World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:6, No:4, 2012

Mechanical-Physical Characteristics Affecting the Durability of Fibre Reinforced Concrete with Recycled Aggregate

Vladimira Vytlacilova

***Abstract*—**The article presents findings from the study and analysis of the results of an experimental programme focused on the production of concrete and fibre reinforced concrete in which natural aggregate has been substituted with brick or concrete recyclate. The research results are analyzed to monitor the effect of mechanical-physical characteristics on the durability properties of tested cementitious composites. The key parts of the fibre reinforced concrete mix are the basic components: aggregates – recyclate, cement, fly ash, water and fibres. Their specific ratios and the properties of individual components principally affect the resulting behaviour of fresh fibre reinforced concrete and the characteristics of the final product. The article builds on the sources dealing with the use of recycled aggregates from construction and demolition waste in the production of fibre reinforced concrete. The implemented procedure of testing the composite contributes to the building sustainability in environmental engineering.

***Keywords*—**Recycled aggregate, Polypropylene fibres, Fibre Reinforced Concrete, Fly ash.

I. Introduction

WASTE management is a relatively young yet a dynamically growing sector of the national economy of most developed countries. Industrially and economically advanced countries have only developed their waste management intensively over the last 20-30 years; the first Waste Act was adopted in the Czech Republic as recently as 1991. Prior to 1991, the handling of waste was subject to no legislative control or rules in the Czech Republic, and was not governed by any sectoral rules with the exception of so-called secondary raw materials [1].

Legal rights and obligations are closely related to administrative tasks. The current Act no. 185/2001 Coll. "*On Waste and Amendment of Some Other Acts*" emphasizes waste prevention, defines the hierarchy of waste handling, and promotes the fundamental principles of environmental and health protection in waste handling [2].

The Waste section comprises information on how to handle generated waste as well as on waste prevention, obligatory handling of selected products, waste types and appliances, and relevant methodological guidelines. Waste is the most frequent and best documented "*by-product*" of human society. Construction and demolition waste (C&DW) constitutes a major portion of the total solid waste production in the world (estimated as 30 – 40%), and most of it is used in landfills, for reclamation or landscaping all the time. Illegal landfills (Fig. 1) of C&DW are a great problem in the Czech Republic.

Vladimira Vytlacilova works for the Department of Concrete and Masonry Structures, Faculty of Civil Engineering, Czech Technical University in Prague, Prague, Czech Republic, e-mail: vladimira.vytlacilova@fsv.cvut.cz.

Fig. 1 Illegal land-fill of construction and demolition waste in nature

Due to specific properties of C&DW and varying degrees of environmental risks, each waste flow requires a specific treatment method. The basic rules for waste treatment are set out by the Waste Act and its executive regulations. The goals and targets for the various waste treatment methods and the optimum ways of achieving them are set out by the "*Waste Management Plan of the Czech Republic for 2003-2013*", which was published in the form of a Government Regulation in compliance with the Waste Act [3].

In the EU there is a common interest in sustainable development in terms of environmental protection. The preservation of the environment and the conservation of the rapidly diminishing natural resources should be the essence of sustainable development. Whereas, on the one hand, there is a shortage of natural aggregates (NA) for the production of new concrete, enormous amounts of demolition waste produced from deteriorated and obsolete structures, on the other hand, create a severe ecological and environmental problem.

It is obvious that the recycling of aggregates for building structures is necessary. One of the ways to solve this problem is to use this 'waste' as aggregates. Such 'recycled' aggregate could also be a reliable alternative to using natural aggregates in concrete construction. The main objective of the presented experimental research is, therefore, the maximum utilization of concrete and, above all, masonry rubble gained from construction and demolition waste in the new production of fibre reinforced concrete.

II. Fibre Reinforce Concrete With Recycled Aggregates

Recycled concrete and masonry aggregates produced from construction and demolition waste is an alternative source for the production of concrete aggregates, and the acceptance of recycled concrete aggregates for the production of new concrete depends on the quality of them. Recycled aggregates differ from natural aggregates by the presence of a considerable proportion of mortar attached to natural aggregates and consequently affecting the properties and performance of concrete.

