BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LVII (LXI), Fasc. 2, 2011
Secţia
CONSTRUCŢII. ĂRHITECTURĂ

USE OF RECYCLED AGGREGATES IN RIGID PAVEMENT CONSTRUCTION

BY

MARIUS-TEODOR MUSCALU[*] and RADU ANDREI

"Gheorghe Asachi" Technical University of Iaşi,
Faculty of Civil Engineering and Building Services

Received: February 21, 2011
Accepted for publication: March 23, 2011

Abstract. The paper presents the actual stage of analysis and laboratory studies, undertaken in the frame of postdoctoral program "Develop and Support Multidisciplinary Postdoctoral Programs in Primordial Technical Areas of National Strategy of the Research–Development–Innovation" 4D-POSTDOC, aiming to produce recycled aggregates with physical-mechanical characteristics suitable for use in rigid pavement construction. Recycled aggregates under investigation are obtained by crushing of cement concrete from the demolition of buildings in Iaşi municipality. The main objective of the research is to achieve a higher economic value of the cement concrete resulted from demolitions by recycling and use in the construction of conventional cement concrete pavements (PCC – plain cement concrete) and roller compacted concrete pavements (RCC). An important benefit resulting by using recycled aggregates in pavement engineering is the reduction of the impact of construction works on the environment by both limiting the exploitation of natural aggregates and the use of landfill construction and demolition wastes. Finally, a technical evaluation of the investigated recycled aggregates quality, in accordance with existing standards and norms, will be considered.

Key words: construction and demolition wastes; cement concrete recycling; recycled aggregates; laboratory studies; rigid pavements.

[*] Corresponding author: *e-mail*: mtmuscalu@yahoo.com

1. Introduction

In what follows the results obtained in the first year of post-doctoral research program ”Innovative technologies and logistical solutions for the reuse of demolition and construction waste in the construction of cement concrete and fiber reinforced cement concrete pavements” are presented.

The research aims to develop the recycling technology of construction and demolition waste (CDW) for obtaining recycled aggregates with physical-mechanical characteristics suitable for use in the construction of plain cement concrete pavements (PCC) and roller compacted concrete pavements (RCC). Also, for improvement of the behavior in exploitation stage, steel fiber reinforcement of PCC/RCC with recycled aggregates will be studied.

To achieve the proposed objectives laboratory tests will be performed to determine and evaluate both the physical-mechanical characteristics of recycled aggregates and the performance of fresh/hardened road cement concrete made with recycled aggregates.

The research is relevant for the social and economic environment from Romania justified by the new legislation on waste, Directive 2008/98/EC, implemented by the European Council to member states. The main objective is to increase, at a minimum of 70% by mass, the reuse and recycling of CDW to minimize the negative effects on the environment and human health (Bâsceanu, 2007).

The most important flow for generation of CDW results from demolition of existing buildings, but significant quantities result also from activities like the construction/renovation of buildings or construction/rehabilitation of road and railroad infrastructures.

2. Construction and Demolition Waste

In 2006, in the European Union approximately 970 million tones (2.0 t/year/person) of CDW have been generated representing 31% from total quantity of wastes (municipal and assimilated wastes, street wastes, CDW, sludge from wastewater treatment, etc.). Statistics have shown that, in Europe, the CDW quantities are growing (1.1 t/year/person in 2002, 1.8 t/year/person in 2004) and that between EU member states there are differences in terms of generated quantities (Fig. 1): 5.5 t/year/person in France, 2.33 t/year/person in Germany, 1.66 t/year/person in UK, 0.74 t/year/person in Spain, 0.04 t/year/person in Latvia, etc.

In some countries such as Bulgaria, Cyprus, Greece and Romania very low generated quantities of CDW have been reported to the European Commission which has been interpreted as a lack of control of public authorities. In Romania, due to lack of a centralized record system of generated CDW, the reported statistics present a low level of confidence. In 2006, according to National Institute of Statistics, in Romania approximately 6,808,837 t of municipal wastes have been generated from which about 474,350 t (6.96%) were wastes from construction and demolition activities (Iacoboaea & Şercăianu, 2009).

