Effect of Mixing Method and Polyvinil Acetate Addition on the Mechanical Properties of Concretes with Recycled Concrete Aggregates

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The paper presents results regarding the mechanical properties of concretes prepared with various amounts of recycled concrete aggregate (RCA). RCA was obtained by the crushing of concrete rubble resulted during the demolition of a block of flats. The concretes with RCA were prepared using three different mixing approaches: one stage mixing (1SM), two stages mixing (2SM) and two stages mixing with polyvinyl acetate addition (2SM PA). Two stages mixing method in the presence of polyvinyl acetate addition, leads to an improvement of the mechanical strengths (compressive and splitting tensile strength due to a better bonding between the binding matrix formed in the new concrete and the old mortar adhered at the surface of RCA grains.

Keywords: recycled concrete aggregate, mixing methods, concretes properties

One of the most important challenges of our present society is the protection of environment. This can be achieved in concrete industry by the replacement of natural aggregates with different types of wastes. The utilization of recycled concrete aggregate (RCA), resulted in construction and demolition (CD) operations, is particularly very promising as 75% of concrete is made of aggregates [1]. This way of actions conserves natural resources and reduces the space required for the landfill disposal of CD waste.

Although it is environmentally beneficial to use RCA in new concrete production, the current technological experience and corresponding legislation are not sufficient to support and encourage the recycling of CD waste. The technical issues which render the use of RCA for structural applications difficult include: weak interfacial transition zones between binding matrix and aggregate, high level of sulfate and chloride contents, cement paste/mortar remains, high porosity, poor grading, high variations in quality etc. [2 - 8].

The porosity of the concrete made with recycled aggregate from CD waste is higher compared with the one of conventional concrete, mainly due to the presence of hardened cement paste/mortar adhering to the surface of natural aggregate grains [6-8].

In order to increase the mechanical properties of recycled aggregate concrete, various methods were proposed i.e. two stage mixing, mechanical and/or thermal treatments, high-performance sonic impulses etc. [4, 6-9].

This paper presents results regarding the influence of two stage mixing procedure in combination with the use of a polyvinyl acetate admixture (a well-known adhesive), on the main properties of concretes prepared with RCA.

Experimental part

Materials and methods

Preparation and characterization of recycled concrete aggregate (RCA)

The RCA used in this paper was obtained from the concrete rubble resulted during the demolition of a block of flats. The concrete rubble was crushed and sieved in order to obtain aggregate sorts 4/8 mm, 8/16 mm and 16/31.5 mm. Each quantity of aggregates (sorts 4/8 mm, 8/16 mm and 16/31.5 mm) has been homogenized using a riffle box.

The RCA density (ρ_a) was determined according to EN 1097-6 [10] and bulk density (ρ_b) according to EN 1097-3 [11].

The content of cement paste (mortar) still present on the surface of RCA grains, was estimated considering the density of natural aggregate from the concrete (ρ_{ag} = 2630 kg/m^3) and the mortar density (ρ_m = 2100 kg/m^3).

The apparent density of RCA grains (ρ_a) containing natural aggregate and mortar (binding matrix) is given by the equation:

$$\rho_a = 100 / [x / \rho_{ag} + (100 - x) / \rho_m] \quad (kg/m^3) \quad (1)$$

where x is the percent of natural aggregate in recycled concrete aggregate (resulted by the grinding of concrete debris).

Preparation and characterization of new concrete

Type I 42.5N Portland Cement was used for the preparation of the new concrete with RCA content. Three types of concretes were made using various proportions of both natural aggregate and recycled aggregate (RCA substitutes the natural aggregate) (table 1).

In this recipes there was kept constant the amount of cement, water and sand (0/4 mm), all bigger sorts being replaced in a proportion of 25, 50 and 75% with RCA from the respective sort, having the same volume.

The concrete mixtures presented in table 1, were homogenized in a concrete mixer by two different methods:

Method 1 - one stage mixing (1SM). All the solid components were introduced in the concrete mixer and homogenized for 3 min. In the next step water was added and the mixture was again homogenized for 2 min. High water reducer additive (Glenium ACE 30) was added in order to obtain a constant consistency (assessed by slump test) of fresh concrete mixture.

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RCA (%) in aggregate mixture	0	25	50	75
0/4 mm NRA (kg/m^3)	734	734	734	734
4/8 mm NRA (kg/m^3)	370	285	187	101
8/16 mm NRA (kg/m^3)	370	285	187	101
16/31.5 mm NRA (kg/m^3)	370	285	187	101
4/8 mm RCA (kg/m^3)	0	88	173	283
8/16 mm RCA (kg/m^3)	0	88	173	283
16/31.5 mm RCA (kg/m^3)	0	88	173	283
Polyvinyl acetate* (l/m^3)	2.8	2.8	2.8	2.8
Cement (kg/m^3)	345	345	345	345
Water (l/m^3)	159	159	159	159
Water to cement ratio (W/C)	0.46	0.46	0.46	0.46

*only for the specimens prepared with the 2SM PA method

Table 1
COMPOSITION OF CONCRETES PREPARED WITH VARIOUS PROPORTION OF NATURAL AGGREGATE (NRA) AND RECYCLED CONCRETE AGGREGATE (RCA)

The resulted concretes were noted 1S0, 1S25, 1S50, 1S75 depending on the percentage of natural aggregate replaced with RCA.