In order to increase the percentage of the reuse of total C&D waste a new concept of the concrete mix design has been developed. The replacement of only 10% to 30% of virgin sand and gravel aggregates is usually used for new concrete. For the new mix design of concrete a composite using 100% recycled aggregates in only one fraction (fine and coarse) is tested to produce concrete of acceptable quality that is sufficient for some structures according to [4–8].

The combination of recycled masonry or concrete rubble, synthetic fibres and a binder creates unusual fibre reinforced concrete; a new composite which offers a wide scope of possible uses in the construction industry. The application of this composite material is ensured by the synthetic fibres which, along with the other components, constitute the tough structure of the composite favourable especially under tensile loading due to its high ductility.

One of the possible applications of the fibre reinforced concrete composite is the strengthening of layers in earth structures like levees, dams or dikes. Inserting slabs in the body of earth structures contributes to the stability and higher resistance of the structures. The slope or dam may have a steeper sloping, which reduces earthmoving work. Inserting fibre-concrete slabs into the dam results in enhanced resistance of the dam in the case of a spill-over that may happen during floods. Suggested utilizations of this composite in earth structures are presented in [7].

The results of the presented laboratory test show the possibilities of using concrete or masonry rubble obtained from C&DW as full replacement of natural aggregates together with synthetic fibres, minimum amounts of cement and, by reason of minimum costs and environmental load, fly ash.

This paper is the continuation of an experimental program with the aim of understanding the behaviour of this composite for use in earth structures. The paper is focused on additional tests that describe the properties of the composite, especially durability properties.

III. Construction And Demolition Waste In Czech Republic

The EU has only recently introduced recycling targets for construction and demolition waste. A 70% recycling target was introduced in the new "*EU Waste Framework Directive 2008/98/EC*" to be achieved by 2020. It only includes recycling of non-hazardous construction and demolition waste and excludes soil and stone [9].

At present, recycled materials in the Czech Republic mostly come from recycled waste of bricks, concrete, asphalt, mixed building waste, various types of aggregates and soil. There are more than 200 recycling centres (static and mobile) and deposits in the Czech Republic which process construction and demolition waste. Unfortunately, the current recycling rate in the Czech Republic is still way behind the urgency of this problem. The total yearly capacity of all the recycling centres in the Czech Republic is about 7.5 million tons, which is 50 % more than the actual production of recycled materials. Recycled masonry and concrete waste, which is the product of these centres, can be graded according to the customer's requirements; the strictest grading is used when the recycled material should be used as aggregates in ordinary concrete. As in the rest of the world, reacting to the demands of the construction industry, the production of this material is growing at a great pace in our country as well.

The Association for the development in the recycling of building materials (ARSM) has summarized the yearly C&DW output since 1999. The debris from demolished buildings is thrown away, causing environmental pollution, or is used as filling material. If the rubble material is sorted and if the presence of all foreign material that could be introduced in the recycling operation, especially deleterious content, is checked thoroughly, the utilization of concrete and masonry rubble for the mixing of structural concrete is possible and eligible. Only very little C&DW waste is recycled for high-specification applications because potential users are deterred by the perceived risks involved.

Since 2007, annual data on waste, including construction and demolition waste, have been summarized by the Czech Environmental Information Agency (CENIA). This agency files the information on waste management in the ISOH database.

Between 2002 and 2006, the data were administered by the T. G. Masaryk Water Research Institute, a public research institution – the Waste Management Centre. Unfortunately, the data obtained in the ISOH database are probably incomplete.

The production of masonry and concrete demolition waste in recycling centres is documented in Fig. 2. This inert, inorganic waste is most suitable for use in new concrete.