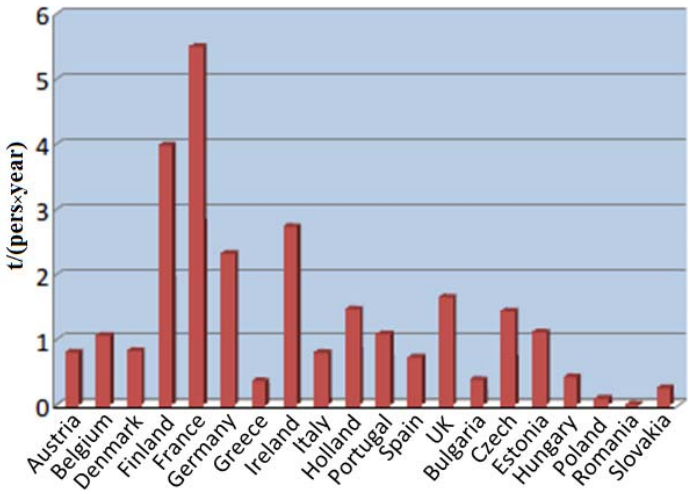


Fig. 1 – Quantities of generated CDW in different EU member states in 2006.

The main factors leading to improper management of CDW in our country are

a) lack of information and interest of contractors regarding environmental protection;

b) lack of knowledge or ignorance of contractors regarding proper waste management in the construction industry;

c) lack of interest for policies to prevent the waste generation in the design/construction stage of buildings;

d) system failure for amendment of contractors, in particular the impossibility to identify responsible organization for storing CDW in inappropriate locations;

e) lack of a national centralized system record of wastes generated from construction and demolition activities;

f) limited number and low capacity of landfills.

It is known that CDW are often disposed in municipality landfills. It is obvious that the volumes of the two types of wastes are becoming equal because of the inert state of most materials from CDW and, for the same reason, landfill capacity is significantly reduced. Recycling of cement concrete resulting from construction and demolition activities is a technical solution leading to significant decrease of costs and environmental issues generated by handling, transport and storage of CDW.

3. Cement Concrete Recycling and Recycled Aggregates

The main material included in CDW is the cement concrete from which, by application of appropriate recycling technologies, recycled aggregates result; they can successfully substitute crushed/quarry natural aggregates to the construction of rigid pavements (Muscalu & Ţăranu, 2010). Thus, by limiting the consumption of natural aggregates and use of recycled cement concrete from CDW, an important impact reduction of the construction on the environment is achieved (http://ec.europa.eu/environment/index_en.htm).

The practical experience has demonstrated that the extraction of cement concrete from CDW is relatively simple, operation that does not require special equipment (Recycling Concrete…, 1999). In the case of building demolition sites it is recommended that materials other than cement concrete are removed as much as possible to avoid contamination. The cement concrete crushing operation should be preceded, where appropriate, by removal of reinforcements and other embedded materials (Poteraş, 2006). For both demolished cement concrete and recycled aggregates measures should be taken to prevent contamination with soil or other materials from demolition process. Documents and drawings from the construction of the demolished buildings, in particular those detailing the quality and composition of the cement concrete, are of important significance because they contain information regarding the performance characteristics of the concrete.

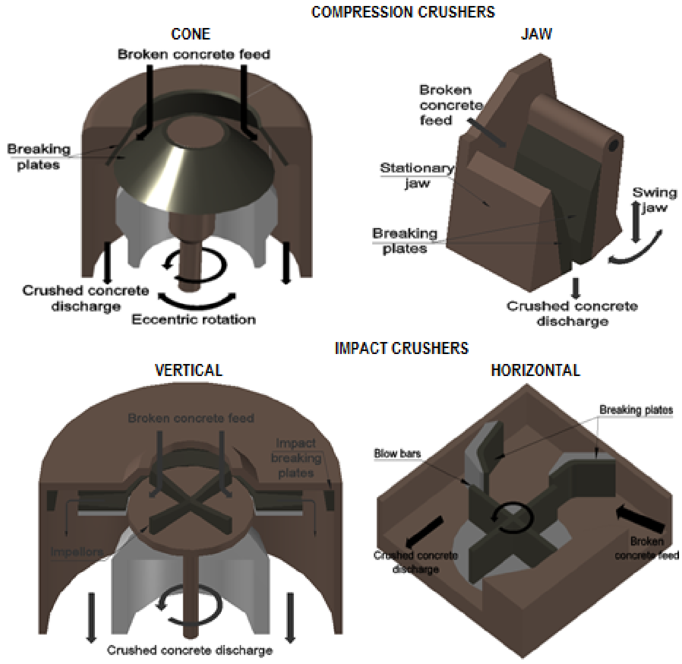


Fig. 2 – Presentation of compression/impact cement concrete recycling equipment.

