BLOCURI DIN BETON CU GOLURI UTILIZÂND DEȘEURI CA ÎNLOCUITORI AI AGREGATELOR NATURALE

CONCRETE HOLLOW BLOCKS WITH WASTE MATERIALS REPLACING THE NATURAL AGGREGATES

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The article presents the experimental and the numerical results obtained on hollow blocks made of concrete with waste materials, as substitution of the natural aggregates. Two types of waste materials were used, shredded Polyethylene terephthalate (PET) bottles and sawdust, to replace the sand in a dosage of 40%. Fly ash was also used for replacing 10% of cement from the regular concrete mix. The density, compressive strength, modulus of elasticity and compressive force-deformation diagrams were experimentally determined. The constructed concrete hollow blocks were tested in compression and the ultimate load and failure types under loading were relieved. A numerical analysis of the concrete hollow blocks behaviour under compressive load using ATENA software was also performed. It was observed that the failure in compression of the tested blocks was a stepwise, progressive type one, the cracks pattern being matched with areas where tensile stresses exceeded the strength of the analysed materials. The results of the carried out studies showed a good correlation between the numerical and the experimental data.

Articolul prezintă rezultatele experimentale și numerice obținute pe blocuri din beton preparate folosind deșeuri ca înlocuitor pentru agregatele naturale. Au fost folosite două tipuri de deșeuri, recipiente din PET tocate și rumeguș pentru înlocuirea nisipului într-un dozaj de 40%. De asemenea, 10% din cantitatea de ciment aferentă rețetei betonului obișnuit a fost înlocuit cu cenușă zburătoare. Au fost determinate experimental densitatea, rezistența la compresiune, modulul de elasticitate și diagrama forță de compresiune-deformație. Blocurile din beton cu goluri construite au fost testate la compresiune fiind evidențiate sarcina limită ultimă la compresiune și modurile de cedare. S-a efectuat și o analiză numerică a comportării la compresiune a blocurilor din beton cu goluri, utilizând programul de modelare cu element finit ATENA. S-a remarcat faptul că cedarea blocurilor supuse la compresiune a fost una de tip progresiv, în trepte, distribuția fisurilor fiind aferentă zonelor în care tensiunile de întindere depășesc rezistențele materialelor analizate. Rezultatele studiilor efectuate au relevat o bună corelare a datelor numerice cu cele experimentale.

***Keywords**: fly ash, shredded plastic bottles, sawdust waste, sustainable development, compressive strength, numerical analysis*

1.Introduction

In the building industry, concrete is the most used construction material due to its high performances and advantages related to its costs, durability and security during its service life. In concrete production, huge quantities of cement and natural aggregates are utilised, and this does not comply with the nowadays criteria of sustainable development [1, 2]. Considering the worldwide requirements related to the reduction of the environmental impact of the construction industry, concrete has a high potential to be an ecological material since in its mixture different types of wastes can be added as aggregates or cement replacement without adversely affecting its properties or, in some applications, particular properties can be achieved. Some types of wastes such as: fly ash, silica fume, ground granulated blast furnace slag, steel slag, various combustion ashes (biomass ashes, sewage sludge ashes and different co-combustion ashes), are already used in preparing different types of cement (composite cement, blast furnace cement, Portland-composite cement, etc) [3-5].

Previous studies on different waste materials revealed that the concrete properties (workability, mechanical strengths, waterproofing, durability, etc.) are improved [6-12]. These wastes are replacing the cement in different dosages [13-15] for preparing various concrete mixes. Wastes obtained from rice husk, banana leaves, bagasse ash, etc. provide pozzolanic properties and are added in concrete mixes [16-21]. Other types of wastes such as those from construction demolition, plastic wastes, tire wastes, polystyrene waste, agro-waste are studied to be utilised as addition or substitution of cement and natural aggregates [22-28].

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Table 1

The mixes for experimental samples/ *Rețetele pentru probe experimentale*

Sample/ *Probă*	Cement Dosage/ *Dozaj de ciment* Kg/m^3	Aggregates/ *Agregate* [Kg/m^3]			Water/ *Apă* [l/m^3]	Fly ash/ *Cenușă zburătoare* [Kg/m^3]	Shredded PET/ *PET-uri tocate* [%] in volume	Sawdust/ *Rumeguș* [%] in volume
		0-4 mm	4-8 mm	8-16 mm				
C1	324	481.8	384	559	172	36	40	-
C2	324	481.8	384	559	172	36	-	40

The main objective of the current paper is to analyse the behaviour of concrete hollow blocks with aggregate substitution by waste materials obtained from shredded plastic bottles (PET) and sawdust.