Method 2 - two stage mixing (2SM). The solid components (except sand) were introduced in the concrete mixer and homogenized for 3 min. The sand and 40% of the total amount of water was added and the mixture was homogenized again for 2 min. Finally the remaining of 60% of water was added and depending on the consistency of concrete was added (or not) the high water reducer additive (Glenium ACE 30). The resulted concretes were noted 2S0, 2S25, 2S50, 2S75, 2S100 depending on the percentage of natural aggregate replaced by RCA.

The fresh concrete was cast in cylindrical moulds (h=200 mm and D=100 mm); the specimens were demoulded after 24 hours and kept in water at 20°C up to 28 days.

A variation of the basic recipe (2SM PA) was achieved using the second method of mixing (2SM) and a supplementary addition of polyvinyl acetate in concrete composition. Polyvinyl acetate was an adhesive class A from MASTERDYNE. This admixture was used in order to improve the adhesion between the RCA and new binding matrix, polyvinyl acetate being a well known adhesive currently used in construction works [5].

Polyvinyl acetate was dispersed in water (40% of total amount), added over the mixture of coarse aggregates and cement and homogenized for 3 min. The sand and the remaining water (60%) were added and concrete mixture was homogenized for 2 minutes. The compositions thus achieved have received the notation 2SM PA.

The end surfaces of the hardened concrete specimens were flattened with sulfur mortar in order to assess the compressive strength (fc). Compressive strength was assessed after 7 and 28 days of hardening using the method presented by SR EN 12390-3: 2009 + AC: 2011 [12]. Indirect tensile strength by splitting was carried out on concrete specimens hardened for 28 days according to the method presented in SR EN 12390-6: 2010 [13].

The static module of elasticity was determined according to SR EN 12390-13:2014 [14].

Results and discussions

The values of apparent density (ρ_a), bulk density (ρ_b) assessed on recycled concrete aggregate are presented in table 2. The decrease of apparent density with the increase in the grain size of aggregates is due to the increase of cement mortar amount on the surface of RCA aggregate [8].

Figure 1 shows the evolution of compressive strengths, assessed after 7 days and 28 days of hardening, for the concretes prepared with the one stage mixing method (1SM) versus the amount of RCA in aggregate mixture.

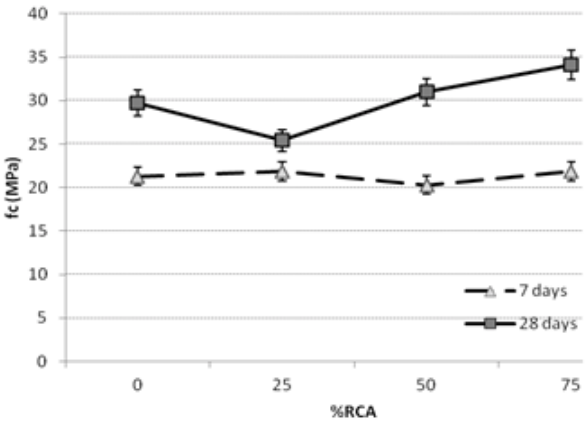

Fig. 1. Compressive strength (fc) of concretes prepared with various amount of recycled aggregates (RCA) and one stage mixing method (1SM)

Granular class (mm)	ρ_a (Kg/m^3)	ρ_b (Kg/m^3)	Estimated amount of mortar (binding matrix) (%)
4/8	2342	1106	48.7
8/16	2333	1177	50.4
16/31.5	2326	1283	51.8

