

## Aspects Concerning the Use of Recycled Concrete Aggregates

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### Abstract

Natural aggregates (gravel and crushed) are essential non-renewable resources which are used for infrastructure works and civil engineering. Using recycled concrete aggregates (RCA) is a matter of high priority in the construction industry worldwide. This paper presents a study on the use of recycled aggregates, from a concrete of specified class, to acquire new cement concrete with different percentages of recycled aggregates.

### 1. Introduction

In European Union member states from Southeast Europe, it is estimated that the construction industry will grow by 4.2% thereafter complicating aggregate supply management. In addition, a significant additional problem that can be associated to the aggregates industry is wasting potential resources through waste dumping of inert waste, especially waste from construction and demolition activities, [1].

In 2012, in Romania, less than 10% of construction and demolition waste (including concrete) are valorized, while the European Union requires that by 2020 this proportion should be at least 70% (Directive 2008/98 / EC on waste, transposed into Romanian legislation by Law 211/2011).

Depending on the efficiency of waste processing and the quality of recycled aggregate concrete (RCA) obtained, poor quality aggregate can be used as foundation material for roads and at the high quality for new concrete on construction, [2].

To obtain good quality concrete using recycled aggregate is necessary to meet the minimum requirements defined by the rules for the manufacture of concrete with natural aggregate. Properties of recycled aggregate (density, granulosity, granule shape, water absorption, weight loss to Los Angeles test, attached mortar content [3] etc.) are the basis for concrete quality; also establishing appropriate proportions between components and the concrete production methods are extremely important for its quality, [4,5].

In the literature [6-8], it was shown that the recycled aggregate concrete (RAC) are less resistant, with 15 to 40% versus concrete with natural aggregates. The factors influencing reducing mechanical resistance include:

- mechanical strength of the original concrete and respectively for recycled aggregates obtained;
- the origin of the original concrete from multiple sources versus once source;
- the amount of attached mortar to recycled aggregates;
- the percentage of replacing natural aggregates with recycled aggregates;
- use of fine recycled aggregates;



The present study aimed the obtaining of some recycled concrete aggregate from established class concrete and their use in different proportions to achieve new concrete. The new concretes are characterized by the point of view of density, mechanical strength, modulus of elasticity etc.) and the factors affecting their properties analyzed.

Should be noted that the use of recycled aggregates in concrete is made on the basis of National/European specific prescriptions (SR EN 206: 2014), with limits for type A or B recycled aggregates. Aggregates obtained by crushing of hardened concretes unused in structural elements are considered reclaimed crushed aggregates, [9].

## 2. Experimental

### 2.1 Obtaining of the recycled concrete aggregate

To achieve recycled aggregates several batches of concrete class C16/20, C25/30 and C35/45 were made, the compositions calculation being made according NE012/2007 and CP012/2007. Tests for producing recycled aggregate was carried out using concrete samples of the established three classes after 28 days of storage under the above conditions, [10]. Cubes with 150mm side were crushed in a first stage with a jaw crusher Liebherr type set at 50 mm nominally. The resulting material was separated by sieving on granulometric sorts and 10-50 sort was used for preliminary tests of crushing in the second stage with a jaw crusher BB 200 Retsch model, respectively a hammer crusher Buffalo Shuttle WA-12-H model.

The fine aggregate, sort 0-2, was analyzed by granulometric point of view getting elementary sorts 0 - 0.063; 0.063 - 0.125; 0.125 - 0.25; 0.25 - 0.5; 0.5 - 1; 1 - 2; > 2 for all three concrete classes for the two crushing variants in the second stage. Comparing granulometric compositions for recycled aggregates (see granulometric curves of the figure 1) obtained with an impact crushing to those obtained with a jaw crusher, generally, a higher proportion of coarse parts (sorts 1-2; > 2) in the aggregate obtained with a jaw crusher is observed, particularly for concrete aggregates from larger class. This is in accord with the literature data [10] according to which the hammer crusher produce more fine part than the jaw crusher and recycled aggregate derived from a higher class concrete is coarser than that coming from a lower concrete.