The organization of a recycled aggregate production site does not differ much from those engaged in the production of natural crushed aggregates; same equipment can also be used for crushing, sorting and storage of recycled aggregates (Muscalu & Ţăranu, 2010).

Recycled aggregates are obtained by compression/impact crushing of broken cement concrete (Won, 1999) using equipment such as those presented in Fig. 2.

For better control of recycled aggregates grading curve it is recommended that the recycling of cement concrete to be carried out in two stages of crushing. First, using a jaw crusher and sieving equipment, the broken concrete is reduced to a granular mix with maximum particle size of 31…40 mm and sorted through the 16/20 mm sieve. In the second stage, the material remaining on the sieve is sent to an impact crusher where the desired maximum size of the recycled aggregate results (Muscalu & Ţăranu, 2010).

Currently, because of both lack of studies in understanding the recycled aggregates and lack of standards and norms for testing and design of cement concrete manufactured with recycled aggregates, most of CDW, especially the mixture from broken cement concrete and bricks, is used in low value applications such as fillings, earthworks and access roads.

4. Experimental Study and Laboratory Tests

Because in the actual economic environment of Romania the recycled aggregates are not a market product, to achieve the research's objectives demolition sites have been identified in the territorial area of Iaşi municipality for purchase of broken cement concrete for direct labor recycling. In Fig. 3 are shown the demolition sites identified in Iaşi municipality in the 01.07.2010… 30.09.2010 period.

Fig. 3 – Identified demolition sites in Iaşi municipality.

Sites *1* and *2* have been identified in Baza 3 area on the right bank of Bahlui, site *3* in Bularga-Ţesătura area and site *4* in Nicolina area. All identified demolition sites aimed to clear the terrain of existing buildings. Main activities include the demolition of industrial buildings (Fig. 4 *a*), crushing of the demolished material (Fig. 4 *b*) and selling of resulting crushed mixture generally used in earthworks and ramps constructions (Fig. 5).

a *b* *c*

Fig. 4 – Demolition process and crushing of demolished material.

Fig. 5 –Use of crushed mixture from demolition sites in earthworks applications.

In Fig. 6 the main component materials of the crushed mixture from demolition sites are shown and in Table 1 are presented details regarding dimensions and frequency.

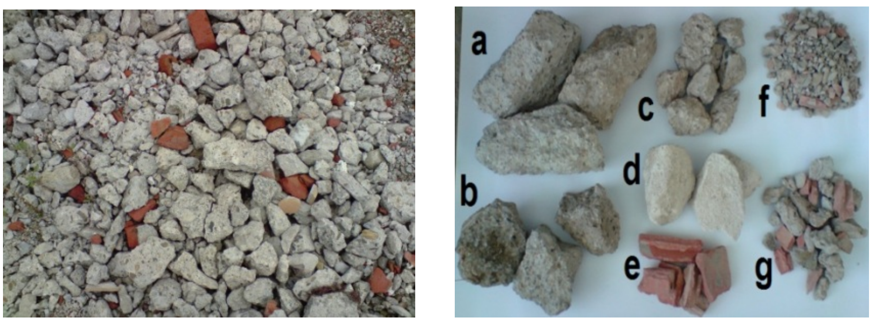


Fig. 6 – Component materials of crushed mixture from demolition sites.

Table 1
Details of Component Materials of Crushed Mixture from Demolition Sites

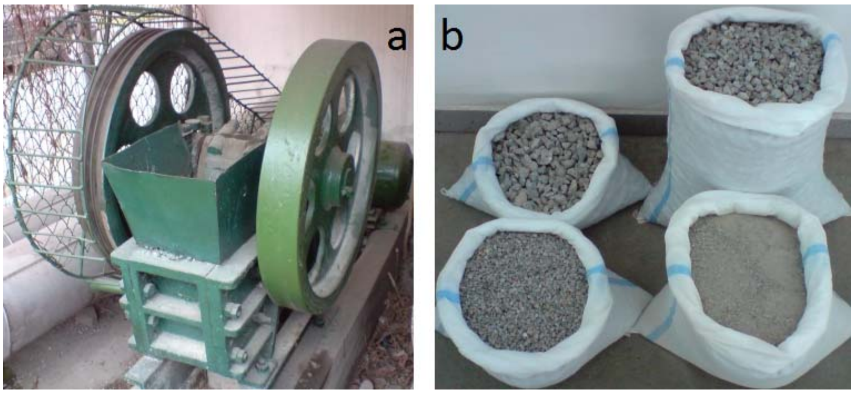
Identifi-cation	Material type	Dimensions mm	Frequency in mixture
A	Broken cement concrete	150…300	Often
B	Broken cement concrete	75…150	Very often
C	Broken cement concrete	40…75	Very often
D	Autoclaved cellular concrete	40…75	Very rare
E	Broken bricks	40…75	Rare
F	Ballast + broken cement concrete and bricks	0…31.5	Often
G	Broken cement concrete and bricks	31.5…40	Often

A and *B* broken cement concrete types can be extracted relatively easy from the crushed mixture by sorting operation using a vibratory sieve of 75 mm and therefore offer the higher recycling potential for obtaining recycled aggregates.

