Experimental Research on Recycled Concrete Fines

REMUS CHENDES, CORNELIU BOB*, CATALIN BADEA, CORNELIU EUSEBIU PODOLEANU, SORIN DAN, LIANA IURES
Politehnica University of Timisoara, 2 T. Lalescu Str., 300223, Timisoara, Romania

Recycling is defined as the process that changes materials into new products for preventing the waste of potentially useful materials, reducing the consumption of fresh raw materials, the energy usage and the air and water pollution. Many of the large, existing buildings which don't have any historical importance, such as industrial type, office buildings or apartments, have a reinforced concrete structure. Recycled concrete is mainly used as coarse aggregate and filler in road construction industry; another usage of it could be adding it into new mixtures. So far this usage has led to a significant decrease in mechanical properties for the new mixture. It is well known that the cement industry is an important energy consumer and also a CO_2 releaser. Present paper is devoted to the use of recycled concrete materials obtained from concrete elements into new mixes as a replacement of the cement. An experimental program was developed in this purpose; physical and physical-chemical tests were made on obtained materials. The mechanical properties of the obtained mortar samples have been also studied.

Keywords: recycled concrete fines, SEM analysis, EDAX, specific surface-BET, mechanical strength, sustainability

Nowadays, the attention on recycling of construction and demolition waste (C&Dw) is increasing. A comparison of the C&Dw recycling around the world was made in 2005 by Oikonomou [1]. Most European countries have high recycling goals when it comes to C&Dw (between 50% and 90%). Many studies on technologies for producing recycled concrete aggregate [2], recycled concrete fines and life-cycle analysis, have been carried out in Japan and US. In the U.S.A., aggregates are divided by use: in pavements (10-15%), road construction and maintenance work (20-30%) and structural concrete (60-70%). In Japan, the concrete recycling ratio is almost 99% and it is used generally as sub-base material in road construction. An important role may also have the waste [3] from different production processes, reused as concrete preparation materials [4].

The biggest energy-consumer component of a concrete is the cement, with high CO_2 emission during the manufacturing process, a part of it being bound by carbonation process [5]. Replacing an amount of cement into a concrete mixture with recycled concrete finest (RCF) it is helpful for environment protection and natural resources preservation.

A disadvantage of replacing a percent of cement with RCF is that the mechanical and elastic property of the obtained material is reduced [6]. This can be caused by the high water absorption of RCF. This effect is also in line with observations from literature [7, 8]. From literature it is well known that with smaller particle fraction of RCF there are obtained better mechanical properties. Another characteristic of smaller particles fraction resulted after crushing and milling the concrete, is the lower SiO_2 content compared with bigger particles fraction of RCF [9].

By demolishing concrete buildings, collecting the used concrete and crush it, there are also created recycled concrete aggregate (RCA). The RCA [10] has different properties than normal aggregates and it behaves differently in concrete mixes. There are also studies focused on the effect of heat treatment on RCA used to obtain new concrete [11], but this aspect was not considered in this study.

Katrina McNeil [12] describes the variation between the properties of RCA concrete compared to normal river aggregates concrete; the results from recent tests show the strength reduction due to higher water absorption of the RCA.

The present policy concentrates on recovery, recycle and reuse (RRR) of various waste including C&Dw. The reuse, recycling and reducing the waste are considered the only methods to recover the wastes generated; however, the implementations still have much room for improvement [13].

According to European Directive 2008/98/EC [14], until 2020 EU countries are obliged to increase the percentage of RRR of demolition waste with at least 70% of the total. In Romania the Law no. 211/2011 [15] was adopted based. Therefore, it is compulsory for the researchers to concentrate on obtaining sustainable methods for using wastes into new domains, including C&Dw.

The targets of the studies presented in this work are the following:

-to observe the material structures of the RCF by use of a complex analysis like SEM, specific surface-BET, EDAX;

-to determine the main mechanical strength of the RCF;

-to demonstrate the importance of a complex analysis for obtaining new materials by using RRR of various types of wastes from construction and demolition.

Experimental part

Studied materials

The RCF was obtained after crushing a concrete beam, realized with concrete compressive strength of 33.2 N/mm^2 at 28 days and 22.9 N/mm^2 at 7 days, established by use of cylindrical samples extracted from the beam.

First the beam was demolished on site using an excavator and pre-crushed using a jaw crusher. The resulted material was transported into a hall where it was crushed using a Prototype Crusher (PC). Afterwards, the obtained material was divided into three grain size groups: RCA1 (having the particle size between 1.0 and 16.0 mm) and RCF-i (with the particle size from 0 to 1mm) and RCF –s (with particle size from 0 to 0.063 mm).