2. Materials and methods

2. 1. Materials

The experimental concrete mixes with waste materials were prepared with cement, river aggregates (three sorts), three types of wastes (fly ash, shredded plastic bottles (PET) and sawdust), water and superplasticizer.

Cement

The cement type CEM I 42.5 R, which is a high early strength cement [3], was used. Two concrete mixtures made with shredded plastic bottles (C1 mix) and with sawdust (C2 mix) were prepared to analyse the density and the compressive strength. The cement dosage from the experimental mixes was of 324 kg/m^3.

Aggregates

Three sorts of natural aggregates have been selected: sort I - natural sand of 0-4 mm, sort II and III - river gravel of 4-8 mm and 8-16 mm, respectively, that meet the requirements of the Romanian standard for granulometric curve [29]. The material quantities used in the studied mixes are given in Table 1. The apparent specific gravity of aggregates was considered 2.7. In the waste concrete mixes, the sort 0-4 mm was substituted by volume with shredded plastic bottles (PET) and with sawdust, in the same percentage of 40% from the aggregate weight, for both types of concrete [30].

Fly ash

In this study, fly ash from Holboca-Iasi Electric Power Plant was used. It was characterized in previous experimental works [31]. The fly ash properties are: dark grey color, spherical particles with sizes between 0.01 μm and 400 μm, specific area of 480-520 m^2/kg, density of 2400-2550 kg/m^3, and the following main chemical components: Si (18.3%), C (17.15%), Al (13.9%), etc.

Shredded plastic bottles

The wastes of plastic bottles were obtained by cutting them in pieces with sizes between 1-4 mm. The experimentally determined density of shredded PET was of 433 kg/m^3.

Sawdust

The sawdust derives from wood industry and was sorted so that the dimensions range between 1 mm and 4 mm. The experimentally established density was of 168 kg/m^3.

Water and super-plasticizer

The water was in a dosage of 172 l/m^3 and Master Glenium SKY 617 superplasticizer from BASF was used in a dosage of 1% from the cement.

2.2. Experimental procedure

The concrete mix with shredded PET (denoted C1) was prepared by mixing all components in the following order: gravel, sand, shredded PET, cement, water and superplasticizer. In case of concrete mix with sawdust (denoted C2), in a preliminary stage, the sawdust was moistened in water for one hour to prevent the absorption of the mixing water. After the concrete mixing, the samples were poured and tested according to the Romanian standards:

- cubes of 150 mm size to determine the compressive strength, f_c [32] and the density [33];
- cylinders of 100 mm diameter and 200 mm height for studying the stress-strain behavior in compression, at the age of 28 days and to determine the modulus of elasticity [34].

The concrete hollow blocks were made using the formwork illustrated in Figure 1. They are denoted HB1 (manufactured using the concrete type C1) and HB2 (manufactured using the concrete type C2).

After 24 hours, the specimens were demolded and kept in laboratory at a temperature of 20°C until testing, Figure 2. At the age of 28 days the blocks were loaded in compression using an universal testing machine, Figure 3 [32].

3. Results and discussion

3.1. Compressive strength of concrete with wastes

The values of the compressive strength, f_c and of the density, experimentally determined at 28 days, are presented in Table 2. They are the mean values obtained by testing three samples according to the provisions of the Romanian standards [32, 33].

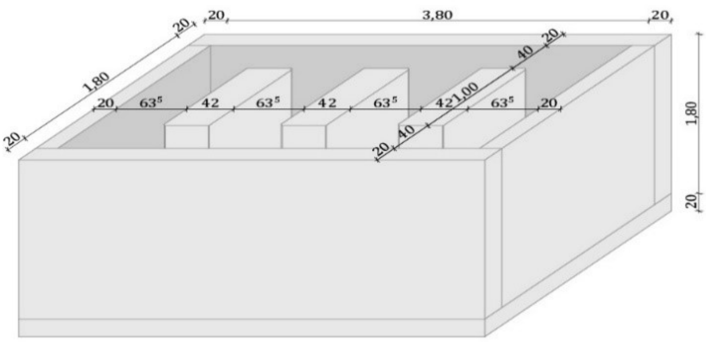


Fig.1 - The formwork for hollow blocks/ *Cofraj pentru blocuri cu goluri*

Fig.2 – Molded and demolded concrete hollow blocks/ *Blocuri din beton cu goluri în cofraj și după decofrare*