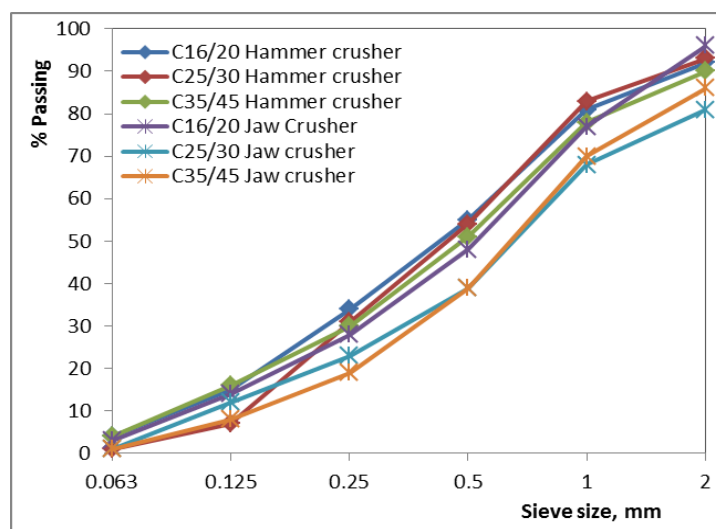


Figure 1 Granulometric curve of the fine aggregate

Finally, for the production of recycled aggregate concrete and to compare their properties with those of the original concrete, through the successive crushing and screening, there were obtained three granulometric classes of recycled aggregate 0-4; 4-8 and 8-16. In this study, for new concrete, only recycled aggregate derived from C25/30 concrete class, obtained with a hammer crusher, was used.

## 2.2 Obtaining the recycled aggregate concrete

The amounts of mixing water, cement, aggregates and additives were established according to NE012/2007 and CP012/2007, following the same steps as in the case of a natural aggregate concrete [11].

The proportions in the mixture were calculated so as to satisfy the following conditions:

- the recycled aggregate to replace the natural aggregate in a proportion of 0% (reference), 20%, 40%, 60%, 80% and 100%, for all sorts used;
- the recycled aggregate was used dry, the necessary water for saturation of the recycled aggregate was added during the components' mixing;
- river aggregate and recycled from crushed concrete, 0/16 mm on 3 granulometric sorts: 0/4; 4/8 and 8/16 mm, respectively;
- slump class of the fresh concrete  $S_2$  ( $50 \div 90$  mm);
- superplasticizer additive / high range water reducer.

As with concrete from which the recycled aggregate was obtained, CEM V A S-V 42,5 N cement was used and as an additive: superplasticizer Glenium 27 (1% weight of cement). Obtaining, preserving and preparation of samples for testing was done according to the rules adopted for concrete with natural aggregate.

In table 1 are shown the compositions for  $1\text{m}^3$  concrete with different proportions of recycled aggregate (R1-R6) and some data of interest such as: fresh concrete slump, A/C global ratio, density of fresh concrete, experimental observations.

*Table 1 Recycled aggregate concrete compositions*

Code samples	Cement, Water, Effective A/C ratio, Glenium 27 Additive	Aggregates on sorts, for $1\text{m}^3$ concrete, kg	Fresh concrete slump, mm	A/C global (real)	Density of fresh concrete, $\text{kg/m}^3$	Observations
R1 0% recycled	Cement: 345 kg for $1\text{m}^3$ concrete; Water: 190 liters for $1\text{m}^3$ concrete; Glenium 27 Additive: 3.3 liters for $1\text{m}^3$ concrete; A/C=0.55	0/4 - 815 4/8 - 454 8/16- 545	65	0.47	2380	Workable
R2 20%recycled		0/4 - 790 4/8 - 440 8/16- 530	80	0.51	2350	Workable
R3 40%recycled		0/4 - 770 4/8 - 430 8/16- 510	70	0.54	2340	Workable
R4 60%recycled		0/4 - 740 4/8 - 410 8/16- 500	90	0.57	2290	Slight water separation
R5 80%recycled		0/4 - 720 4/8 - 400 8/16- 480	60	0.58	2270	Low cohesion, Nonworkable
R6 100%recycled		0/4 - 695 4/8 - 385 8/16- 465	50	0.62	2240	Low cohesion, Nonworkable

According to experimental observations, recycled aggregate concrete loses its cohesion and becomes more nonworkable as the percentage of recycled aggregate increases.

If to the establishment of theoretical composition the A/C ratio was 0.55, the real (experimental), for carrying out the slump class the A/C ratio was initially used small, in the case of compositions with 0, 20 and 40% recycled aggregate and over the theoretical value in the case of recipes with a lot of recycled aggregate (80 and 100%). This is due, of course, to the increase of need for absorption water when increasing the amount of recycled aggregates.