* email: cbob@mail.dnttm.ro, Tel:+40740191006

Sieve size	% retained in each sieve	cumulative % passing each sieve
1,0 mm	0	100
500 µm	34.8	65.2
250 µm	25.9	39.3
125 µm	19.9	19.4
63 µm	12.7	6.7
passing 150 µm	6.7	

Table 1
PARTICLE SIZE DISTRIBUTION FOR CRUSHED CONCRETE - RCF-i

Material	Particle size [mm]	Specific surface - BET [m^2/kg]	Mean pores volume [mm^3/g]
RCF-i *	0.0-1.0	643	21
RCF-s *	0.0-0.063	731	34
CEM II 42.5N *	0.0-0.08	1720	64
Different type of cements **	0.0-0.08	686-2000	-

Table 2
SPECIFIC SURFACE-BET METHOD

*Own results;**Results from literature [17]

The RCF-i material was sieved into fractions such as: 500µm-1mm, 250-500µm, 125-250µm, 63-125µm and <63µm with the particle size distribution represented in table 1.

Physical and physico - chemical analysis

Using the BET method, the specific surface area of the two particle sizes studied was determined. Boubitsas [16] obtained for cement CEM I 52.5 a specific surface area of 1760 m^2/kg.

The experiment was conducted at a temperature of 20° C (using N_2), the same temperature as the storage hardware and prisms obtained subsequently.

To obtain the specific surface area and the total pore volume it was used a Nova 1200e device.

In order to prepare the sample, it has been degassed in vacuum for 5 h. The analysis has been made by a volumetric method, that is, by introducing the nitrogen. Also, to keep the temperature constant, the analysis was made at 77K. The specific surface was determined by the multi-BET method and the total pore volume was determined from the last point of the adsorption-desorption isotherm.

A specific surface area of 643 m^2/kg in the case of RCF-i was obtained and the pore mean volume of 34 mm^3/g. In the case of RCF-s, the specific surface area obtained was of 731 m^2/kg, for a pore mean volume of 21 mm^3/g. For the cement CEM II 42.5 used in the composition of the crushed beam, we have obtained a specific surface of 1720 m^2/kg.

The image analysis was also performed on the material obtained (RCF) by using electronic microscopy SEM (fig. 2-a, b)