Fig.3 – Compressive test of the concrete hollow blocks/ *Încercarea la compresiune a blocurilor din beton cu goluri*

Table 2

Experimental values of the compressive strength and of the density
Valori experimentale ale densității și ale rezistenței la compresiune

Concrete mix/ *Rețeta de beton*	Compressive strength/ *Rezistența la compresiune, f_c* [MPa]	Density/ *Densitatea* [kg/m^3]
C1	23.33	2125
C2	13.63	2009

According to the results observed in Table 2, the concrete mix with shredded PET (C1) presented a higher value of the *compressive strength* than the concrete mix with sawdust (C2), for the same dosage of aggregate replacement. It has been noticed that the sawdust adhered better to the cement paste than the shredded PET. But the higher values of the compressive strength obtained on C1 mix can be explained by the fact that PET waste contributes by its own strength to the improvement of the transverse tensile behaviour (Poisson's effect) of this concrete mix. The average value of f_c for concrete mix C1 indicates that this type of concrete can be used as structural material for load bearing elements [35].

The density of concrete mix with PET waste was higher than that of the concrete mix with sawdust for the same dosage of aggregate replacement. Both density values were smaller than that of the regular concrete. The density of the concrete mix C2 indicates that for a small increase of the aggregate substitution, this concrete could be used as a lightweight construction material for non-structural applications.

3.2. Compressive behaviour of concrete with wastes

In Figure 4, the compressive force-displacement curves obtained on standard samples for concrete mixes C1 and C2 are presented.

The curves are non-linear from the first stage of loading until the maximum value of the load. After that, a decrease of the ultimate force and a non-elastic behaviour were recorded for the concrete mix with PET (C1) and a quasi-elastic behaviour was observed for the concrete mix with sawdust (C2). The deformations at failure are approximately the same for both types of concrete, but a slightly higher deformation can be noticed in the case of concrete mix with shredded PET (C1).

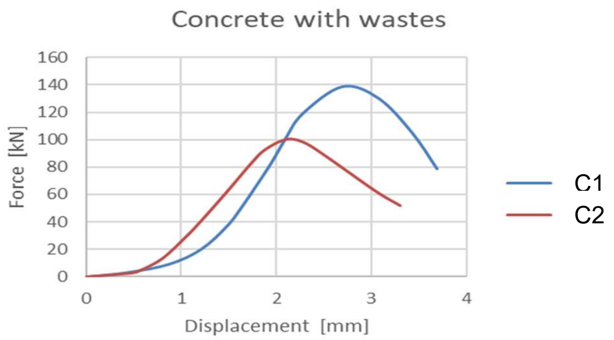


Fig.4 – Compressive force-displacement diagram of concrete with wastes/ *Diagrama forță de compresiune – deplasare a betonului cu deșeuri*

3.3. Modulus of elasticity for concrete with wastes

For the two concrete mixes C1 and C2, the modulus of elasticity was determined in accordance with [34], leading to the following values:

- for C1: E_{C1} = 20115.9 N/mm^2
- for C2: E_{C2} = 16372.3 N/mm^2

3.4. Concrete hollow blocks - compressive test

The constructed concrete hollow blocks were subjected to axial compression. The force was applied along the height of the hollow blocks. The maximum value of the load was divided by the gross contact area of the hollow blocks, including holes and it was denoted f_{chb1}, and by the net contact area, denoted f_{chb2}.

The indirect tension test according to [36] was performed and the split tensile strength was calculated with equation (1):

$$f_{thb} = \frac{2P}{\pi LH} \tag{1}$$

where:

- *P* is the maximum load, in kN;
- *H* is the height of the blocks (180 mm);
- *L* is the split length, 80 mm, if the holes area is neglected (f_{thb2}), or 180 mm if the total block length is taken into account (f_{thb1}).

The results of the tests are given in Table 3.