### 2.3 Characterization of recycled aggregate concrete

All concrete samples, cubes ( $d=15\text{cm}$ ) and cylinders ( $d \times h=15 \times 30\text{cm}$ ), were demoulding after a day and kept in water at  $20^\circ\text{C} \pm 2^\circ\text{C}$ , until the date of 28 days necessary for determinations on hardened concrete. Preparing and maintaining test specimens was done according to standards.

Compressive strength was determined following a request by friction using a hydraulic press 3000kN with a loading speed of  $0.6 \pm 0.2 \text{ N/mm}^2 \cdot \text{s}$ , according to SR EN 12390-3. Previously, concrete samples (cubes) were weighed and geometrically measured to calculate the apparent density.

On polyhedral samples with fresh surface (carved from cubes with sides of 15cm), with surface area approximately equal, it was determined water absorption (the open porosity) after 24 hours in which the samples of concrete were kept in water at  $22^\circ\text{C}$ .

It has been calculated the volumic absorption,  $A_v$  (%), with the relation (1),

$$A_v = [(m_I - m)/(m_I - m_2)] \cdot 100, \quad (1)$$

where  $m$  is the mass of dry material to constant weight,  $m_I$  – the mass of saturated material with water, after 24 hours and  $m_2$  – the mass of saturated material hydrostatic weighed.

As a nondestructive method for analyzing hardened concrete was used ultrasonic method using an betonoscop UTD 1004 NAMICON type which measure the ultrasonic propagation time ( $t$  in seconds) through concrete. The dynamic modulus of elasticity was calculated using the equation (2),

$$E_d = V_L^2 \cdot \rho_a \cdot \frac{(1 + \nu_d) \cdot (1 - 2 \cdot \nu_d)}{(1 - \nu_d)} \quad (2)$$

in which:

- $V_L$  is the ultrasonic pulse velocity,  $V_L = 0,15/t$  (m/s);
- $\nu_d$  - Poisson coefficient ( $\nu_d = 0,22$ );
- $\rho_a$  - apparent density of the hardened concrete,  $\text{Kg/m}^3$ .

Static modulus of elasticity was determined by means of electronic press by 3000kN, equipped with load and displacement sensors, for cylindrical concrete samples with different proportions of recycled aggregate.

### 3. Results and discussions

In figure 2 are represented on the same graph the variations of apparent density and compressive strength depending on the percentage of recycled aggregate in hardened concrete. A decline in concrete density was observed with the increase in content of the recycled aggregate, situation also evidenced in the case of densities obtained for fresh concrete. Obviously, this behavior is due to the smaller density of the recycled aggregate compared to the natural aggregate.

The compressive strength of concrete has a surprising variation which was expected to decline by increasing the percentage of the recycled aggregate. This was not confirmed by the destructive tests carried out, much more so, in some compositions seeing a slight increase in strength to concrete with natural aggregate, figure 2.

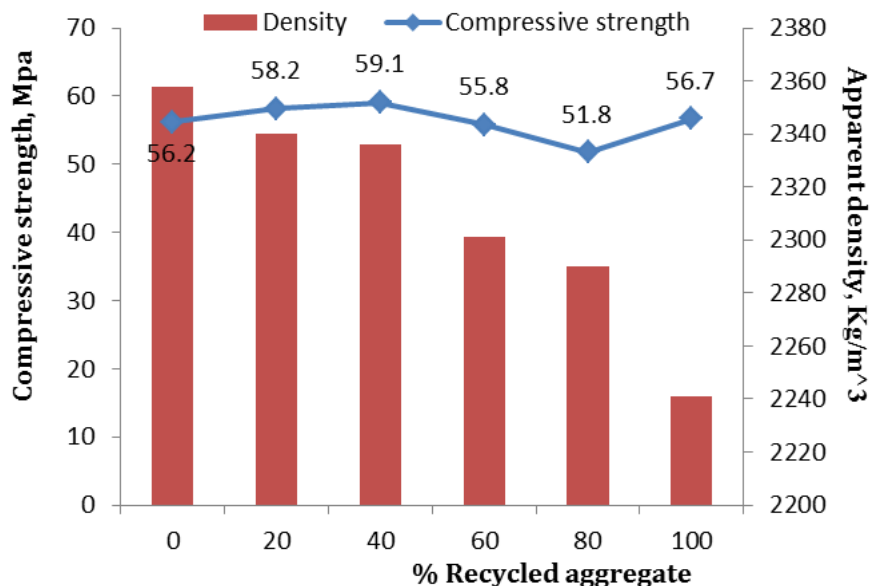


Figure 2 The variation of apparent density and compressive strength of concrete, depending on the proportion of recycled aggregate content.