Table 2
APPARENT DENSITY (ρ_a) AND BULK DENSITY (ρ_b) OF RCA

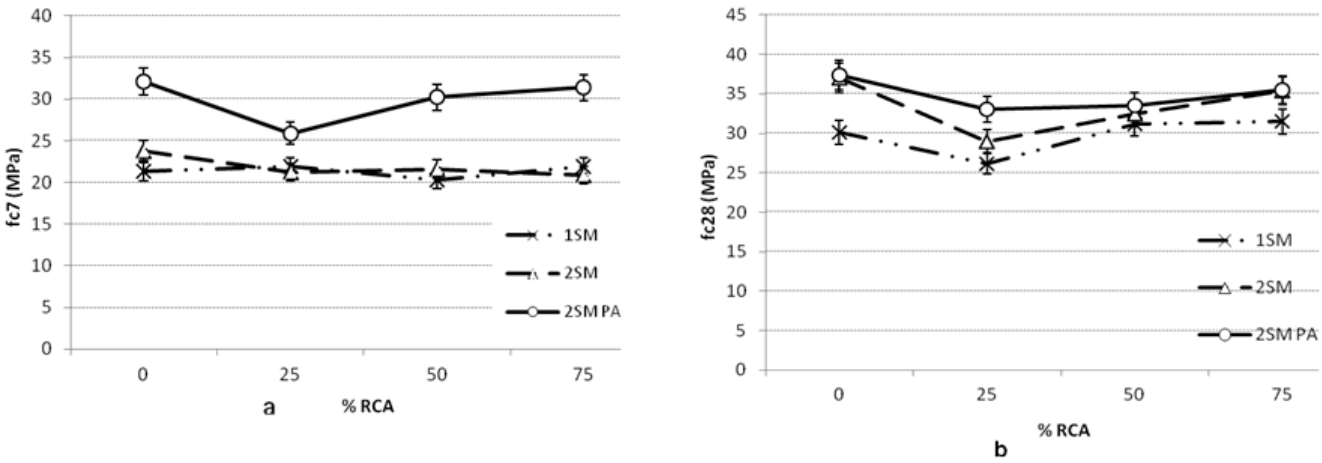

Fig. 2. Compressive strength (fc) of concrete prepared by one stage mixing method (1SM), two stage mixing method (2SM) and two stage mixing method with polyvinyl acetate admixture (2SM PA): a) 7 days; b) 28 days

It can be observed a certain increase of the compressive strength values with the increase of RCA amount (over 50%) in aggregate mixture, especially after 28 days of hardening. This apparently surprising evolution can be explained by: i) the high compressive strength of initial concrete rubble and ii) the angular shape and rough surface of RCA (obtained by crushing) which determines a better adherence to the new cement stone as compared with the natural round and smooth grains specific for natural aggregate.

Figure 2 shows the variation of compressive strength versus the amount of recycled concrete aggregate (RCA) for the three methods of mixing used in this research.

The use of 2SM mixing method determines a slight increase of compressive strength values as compared with 1SM especially after a longer hardening period (28 days - fig. 3b). The addition of polyvinyl acetate (2SM PA) determines an increase of the compressive strengths values (over 30% after 7 days and over 10% after 28 days as compared with one stage mixing).

Figure 3 shows the evolution of splitting tensile strength versus the amount of RCA in aggregate mixture. One can observe a good correlation with the evolution of compressive strength i.e. higher values (more than 10%) for the concrete obtained by 2SM method (as compared with 1SM method). There is a significant positive effect of the of polyvinyl acetate admixture – more than 25% increase of indirect tensile strength by splitting when compared with one stage mixing and more than 10% when compared with one two stage mixing.

Figure 4 shows, as an example, the stress - strain diagram recorded for 1S25 concrete. From this type of diagrams were determined the values of static elasticity modulus for the concretes obtained using the three mixing methods (fig. 5).

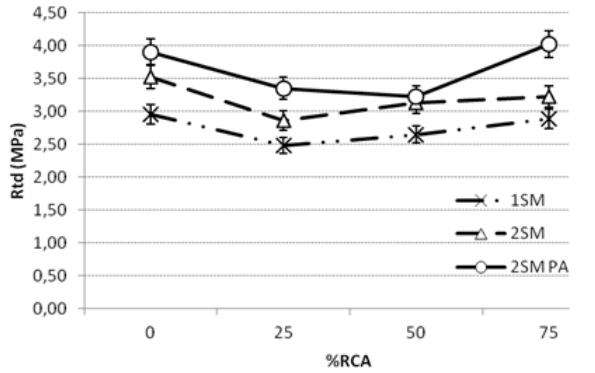

Fig. 3. Indirect tensile strength by splitting (f_{td}) for concretes obtained by one and two stages mixing - with or without of polyvinyl acetate mixture, cured for 28 days