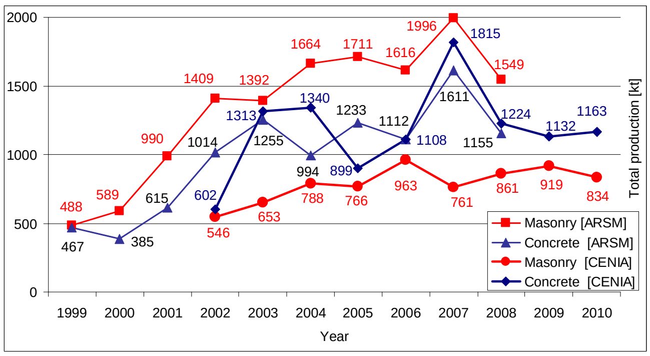

Fig. 2 Total production of crushed demolition waste in recycling centres in the Czech Republic (in thousand tons)

[Source: ARSM, CENIA] [10-11]

IV. Terminology In Recycling

The following terminology will be used in publications about recycled materials:

Construction and demolition waste are waste materials which arise from the construction or demolition of buildings and/or civil engineering infrastructure, including hard C&D waste and excavation waste, whether segregated or mixed. It could be broken concrete, bricks, masonry, soil, asphalt, tiles, wood, plastic, metal etc. from demolished buildings.

Recycled concrete (RC) or *concrete rubble* (CR) is hardened (old) concrete that has been processed for reuse, usually as aggregates. It has been demolished and removed from pavements, bridges, foundations, or buildings and crushed into various sizes for reuse.

Recycled masonry or brick (RM) or *masonry rubble* (MR) is old masonry from building that has been processed for reuse, usually as aggregates. It contains a certain amount of mortar debris.

Recycled concrete aggregates (RCA) are aggregates produced by the crushing of original concrete (inorganic material previously used in construction and principally comprising crushed concrete). Such aggregates can be fine or coarse recycled aggregates. They may also be referred to as recycled aggregates. Recycled concrete aggregates are increasingly available and are often an economical alternative to new aggregates.

Recycled aggregate concrete (RAC) is concrete produced from recycled aggregates or a combination of recycled and conventional aggregates such as sand, gravel, or crushed stone. Sometimes it is referred to as new concrete. RCA is obtained from crushing demolished concrete structures, discarded precast elements and unused hardened concrete.

V. Experimental Programme

The experimental programme dealt with the verification of selected material characteristics of the composite relevant for the presumed applications – compressive strength, splitting tensile strength, flexural tensile strength and modulus of elasticity. These basic mechanical-physical characteristics are most important for the estimation of the advisability of the production of this composite and are very important for the proposed dimensions of structural elements.

To use this composite in practice it was necessary to perform additional tests that have a large impact on both the design of structures in practice and for a better understanding the behaviour of the composite.

One of the most important properties of concrete as well as fibre reinforced concrete is durability, which ensures that it will preserve performance throughout its life. Insufficient durability leads to its degradation and deterioration of its mechanical- physical properties.

Durability is the ability of concrete to resist the action of weathering, chemical attacks, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment and the properties desired. Concrete ingredients, their proportioning, interactions between them, placing and curing practices, and the service environment determine the ultimate durability and life of concrete.

Important conditions and deterioration mechanisms in concrete structures are freezing and thawing, alkali – silica reaction, alkali – carbonate reaction, corrosion, carbonation, chemical incidence (SO_4^{2-}), deicer scaling or fire resistance.

There are many types of tests for the assessment of durability, both physical and chemical durability. The tests included in this experimental programme were the assessment of the absorptivity of composites, the freeze-thaw resistance and the resistance of composite surfaces to defrosting chemicals according to Czech standards.

The procedure of testing composites followed:

- economic criteria (cost minimization)
- simplicity of technology
- maximum utilization of recycled aggregate
- possible applicability in practice
- controlled material properties of composite
- contribution to building sustainability.

To obtain a comparison of the effect of recycled aggregate on these mechanical-physical properties of cement composites with fibres and fly ash eight series of testing samples were produced.

For all tests, each result is the average of three samples. This experimental work is the continuation of research at CTU in Prague [4-8].