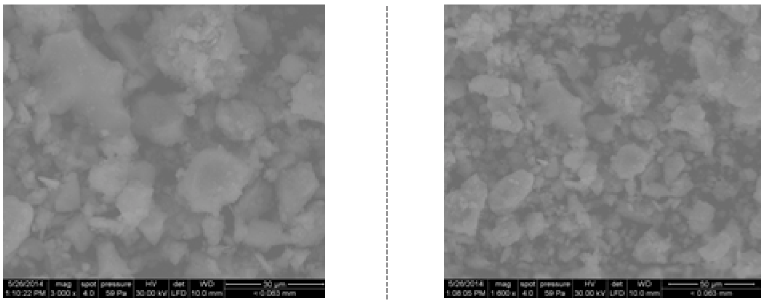

Fig.1a SEM images of RCF - s

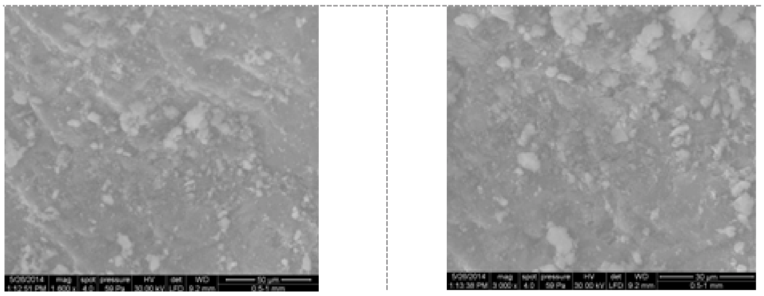

Fig.1b SEM images of RCF - i

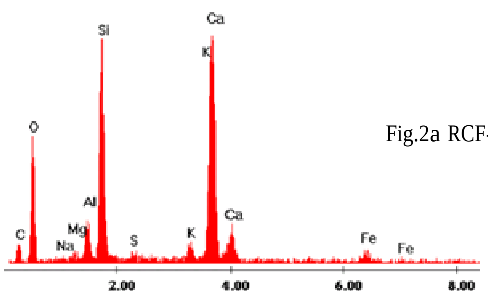

Fig.2a RCF-i EDAX

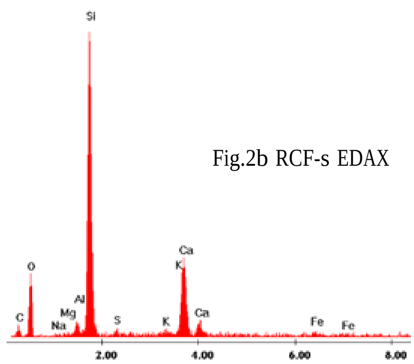

Fig.2b RCF-s EDAX

PHASE	COMPONENTS			
	Ca Wt%	Si Wt%	O Wt%	C Wt%
RCF-i	9.18	27.67	38.04	20.04
RCF-s	16.55	14.07	46.80	16.22
Δ=RCFs/RCF-i	1.80	0.51	1.23	0.8

Table 3
RCF COMPONENTS

Mortar Mixture	Binder					W/C
	CEM I 52.5R [%]	RCF initial-below 1 mm [%]	RCF Sieved below 63μm [%]	Sand [%]	Water [%]	
I	22.2	0	0	66.7	11.1	0.5
RCF1-i	18.7	3.3	0			
RCF1-s	18.7	0	3.3			
RCF2-i	15.4	6.6	0			
RCF2-s	15.4	0	6.6			
RCF3-i	12.1	9.9	0			
RCF3-s	12.1	0	9.9			
RCF4-i	5.5	16.5	0			
RCF4-s	5.5	0	16.5			

Table 4
RCF MORTAR MIXTURES
(NOTE: % ARE WITH RESPECT TO WEIGHT)

From microscopic observations, the surface topography of the two materials can be compared. It is noted that RCF-s material has the form of asymmetric clumps with varying sizes. In RCF-i case, it can be observed that the material is similar size (<0.063mm) rather scattered, as individual particle.

From EDAX analysis, the percentage of chemical compound is observed. This thing is changes after sieving the RCF. The variations from figure 2a) and figure 2b) are inserted in table 3 for significant compounds.

CaOH is found as powder and has a softer structure than CaO noted in table 3 with C and being found as small rocks. From this reason, after sieving RCF-i the C remains in a bigger quantity on the bigger sieves and CaOH doesn't. This fact can be seen also for the Si.

From the figures and table above the following can be noted:

- significant increase by 80% of Ca from CaOH, for RCF-s compared with RCF-i, which represents the basic element of the active substances of ordinary Portland cement (OPC) and together with the O_2 give an increase of the mechanical properties;

- an important decrease of Si after sieving. It is important to note that this element is incorporated in a big proportion in the sand and gravel, components chemically inert in the concrete.

Tested compositions for mechanical properties

Standard mortar was made (table 4) using Portland Cement CEM I 52.5R in accordance with SR EN 197-1 [18], from LAFARGE (Greece).The aggregate used in the research is standardized sand CEN-NORMSAND EN 196-1 [19] which is natural rounded sand. The water/cement ratio was fixed to 0.5.

A number of 27 samples were cast for bending tensile test (160 x 40 x 40 mm).

For the initial particle size RCF-i and for the particle size after sieving with the 63μm sieve RCF-s, the mixing components are presented in table3. Each specimen was de-molded after 24 h and stored in water for the next 27 days at 20°C.

Experimental part

Tensile strength

Experimental program results are summarized in figure 3 and figure 4, concerning tensile strength and compressive strength. The results refer to strength for different quantities of cement replacement.

In figure 3 one can observe that the bending tensile strength obtained in the case of RCF-s is 5 up to 10 % higher than the one obtained with RCF-i. By increasing the percentage of cement replacement, the bending tensile strength (flexural strength) will decrease for both, RCF-i and RCF-s. The decrease of tensile strength of RCF-i and