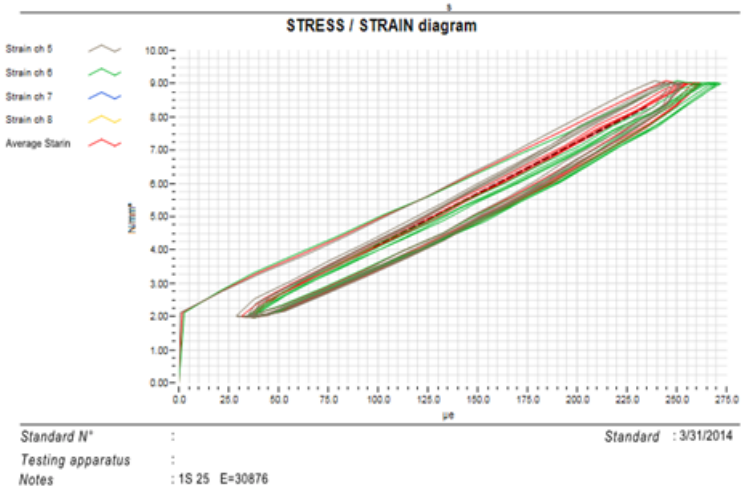

Fig.. 4. Stress-strain diagram for 1S25 concrete

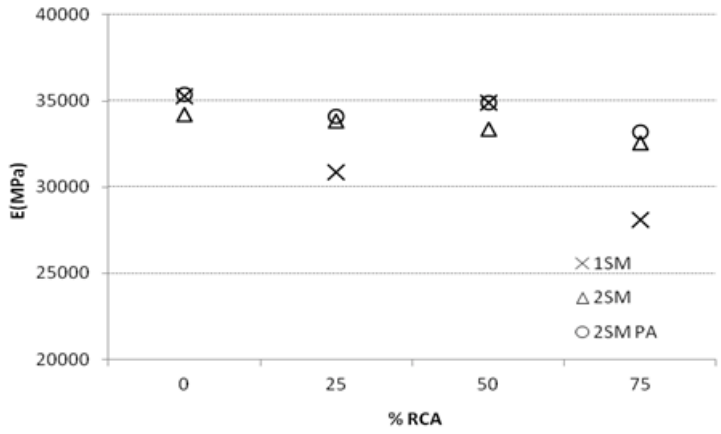

Fig. 5. The static elasticity modulus (E) of concrete obtained through on and two stages mixing with or without of polyvinyl acetate

One can notice a decrease of the values of elasticity modulus with the increase of RCA content in aggregate mixture and this can be explained by the increase of mortar amount in concrete; it is well known the fact that mortar has a lower value of elasticity modulus as compared with natural aggregate [15]. Moreover, the presence of an interfacial transition zone, between the cement matrix of the new concrete and mortar from the surface of RCA grains, with low mechanical strength, contributes to the decrease of elasticity modulus values.

The elasticity modulus values assessed for the concretes prepared by the two stages mixing method, with or without addition of polyvinyl acetate, are in some cases much higher than the one achieved in concrete prepared by one stage mixing; this can be explained by a higher adherence between the cement paste/mortar formed in the new concrete and the old cement paste/mortar adhered at the surface of RCA grains.

Conclusions

Two stages mixing method leads to an improvement of the mechanical strengths (compressive and indirect tensile strength by splitting**)** due to a better bonding between the cement paste formed in the new concrete and the old cement paste/mortar adhered at the surface of RCA grains.

The values of the static modulus of elasticity decrease with the increase of the RCA content in aggregate mixture, mainly due to the increase of cement paste/mortar amount. The addition of polyvinyl acetate seems to improve mechanical strength when combined with the two stages mixing method.

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References

1.RYU, J. S., J. Mater. Sci. Lett., 21, 2002, p.1565-1567
2.TAM, V., TAM, C.M., Constr. Build. Mater., 22, 2008, p.2068-2077
3.TAM, V., GAO, X.F., TAM, C.M., Cem. Concr. Res., 35, 2005, p.1195-1203
4.TAM, V., TAM, C.M., WANG, Y., Constr. Build. Mater., 21, 2007, p.1928-1931
5.MATIAS, D., BRITO J., ROSA, A., PEDRO, D., Constr. Build. Mater.,44, 2013, p.101-109
6.SUI, Y., MUELLER, A., Mater.Struct, 45, 2012, p.1487-1495
7.BADANOIU, A, MUSTATEA, F., VOICU, G., Rev. Chim.(Bucharest), **64**, no.9, 2013, p.1015
8.VOINITCHI, R.C., CRACIUN, V., VOINITCHI, C.D., BADANOIU, A., VOICU, G., Rev. Rom. Mater.Journal, 44 (3), 2014, p.207-212
9.LINSZ, E., MUELLER, A., Int. J. Miner. Process., 74, 2004, p.199–208
10.*** SR EN 1097-6:2013 Tests for mechanical and physical properties of aggregates - Part 6: Determination of particle density and water absorption
11.*** SR EN 1097-3, Test for mechanical and physical properties of aggregates. Part 3: Determination of loose bulk density and voids
12.*** SR EN 12390-3:2009/AC: 2011, Testing hardened concrete - Part 3: Compressive strength of test specimens
13.*** SR EN 12390-6:2010, Testing hardened concrete - Part 6: Tensile splitting strength of test specimens
14.*** SR EN 12390-13:2014, Testing hardened concrete - Part 13: Determination of secant modulus of elasticity in compression
15.CORINALDESI, V., Construction and Building Materials, 24, no. 9, 2010, p. 1616–1620

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