VI. Materials

A. Recycled masonry and concrete aggregates

This work aims to analyze the influence of two types of aggregates, one from recycled concrete and the other from recycled masonry, that fully substitute natural aggregates in the properties of new concrete. Recycled masonry aggregates were from two locations. Recycled aggregates in concrete replace 100% content of natural aggregates. Unclean brick, masonry or concrete rubble was shattered in a recycling company. This construction and demolition waste arising from demolition may be contaminated with mortar and plaster, and it is also often mixed with other materials such as timber, metal or glass. This aggregate was supplied by a local demolition company (KARE and WEKO, Prague) where it was passed through a jaw crusher and was transported to a laboratory. After using a jaw crusher only one fraction (0/32 mm) of recycled masonry or concrete was obtained and used for the recycled concrete mix design in this experimental program.

The grading size curve of the aggregates used and other properties are presented in [8]. Reference concrete was made with natural sand of the 0/4 mm fraction and coarse gravel in fractions of 4/8 and 8/16 mm.

B. Cement

Commercial Portland Mixed cement of the CEM II/B-M (S-LL) 32.5R type (Heidelbergcement Group, Mokrá) according to EN-197-1 was used. The amount of cement was 300 kg/m^3 for specimens C3, B3, P3 and CB3. Half of the specimens

(CP, BP, PP, CBP have reduced amounts of cement by 10% compensated by 20% of the fly-ash mass. The characteristics of cement are shown in Table 1.

TABLE I
CHARACTERISTICS OF CEMENT

Characteristics	Volume	x% by weight
Cement clinker	65-79	x% by weight
Blast-furnace slag and lime stone	21-35	x% by weight
Supplementary	0-5	x% by weight
Specific surface	553	m^2/kg
Consistence	29.2	%
Stability of volume	0.9	mm
Compressive strength (28 days)	46.7	MPa
Flexural tensile strengths (28 days)	8.1	MPa
Sulphate volume	2.5	x% by weight
Cl	0.079	x% by weight
K_2O	0.79	x% by weight
Na_2O	0.16	x% by weight
Na_2O equiv.	0.68	x% by weight

C. Polypropylene fibres

FORTA FERRO® synthetic polypropylene fibres were used for experimental tests The dosage of these fibres was determined as 1.0 % of the volume content. FORTA-FERRO® are non-corrosive, non-magnetic, and 100% alkali proof fibres with a length of 54 mm, specific gravity of 910 kg/m^3 and tensile strength of 620-758 MPa [12].

D. Fly ash

Fly ash from Třinec, CR was used for experimental tests. Its chemical composition is given in Table II [13].

TABLE II
CHEMICAL COMPOSITION OF FLY ASH

Component	x% by weight
SiO_2	53.5
Al_2O_3	21.5
Fe_2O_3	5.8
FeO	0.2
TiO_2	0.,9
Cr_2O_3	< 0.1
P_2O_5	0.4
CaO	6.7
MgO	3.2
MnO	< 0.1
K_2O	2.6
Na_2O	0.2
C	2.6
S	2.5

Fly ash was first used in concrete in the 1970s. After extensive research and several decades of successful utilization of fly ash, there is no basis for any restrictions on the quantity of fly ash that should be permitted to be used in concrete. The performance benefits fly ash provides to the mechanical and durability properties of concrete have been well researched and documented in actual structures [7-9].

E. Water

The amount of water should be decided according to workability requirements. The water / cement ratio in the samples was 0.48 – 0.7.

F. Mixing Procedure

Mixing was carried out in two stages. Initially, aggregates, cement and eventually fly ash were mixed in a pan mixture for about 1.5 minutes. Successively, fibres and part of water were added to solid particles and the mixing continued for another 3 minutes.

At the end of this mixing the second part of water was added to the mix and fresh fibre reinforced concrete mix was mixed for further 2 to 3 minutes.

G. Design of Mix Proportion

The key parts of the fibre reinforced concrete mix are the basic above mentioned components: aggregates – recyclate, cement, fly ash, water and fibres. The composition of aggregates and admixtures is show in Table III.