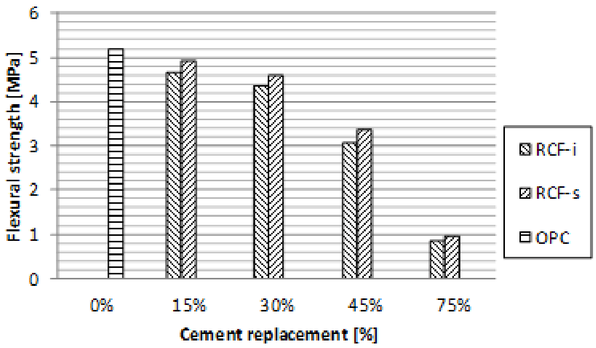

Fig. 3. Tensile strength at 28 days

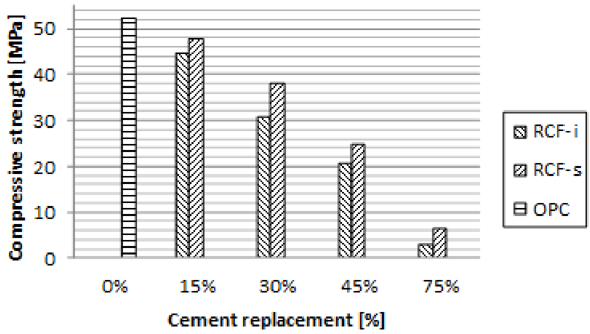

Fig. 4. Compressive strength at 28 days

RCF-s is slower than the material with 30% cement replacement, presented in [12].

Compressive strength

For the 15, 30 and 45% cement replacement, a higher compressive strength with 20% for RCF-s than for RCF-i can be observed. In case of 75% replacement the difference is greater, RCF-s samples having a two times higher compressive strength than RCF-i. The rate of decreasing for compressive strength is almost linear with the increasing of cement replacement, for both batches RCF-i and RCF-s: 25% respectively 39 for 30% replacement as well as 51% respectively 60% for 45% cement replacement.

Compared with data from [12], the decreasing rate for compressive strength in RCF-i case has similar decrease rate, while the RCF-s has a slower decrease rate.

Conclusions

This paper presents experimental results for the physical and physicochemical analysis of the recycled concrete. It also presents mechanical properties of mortars obtained by substituting, in different percentages, the cement with recycled fines. On the other hand an original analysis on sustainability of new mortars is presented. From this investigation, the following conclusions can be drawn:

(1) Replacement 15-75% of OPC with RCF leads to a decrease between 70% up to 80% of the mechanical strength. For 75% replacement, the total decreasing of compressive strength for RCF-i is 93% and for the RCF-s is 87%; for tensile strength, the total decreasing is 86% for RCF-i and 82% for RCF-s. Such results are in accordance with specific surface of RCF material table 2.

(2) The influence of grain size and specific surface BET are important parameters which influence mortar mechanical strengths. In case of tensile strength, the increasing from RCF-i to RCF-s is between 5 up to 25%; for compressive strength, the increasing from RCF-i to RCF-s is between 8 and 50%. The increase is bigger for smaller percent of replacement.

(3) From SEM EDAX determination, the percent of active elements, such as Ca, increases with 80% for RCF-s compared to RCF-i; on the other hand, the percent of Si decreases with 49%. The higher value of Ca and O_2 explain the increase of mechanical strength for RCF-s.

References

1. OIKONOMOU N.D., Cement and Concrete Composites 27: 315-318 (2005).
2. RADONJANIN V., et al., Construction and Building Materials 47 (2013) 1503–1511.
3. SAMIEI R.R., et al., Construction and Building Materials 84 (2015) 84–94.
4. BOB C., et al., Lambert Academic, Civil Engineer Approach 2010, Building sustainability.
5. BOB C. et al., Romanian Journal of Materials 2012, 42 (4), 370 - 380.
6. KANG T. H., et al., 18th international association for bridge and structural engineering congress on innovative infrastructures, Seoul, Korea (2012).
7. SHUI Z., et al., Construction and Building Materials 23, 531-537 (2009).
8. SHUI Z., et al., Construction and Building Materials 22, 1723-1729 (2008).
9. FLOREA M.V.A., BROUWERS H.J.H., 18th International Conference on Building Materials (IBAUSIL), Germany; 01/2012 .
10. VOINITCHI R.C., et al., Romanian Journal of Materials 2014, 44 (3), 207 - 212.
11. KHALDOUN R., Building and Environment 42 (2007) 407–415.
12. MCNEIL K., et al., International Journal of Concrete Structures and Materials Vol.7, No.1, March 2**0**13.
13. TAM V.W.Y, TAM C.M., 4th Building and Environment 41 (2006) 1649–1660.
14.***Directive 2008/98/ec, http://ec.europa.eu/environment/waste/framework.
15. ***Romanian Law no. 211/2011, published in the Official Journal no.837/November 2011.
16. BOUBITSAS D., Replacement of Cement by Limestone Filler: The Effect on Strength and Chloride Migration in Cement Mortars.
17. HARRIGAN E.T., National Cooperative Highway Research Program April 2013, Research Results Digest 382.
19.*** SR EN:197-1:2011Composition, specifications and conformity criteria for common cements.
18. *** SR EN:196-1:2005 Methods of testing cement Part 1: Determination of strength

Manuscript received: 24.03.2016