The type of waste influenced the *compressive strength f_{chb}* of blocks: in the case of blocks with PET waste (HB1 and HB2), both compressive strength values were bigger than those obtained on blocks with sawdust (HB3 and HB4). According to [37], the minimum value of the compressive strength must be 7 N/mm^2 and only the blocks with PET satisfies this condition for their use in seismic areas. Comparing with other types of blocks, for example, blocks of aerated cellular concrete for which the minimum compressive strength is 2.5 N/mm^2, the blocks of concrete with sawdust can be used for partition walls [38].

The split tensile strength f_{thb} of blocks also depends on the type of waste: in the case of blocks with PET waste (HB1 and HB2), both tensile strength values were bigger than those obtained on blocks with sawdust (HB3 and HB4). Analysing the tensile strength depending on the gross area, in the case of blocks with wastes, the value of the tensile strength is about 13-14% of the compressive strength of the blocks. These values are in accordance with those given in the literature for the tensile strength of hollow blocks [39], which vary between 8% and 16% of the compressive strength.

3.5. Failure mode

During the tests in compression, both types of blocks failed gradually, firstly with the occurrence

Table 3

Experimental results of the tests on hollow blocks/ *Rezultate experimentale ale testelor realizate pe blocuri cu goluri*

No.	Sample/ *Probă*	Sizes of blocks/ *Dimensiunile blocurilor* [mm]	Maximum force/ *Forța maximă*, P [kN]	f_{chb1} [N/mm^2]	f_{chb2} [N/mm^2]	f_{thb1} [N/mm^2]	f_{thb2} [N/mm^2]
1	HB1 (PET waste)	380x180x180 mm	562.10	8.22	10.07	1.11	2.48
2	HB2 (PET waste)	380x180x180 mm	540.20	7.89	9.68	1.06	2.39
3	HB3 (sawdust waste)	380x180x180 mm	390.42	5.71	6.99	0.77	1.73
4	HB4 (sawdust waste)	380x180x180 mm	378.60	5.53	6.78	0.74	1.67

Fig.5 - Failure modes of concrete hollow blocks/ *Moduri de cedare a blocurilor din beton cu goluri*

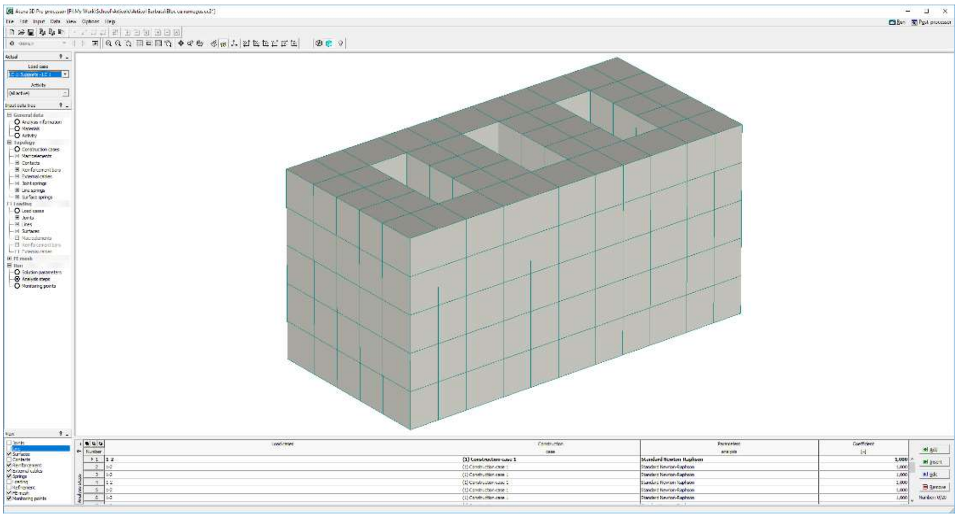
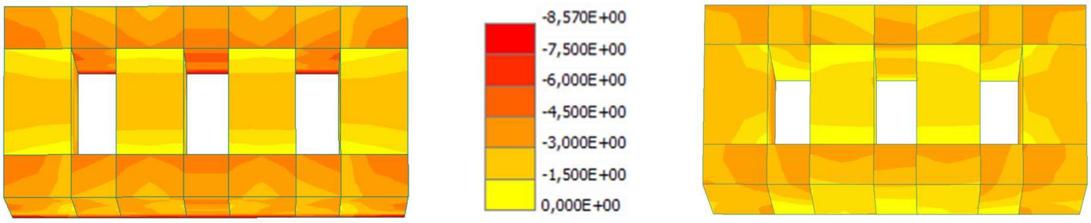