TABLE III
COMPOSITION OF AGGREGATE AND ADMIXTURE IN SAMPLES

Samples	Aggregate	kg/m^3	Admixture
C3	Recycled masonry WEKO	1358	-
CP	Recycled masonry KARE	1466	Fly ash
B3	Recycled concrete	1818	-
BP			Fly ash
P3	Natural sand 0/4mm Natural gravel 4/8 mm Natural gravel 8/16 mm	870 235 785	-
PP			Fly ash

VII. MECHANICAL – PHYSICAL PROPERTIES

The results of mechanical – physical properties of the samples of fibre reinforced concrete with masonry or concrete recycled aggregates are obvious from Tables 4 – 5 below. The reported values are the average strength of three specimens. Some of these results were presented in a separate paper [8] and are presented here by reason of investigation of their effect on the durability of composites.

Bulk density was specified in accordance with the respective ČSN EN 12390-7 “*Testing of hardened concrete, Part 7: Density of hardened concrete*“.

Compressive strengths of the specimens were tested according to the methodology of ČSN EN 12390-3 “*Testing of hardened concrete, Part 3: Compressive strength of test specimens*”. A set of three standard cubes 150x150x150 mm for each test was tested at the age of 28 days. Compressive cylindrical strength was tested using the modulus of elasticity test.

Splitting tensile strengths of the specimens were tested according to the methodology of ČSN EN 12390-6 "*Testing of hardened concrete, Part 6: Tensile splitting strength of test specimens*" and, like in compressive strengths, they were tested on standard cubes.

Flexural tensile strengths of the specimens were tested according to the methodology of ČSN EN 12390-5 "*Testing of hardened concrete, Part 5: Flexural strength of test specimens*". This is a test on concrete beams to resist failure in bending. The tests were performed on prisms with four-point bending as specified in the standard. The bending test (force/deflection) performed by so-called controlled deformation on prisms with dimensions of 100x100x400 mm represents the most conclusive test for the identification of the properties of the tested composites.

The modulus of compression was identified under the European standard ČSN ISO 6784 "*Determination of static modulus of elasticity in compression*" on a standard cylinder with a diameter of 150 mm and a length of 300 mm.

TABLE IV
PROPERTIES OF COMPOSITES

Samples	Bulk density [kg/m^3]	Compressive cylindrical strength [MPa]	Compressive cube strength [MPa]
C3	1871	25.5	23.69
CP	1714	13.5	15.21
B3	2219	27.5	30.31
BP	2203	255	27.32
P3	2301	39.5	44.78
PP	2265	29.5	27.41

TABLE V
PROPERTIES OF COMPOSITES

Samples	Tensile splitting strength [MPa]	Modulus of elasticity [GPa]	Flexural tensile strength [MPa]
C3	2.56	10.3	3.62
CP	2.16	7.4	2.21
B3	3.12	17.57	3.46
BP	2.98	17.57	3.72
P3	3.13	32.1	4.52
PP	2.41	26.13	3.41

VIII. DURABILITY PROPERTIES

In terms of durability tests the assessment of the absorptivity of composites, the freeze-thaw resistance and the resistance of composite surfaces to defrosting chemicals was performed.

All tests were performed according to Czech standards:

- ČSN 73 1316 Determination of moisture content, absorptivity and capillarity of concrete
- ČSN 73 1380 Testing the freeze-thaw resistance of concrete - Internal structural damage
- ČSN 73 1322 Determination of frost resistance of concrete
- ČSN 73 1326 Resistance of cement concrete surface to water and defrosting chemicals (method A)
- ČSN EN 12504-4 Testing concrete - Part 4: Determination of ultrasonic pulse velocity
- ČSN 73 1371 Non-destructive testing of concrete – Method of ultrasonic pulse testing of concrete

A set of three standard samples for each test and a series of composites were tested at the age of 90 days. The freeze-thaw resistance test was done on standard prisms 100x100x400 mm, the absorptivity test on half cubes 150x150x150 mm and resistance to defrosting chemicals was tested on a half of a standard cube 150x150x150 mm, too.