The explanations for such behavior arise from the following:

- concrete from which the recycled aggregate comes has not been used, its quality is very good, not containing impurities as it usually happens to the demolition aggregate;
- recycled aggregate was obtained by crushing, it has "fresh" surfaces, roughness, which provides a better adhesion to the cement paste compared to the river aggregate;
- unhydrated cement granules of recycled aggregate allow the formation of additional amounts of hydrocomponents with binding properties, during setting and curing of the new concrete, which leads to a strengthening of the structure.

The water absorption of recycled aggregate concrete is greater with the higher proportion of recycled aggregate in concrete (which has a high porosity compared to natural aggregate), correlated with increasing real A/C ratio, used. This is evidenced in figure 3.

Nondestructive tests indicates the decreased of the longitudinal ultrasonic propagation velocity by increasing the proportion of recycled aggregate in concrete (table 2), respectively with porosity increasing and density decreasing of the concrete ( $V_L=340\text{m/s}$  in air and approx.  $5000\text{m/s}$  in metallic bar for calibration).

With the help of stress-strain diagram, drawn using an loading and unloading program of the specific charges, it was determined the static modulus of elasticity by the slope of the graphic (figure 4), after stabilization of the deformations.

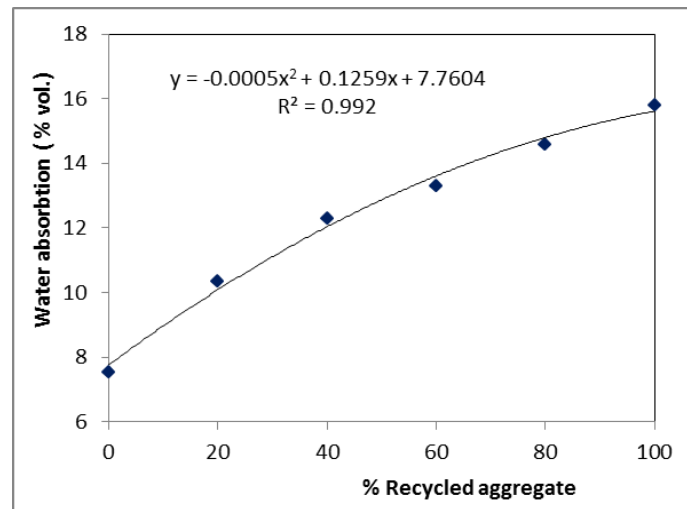


Figure 3 The variation of water absorption (% vol.), depending on the proportion of recycled aggregate content.

