic specimens

3.3. Flexural strength

Fig. 4 shows the flexural strength at 28 days age. Again, it can be noticed that the percentage of 5% marble fillers gives higher strength for RAC mixture in comparison with normal concrete CAC, evaluated at 9.765 MPa and 8.932 MPa respectively, with an increase of about 10%. The recycled concrete with 10 % fillers shows the lowest resistance compared to the other concrete mixes of RAC when compared with control concrete (CAC). The reduction in strength is about 15% when the dosage of fillers is increased to 10% (7.627 MPa, 8.932 MPa) (Table 4). This important reduction could be attributed to the higher effective water demand due to the greater absorption of this type of recycled aggregate and also to the fineness of marble fillers that needs more water in the batching preparation of mixes. This is in accordance with results found by Rao (2005), where a reduction in flexural strength of 15-20% was noticed for RAC compared to reference concrete at 100% replacement. All the mixes are prepared for a fixed workability that implies a controlled W/C ratio.

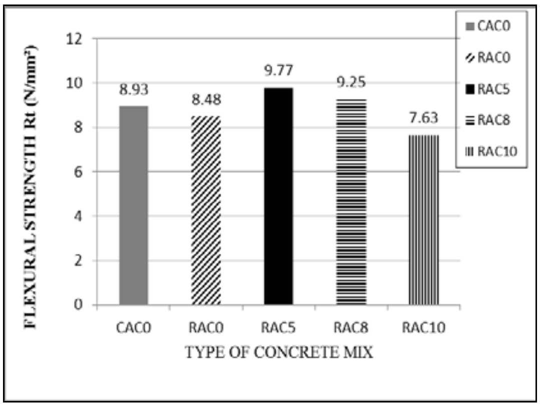

Fig. 4. Flexural strength R_t versus type of concrete mix at 28 days

In general the RAC mixes behave in such a manner to give slightly reduced flexural strength less than 10% compared to reference concrete at 28 days. Studies have also shown that the addition of cementitious admixtures such as silica fume helps to improve of the RAC properties compared to control concrete (Ajdukiewicz and Kliszczewicz, 2002).

3.4. Rebound hammer results

This indirect test is performed in order to get complementary information about the concrete mechanical strength. Fig. 5 illustrates that strength development is similar for all concrete mixes regardless the type of aggregate. The effect of marble fillers addition on the mechanical strength is the most advantageous for recycled aggregate concrete with 5% incorporation of fillers. RAC_5 showed higher strength when compared to control concrete at 28 days, with 38.8MPa, and 25.7 MPa, respectively (Table 5).

Table 4. Results of flexural strength and density for Recycled Aggregate Concrete (RAC) and crushed aggregate concrete (CAC) at 28 days age (prismatic specimens)

Age days	*Mix*	*Fillers dosage (%)*	*density ρ (Kg/m^3)*	*Velocity V (Km/s)*	*Calibration factor K*	*Flexural Strength R_t (N/mm^2)*
28 days	CAC_0	0 %	2393	4.45	3.35	8.93
	RAC_0	0 %	2358	4.36	3.41	8.48
	RAC_5	5 %	2368	4.58	4.76	9.77
	RAC_8	8 %	2318	4.47	3.11	9.25
	RAC_{10}	10%	2340	4.27	2.66	7.63

The Index (0, 5, 8 and 10) refers to the marble fillers percentages

Table. 5. Results of mechanical strength and density for crushed aggregate concrete (CAC) and recycled aggregate concrete (RAC) for cubic specimens

Age Days	*Mix (%)*	*Density ρ (Kg/m^3)*	*Velocity V_u (Km/s)*	*Coeff K*	*Rebound hammer S/R_s (N/mm^2)*	*Ultrasonic Strength R_u (N/mm^2)*	*Compressive Strength R_c (N/mm^2)*	*Improvement ratio [Ci]*
7	CAC_0	2393	4.26	2.676	21.1/13.2	20.80	21.50	-
	RAC_0	2303	4.22	2.874	20.2/12.1	20.48	21.40	-
	RAC_5	2250	4.39	2.750	22.3/14.2	22.53	23.43	-
	RAC_8	2253	4.25	2.90	20.3/12.3	20.90	21.73	-
	RAC_{10}	2203	4.11	2.970	19.3/11.7	18.31	19.56	-
14	CAC_0	2395	4.32	3.398	26.0/19.6	27.79	28.90	-
	RAC_0	2283	4.27	3.810	25.4/18.6	28.35	29.66	-
	RAC_5	2257	4.45	3.345	27.4/21.6	29.61	30.20	-
	RAC_8	2255	4.40	3.423	26.3/20.6	28.93	29.63	-
	RAC_{10}	2270	4.26	3.660	24.1/16.9	27.36	27.90	-
21	CAC_0	2395	4.36	3.398	29.5/22.3	29.40	28.90	
	RAC_0	2264	4.36	3.671	29.1/21.9	31.77	30.63	-
	RAC_5	2276	4.45	3.600	32.3/27.4	32.13	33.00	-
	RAC_8	2261	4.45	4.570	30.6/23.4	40.50	32.43	-
	RAC_{10}	2260	4.32	3.630	28.1/20.6	28.51	29.20	
28	CAC_0	2400	4.45	3.349	31.4/25.7	31.52	32.25	1
	RAC_0	2296	4.44	3.497	30.4/24.1	31.20	31.93	0.99
	RAC_5	2283	4.60	3.532	33.6/38.8	36.10	36.87	1.14
	RAC_8	2300	4.50	3.600	31.3/25.2	33.95	34.76	1.07
	RAC_{10}	2270	4.39	3.483	29.8/23.0	29.36	31.10	0.96