The top surface of the cube was exposed to 50 cycles (2x25) of freezing and thawing in the presence of a 3% NaCl solution. The performance of concrete was evaluated visually and by determining the cumulative scaling residue in g/m^2. Ultrasonic pulse testing is a new way of the frost resistance determination of concrete using methods for the structural damage monitoring. The relative dynamic modulus of elasticity ($RDM_{UPPT,n}$) is an important evaluation criterion for the assessment of the damage volume, calculated either from the resonance frequencies or from the propagation velocity of ultrasonic waves. Below are shown the quoted results of the monitoring related to the concrete surface based on cycles.

Table VI shows the surface absorptivity after 15 min. in g / 1m^2 and the absorptivity of tested composites.

TABLE VI
SURFACE ABSORPTIVITY AND ABSORPTIVITY

Samples	Surface absorptivity 15 min [g / 1m^2]	Absorptivity [%]
C3	1946	9.9
CP	2478	12.5
B3	1433	5.7
BP	1426	11.1
P3	778	4.3
PP	1368	3.5

Fig. 3 shows scaling after 25 and 50 cycles in g / 1m^2 by testing resistance to defrosting chemicals

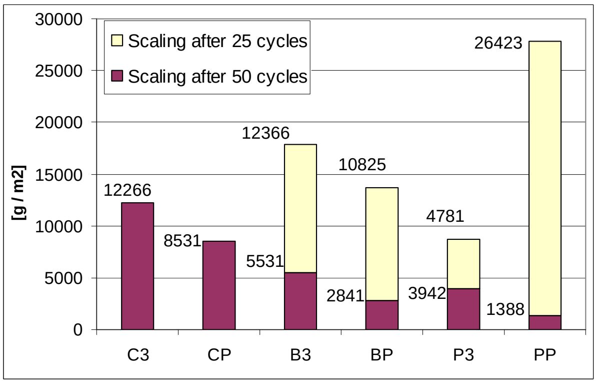

Fig. 3 Concrete surface resistance to defrosting chemicals

The relative dynamic modulus of the samples without fly ash is shown in fig. 4 and with fly ash in fig. 5. The values of the relative modulus of the samples with CP fly ash could not be tested after 20 and 30 cycles and with BP after 30 cycles.

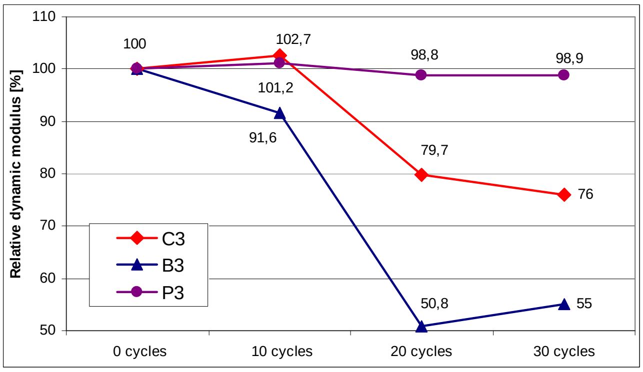

Fig. 4 Relative dynamic modulus of elasticity of composite without fly ash

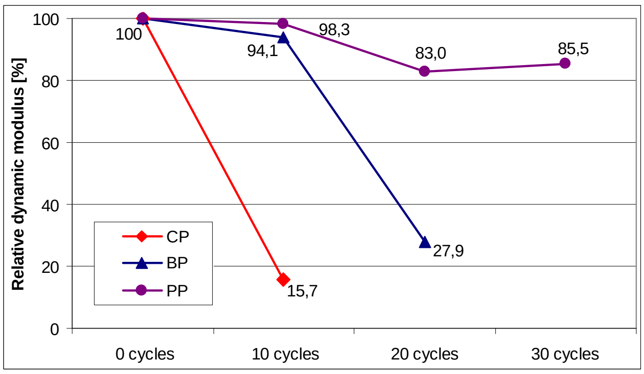

Fig. 5 Relative dynamic modulus of elasticity of composite with fly ash

IX. Results And Discussion

The tested composite material with full replacement of natural aggregates with masonry or concrete rubble has limited, but well utilizable properties for building structures. The application of this composite is ensured by synthetic fibres, which change the behaviour of this material. A positive effect of fly ash as partial replacement of cement in concrete was proved by the test results.