In Fig. 7 is shown the negative effect of the presence of A type broken concrete in the crushed mixture used in earthworks applications leading to both variable bearing capacity and patchy of the constructed layer. These results can have a major contribution in the failure of the upper layers of the road structure. Thus, extraction and recycling of the 150…300 mm broken cement concrete lead to both obtaining a crushed mixture suitable for earthworks applications and adequate economic recovery of the cement concrete.

Fig. 7 – The effect of 150…300 mm broken cement concrete on the uniformity of the constructed layer.

Recycled aggregates studied in this research are direct labor produced by crushing of 75…300 mm broken cement concrete from demolition wastes using a jaw breaker (Fig. 8 *a*). In Fig. 8 *b* the resulting recycled aggregates sorted by 0…4 mm, 4…8 mm, 8…16 mm and 16…25 mm particle size classes are presented.



a *b*

Fig. 8 – Used jaw crusher and resulting recycled aggregates.

In Table 2 and Fig. 9 the grading curve distribution of the recycled aggregate is ilustrated.

Table 2

The Grading Curve Distribution of Obtained Recycled Aggregates

Sieve size mm	0.20	0.63	1	2	4	8	16	25	32
Passing %	2.59	6.34	8.54	13.63	22.88	43.37	87.84	98.29	100.00

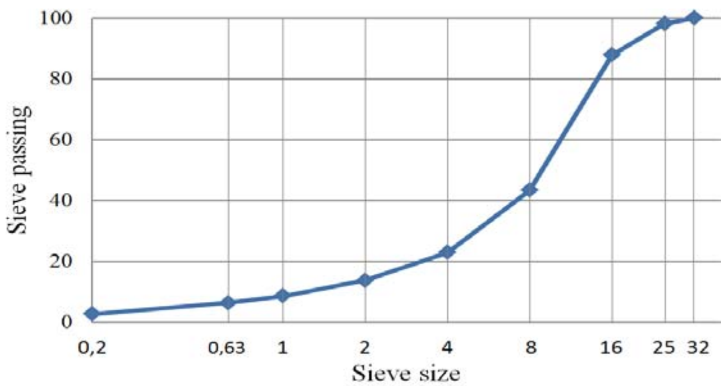


Fig. 9 – The grading curve of obtained recycled aggregates.

To study the possibility of using recycled aggregated in rigid pavement construction emerged the need for a comparative analysis between their physical-mechanical characteristics and the performance characteristics imposed by standards and norms for natural crushed aggregates. In Table 3 the results of the undertaken laboratory tests are presented.

Table 3
Physical-Mechanical Characteristics of Recycled Aggregates[1] and Standards/Norms Requirements for the Performance of Crushed Gravel[2] and Chippings[3] Used in Rigid Pavement Construction

Characteristic, [M.U.]	Aggregate size, [mm]	RA[1]	CG[2]	C[3]
Sand equivalent, [%]	0…4	72.84	min. 85	–
Activity coefficient, [n/a]	0…4	1.04	–	max. 1.5
<0.1mm particle size content, [%]	4…8	0.2	–	max. 1.5
	8…16	0.1	–	max. 1.0
	16…25	0.1	–	max. 0.5
Los Angeles wear coefficient, [%]	4…8	24.25	max. 35	max. 18
	8…16	26.01	max. 30	max. 18
	16…25	27.30	max. 25	max. 18
MicroDeval wear coefficient, [%]	10…14	18.80	–	max. 20
Dry state density, [mg/m^3]	4…8	2.2163	–	–
	8…16	2.3034	–	–
	16…25	2.2539	–	–
Saturated state density, [mg/m^3]	4…8	2.3427	–	–
	8…16	2.4035	–	–
	16…25	2.3788	–	–
Absorption coefficient, [%]	4…8	5.70	–	–
	8…16	4.34	–	–
	16…25	5.54	–	–
Crushing coefficient, [%]	4…8	81.86	min. 65	min. 90
	8…16	80.75	min. 65	min. 90
	16…25	89,50	min. 65	min. 90
Impact wear coefficient, [%]	8…12.5	44.27	–	–

The allowable values for the characteristics of crushed gravel and chippings used in rigid pavement construction are standard requirements and specific for first technical road class (highways, intense traffic roads).