The Index (0, 5, 8 and 10) refers to the marble fillers percentages

This shows an improvement of the strength around 35% by the means of indirect testing, whereas the results of strength for compressive tests showed only an increase of about 14%. However, at the age of 28 days, the higher dosage of 10% fillers presented a lower rebound hammer number compared to CAC mixes.

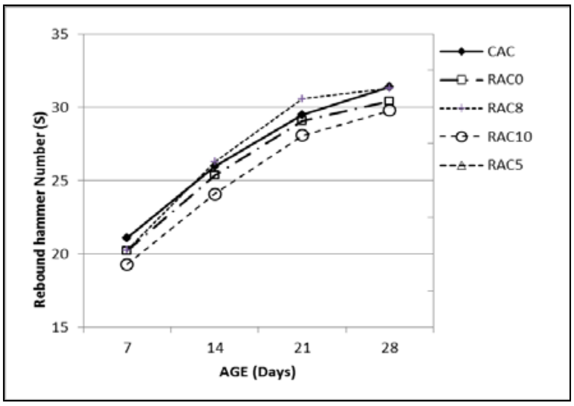

Fig. 5. Rebound hammer Number S development for RAC and CAC mixes

The reduction in strength noticed is about 12%, when RAC_8 performances are compared to conventional concrete.

3.5. Ultrasonic tests

The test results in Fig. 6 shows that the 5 % fillers dosage gives better values of strength. It is noted that there is a slight decrease of strength for higher percentages 10 % for RAC_{10} compared to CAC mixes. The same trend of velocity for concrete incorporating MF was reported in previous studies (Belaidi et al., 2012; Corinaldesi, 2010).

The recycled concrete RAC proved to give higher values compared to normal concrete CAC at the optimal dosage of 5 % according to Fig. 6 at any age. For 28 days age, the concrete test results registered values of ultrasonic velocity V_u estimated at 4.60 km/sec, 4.45 km/sec, respectively. The increase in strength due to the addition of this optimal dosage is about 16 %. Uysal and Sumer (2011) reported that the incorporation of marble powder have showed better performances at early age; this could be attributed to the denser matrix of cement grain better packing due to the addition of marble powder.

Furthermore, the results of strength by the means of ultrasonic non-destructive test seems to be identical to those given by the compression tests for all mixes of conventional concrete CAC and recycled mixtures at the age of 28 days. This is true for any percentage of incorporated marble fillers, with 5 % dosage showing the most identical results, with R_u equals 36.10 MPa and R_c reaches 36.87 MPa (Table 5). The results obtained for strengths in the present study using the indirect ultrasonic method, proved to be more reliable than the rebound hammer test, since they are in better accordance with the values given by compression test (direct destructive method) for RAC strength assessment.

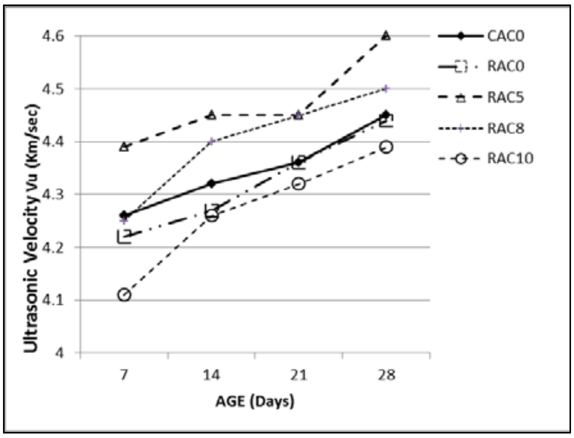

Fig 6. The Ultrasonic Velocity development V_u for RAC and CAC mixes

4. Conclusions

The density of recycled aggregate concrete is lower compared to crushed aggregate concrete. This fact is attributed to the type of recycled aggregate having higher air content compared to normal concrete. It can be noticed that the compressive strength development along first 28 days is similar for both RACs and CAC.

The recycled aggregate concrete shows higher strengths compared to normal concrete for marble fillers dosage of 5%. This addition contributes to limiting voids in the concrete matrix. As a result, a good quality recycled aggregate concrete is achieved with higher compactness and enhanced strength.

Non-destructive methods (ultrasonic and rebound hammer test) can be used to assess the strength of RAC, but a correction coefficient is required to obtain a similar value to the compressive strength given by the compression tests.

Finally, the optimal percentage of about 5% contributes to enhancing the performance of recycled aggregate based on marble fillers which leads to the economy of the blend amount utilized for mixtures. The results of the present study would directly benefit the construction industry besides the positive impact on the environment preservation by limiting waste disposal problems.

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