Based on the presented results, it can be concluded that fibre reinforced concrete with such characteristics is applicable in practice. The selected areas of applications are earth structures and dams and, therefore, it will perform in other settings than ordinary concrete in building structures.

It is necessary to say that this material was tested with small amounts of cement and due to the anticipated application in earth structures the fibre reinforced composite was produced as porous concrete with lacunose structures. The results of the composites confirm the premise of no frost resistance and resistance to defrosting chemicals. The composite was prepared without additions. The difference in strength properties between recycled aggregates and natural aggregates in the prepared mix design of composites was unexpectedly minimal. The difference in durability properties, on the other hand, was great.

Acknowledgment

The article was elaborated with financial support from the grant project of the Czech Science Foundation No. 104/10/1128 “Identification of material characteristics of cementitious - fibre composites with a full application of recycled materials”.

References

[1] www.mzp.cz, February 2012.
[2] Act no. 185/2001 Coll. “On Waste and Amendment of Some Other Acts.
[3] Waste Management Plan of the Czech Republic for 2003-2013.
[4] Vytlacilova, V.; Fibre concrete with recycled aggregates as a full substitution of natural aggregates, Dissertation, Prague, 2009.
[5] Vyborny, J., Hanzlova, H., Vytlacilova, V., Vodicka, J.; Fibre concrete produced with recycled aggregate from construction and demolition waste, Beton TKS, 2/2010.
[6] Vytlacilova, V., Vodicka, J.; Properties of fiber reinforced concrete using recycled aggregates, Advances in Control, Chemical Engineering, Civil Engineering & Mechanical Engineering, Tenerife, 2010.
[7] Vodička, J., Vytlacilova, V.; The models suitable for application of fibre concrete with recycling material, Central Europe toward Sustainable Building, Prague 2010.
[8] Vytlacilova, V.; Effect of recycled aggregate on mechanical – physical properties of fly ash-based composites with fibres, International Journal of Chemical and Environmental Engineering, 59, 2011.
[9] Tojo, N., Fischer, Ch.; Europe as a Recycling Society, European Recycling Policies in relation to the actual recycling achieved, ETC/SCP working paper 2/2011, European Environment Agency.
[10] www.arsm.cz, February 2012.
[11] www.cenia.cz, February 2012.
[12] Technical sheet FORTA FERROTM, 06/ 2011.
[13] http://waste.fce.vutbr.cz/Odpad/Popilek_chem.html, 06/2011.
[14] Zhang, Y., Wei,S., Shengxia, Ch.; Study on properties of rubber included concrete under wet-dry cycling, Measuring, Monitoring and Modeling Concrete Properties, pp. 395-401, 2006.

[15] Jian Yang, Qiang Du, Yiwang Bao; Concrete with recycled aggregate and crushed clay bricks, Construction and Building Materials 25, 2011, pp. 1935-1945.

[16] Mokal, M.; Achieving sustainable construction through use of fly ash in concrete – An Indian experience, Sustainable Construction Materials and Technologies, London, 2007.

[17] Hebhoub, H., Aoun, H., Belachia, M., Houari, H., Ghorbel, E.; Use of waste marble aggregates in concrete, Construction and Building Materials 25, pp. 1167-1171, 2011.

[18] Chakradhara, M., Bhattacharyya, S.K., Barai, S.V.; Influence of field recycled coarse aggregate on properties of concrete, Materials and Structures, 05/2010.

[19] Angulo, S. C., Carrijo, A. D., Figueiredo, A. D., Chave,s A. P., John, V. M.; On the classification of mixed construction and demolition waste aggregate by porosity and its impact on the mechanical performance of concrete, Material and Structures, pp. 519-528, 2010.

[20] Ohtsu, M.; Nondestructive evaluation of damaged concrete due to freezing and thawing by elastic-wave method, Journal of advanced concrete technology, pp. 333-341, 3/2005.