5. Conclusions

The cement concrete recycling from CDW leads to improvement of environmental pollution parameters by preserving natural resources and generating free space in landfills. Also adequate economical value recovery of the cement concrete will be achieved by producing recycled aggregates which can be used in higher value construction works.

The experimental study shows that with minimum effort, appropriate aggregates can be obtained by cement concrete recycling which may compensate the consumption of needed natural crushed aggregates in pavement engineering.

The performed laboratory tests have proved that recycled aggregates had similar performance characteristics with crushed gravel as chippings used in rigid pavement construction. The resulted recycled aggregates present a continuous grading curve, an important characteristic for the performance of the cement concrete slabs.

Recycled aggregates and natural crushed aggregates can be used concomitant for the construction of cement concrete pavements in different proportions. In literature (Won, 1999) laboratory tests show that if maximum 30% of natural aggregates used in cement concrete manufacturing is replaced with recycled aggregates, the performance characteristics of hardened concrete are not significantly affected. This could be the most simple, economical and less problematic method for using recycled aggregates in concrete manufacturing.

Acknowledgements. This paper was supported by the project "Develop and Support Multidisciplinary Postdoctoral Programs in Primordial Technical Areas of National Strategy of the Research–Development–Innovation" 4D-POSTDOC, contract nr. POSDRU/89/1.5/S/52603, project co-funded from European Social Fund through Sectorial Operational Program Human Resources 2007…2013.

REFERENCES

Bâsceanu E.C., *Deşeurile din Construcţie şi Demolare*. Simp. "Impactul Acquis-ului Comunitar asupra Echipamentelor şi Tehnologiilor de Mediu", Agigea, 2007.

Iacoboaea C., Şercăianu M., *Reciclarea deşeurilor din construcţii şi demolări – o necesitate?*. Rev. Econ. Română, **XII**, *33* (2009).

Muscalu M.T., Ţăranu N., *Use of Recycled Materials in Pavement Construction*. The 8th Internat. Symp. Highway and Bridge Engng., Vol. "Technology and Innovation in Transportation Infrastructure", Iaşi, 2010.

Poteraş G., *Reciclarea materialelor provenite din reciclări şi dezafectări*. Bucureşti, 2006.

Won M.C., *Use of Crushed Concrete as Aggregate for Pavement Concrete*. Res. Section, Constr. Div., Texas Dept. of Transp., Texas, USA, 1999.

* * * *Recycling Concrete and Masonry*. Environm. Council of Concr. Organiz., 1999.

* * * *Directive 2008/98/EC* of the European Parliament and of the Council, 2008.

* * * http://ec.europa.eu/environment/index_en.htm.

* * * http://www.insse.ro.

UTILIZAREA AGREGATELOR RECICLATE LA EXECUŢIA STRUCTURILOR RUTIERE RIGIDE

(Rezumat)

Se prezintă rezultatele unor analize şi studii de laborator întreprinse în cadrul programului postdoctoral "Dezvoltarea şi susţinerea de programe postdoctorale multidisciplinare în domenii tehnice prioritare ale strategiei naţionale de cercetare–dezvoltare–inovare" 4D-POSTDOC, ce urmăresc obţinerea de agregate reciclate cu caracteristici fizico-mecanice corespunzătoare utilizării la realizarea de structuri rutiere

rigide. Agregatele reciclate ce fac obiectul cercetării sunt obţinute prin concasarea betonului de ciment provenit din dezafectarea unor construcţii de pe raza municipiului Iaşi. Obiectivul principal al temei de cercetare este valorificarea corespunzătoare a betonului de ciment rezultat din demolări prin reciclare şi utilizare la execuţia dalelor structurilor convenţionale din beton de ciment rutier (BcR) şi beton de ciment compactat prin cilindrare (RCC – roller compacted concrete). Un beneficiu important obţinut prin utilizarea agregatelor reciclate în tehnica rutieră din ţara noastră îl constituie diminuarea impactului lucrărilor executate asupra mediului înconjurător atât prin limitarea exploatărilor de agregate naturale cât şi prin utilizarea depozitelor de deşeuri din construcţii şi demolări (DCD).