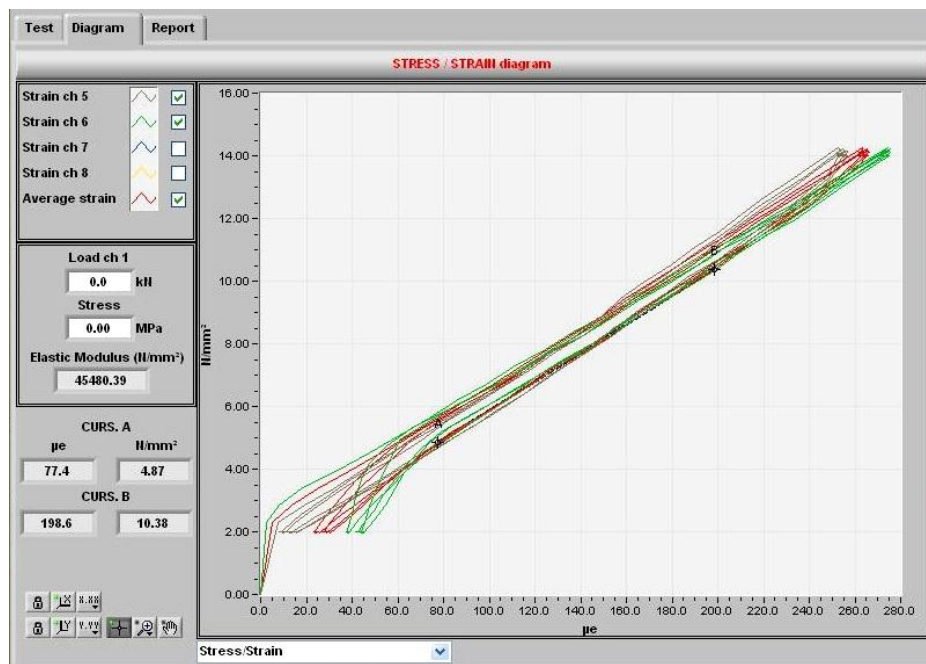


Figure 4 Software interface used for determination of the static modulus of elasticity for the R3 concrete.

Table 2 Recycled aggregate concrete characteristics

Characteristics	R1, 0% recycled	R2, 20% recycled	R3, 40% recycled	R4, 60% recycled	R5, 80% recycled	R6, 100% recycled
Ultrasonic pulse velocity, $V_L$ (m/s)	4688	4505	4491	4386	4333	4261
Dynamic modulus of elasticity, $E_d$ (MPa)	45345	41554	41226	38731	37620	35602
Static modulus of elasticity, $E_s$ (MPa)	48254	47059	45480	43952	38333	32983

The static modulus of elasticity and the dynamic modulus of elasticity, obtained by nondestructive ultrasonic method, shows a decrease values by increasing the proportion of recycled aggregate in concrete, respectively by increasing the A/C ratio (table 2 and figure 5). This is attributed to a lower modulus of elasticity of the recycled concrete aggregates compared to natural aggregate and modulus of elasticity of the new cement stones from concrete [12-13].

Generally, dynamic modulus of elasticity is greater than the static modulus [14], different behavior in this case are due to the fact that for  $E_s$  determinations were carried out at 365 days and 28 days for  $E_d$ .

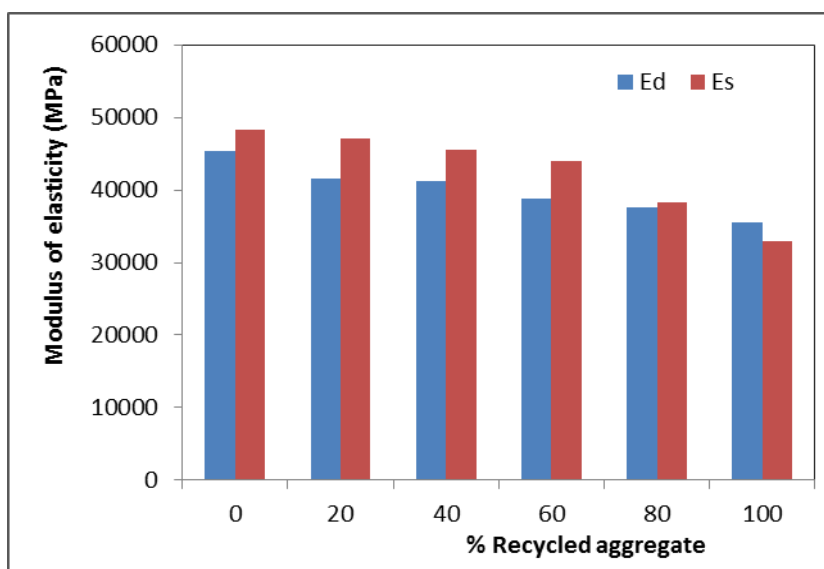


Figure 5 The variation of modulus of elasticity (% vol.), depending on the proportion of recycled aggregate content.

#### 4. Conclusions

Increasing the use of recycled aggregates in new concrete will help eliminate demands on natural resources, reduce landfill disposal, and reduce energy costs associated with transport. The aim to characterize the recycled aggregates is their valorification in new concrete used in construction.

In this regard have been made a series of concrete in which the recycled aggregate content was varied from 0 to 100%. The new concrete were characterized by point of view of the change in the density, compressive strength, water absorption, ultrasonic pulse velocity and modulus of elasticity with the proportion of recycled aggregates.

The majority of these properties shows lower values by increasing the share of recycled aggregate in concrete. This is attributed, particularly, to the presence of adhered mortar in recycled aggregate which causing increased porosity and leads to lighter concretes.

Also, it has been shown that an increase in recycled aggregate content not necessarily mean a reduction in compressive strength, quality of the aggregate having a decisive role.

#### Acknowledgement

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