Fig.6 – The FEM model in ATENA software/ *Modelul cu element finit în programul ATENA*



a. HB1 *b. HB2*

Fig.7 - Stresses in concrete blocks obtained with ATENA software/ *Tensiuni în blocurile de beton rezultate din programul ATENA*

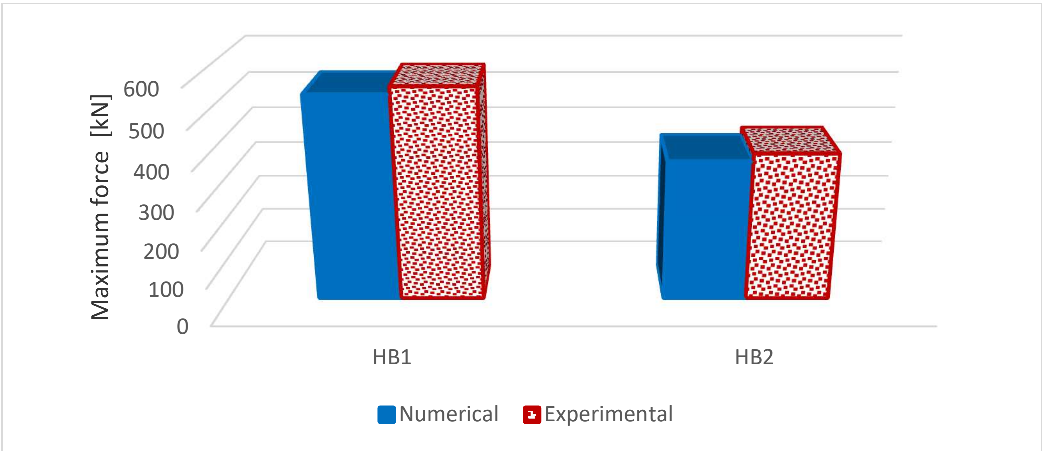


Fig.8 - Comparison between the numerical and the experimental results/ *Comparație între rezultatele numerice și experimentale*

of visible vertical cracks on the entire lateral surface area. The most damaged zones were near the holes. The failure was a stepwise, progressive type one, until the complete deterioration of the blocks, Figure 5.

3.6. Numerical analysis

The numerical analysis was made using ATENA software, a specialised program for concrete elements and structures. In order to obtain accurate results in non-linear analysis, the initial data must be as precise as possible.

Thus, the mechanical characteristics of the components were defined in the program according to their properties. The non-linear behavior of materials was inserted in the ATENA software as input data and the load was gradually applied, in 15 kN steps.

The distribution of stresses obtained with the FEM analysis is presented in Figure 7. The crack pattern was matched with areas where tensile stresses exceeded the strength of the studied materials

A comparison between the numerical and the experimentally obtained results is also illustrated in Figure 8.

A good correlation between the numerical and the experimental data was obtained.

4. Conclusions

In the experimental program, two types of wastes were used for preparing concrete with aggregate substitution. The 0-4 mm sort of natural aggregate was replaced, in volume, by shredded PET and sawdust respectively, in a dosage of 40% from the weight of sand. Hollow blocks with both types of concrete were manufactured and subjected to axial compression.

The density, the compressive strength, the force-displacement diagram and the modulus of elasticity of concrete with both types of wastes were analyzed. The compressive strength of concrete with PET waste was higher than that of concrete with sawdust for the same dosage of aggregate replacement. Also, the density of the concrete with PET waste was higher than that of the concrete with sawdust. The concrete with 40% replacement of 0-4 mm sort aggregates with PET waste presented values of density and compressive strength which indicate that this type of concrete can be used as structural concrete.

The blocks with shredded PET had shown better behaviour in compression and indirect tension than the blocks with sawdust. Both types of blocks presented a gradual failure.

The numerical analysis was performed using the ATENA software. The cracks pattern was matched with areas where tensile stresses exceeded the strength of concrete. A good correlation between the numerical and the experimental data was obtained. The development of models for analyzing the behaviour of masonry elements will continue in future research works.

The values of mechanical strengths of blocks experimentally obtained can satisfy the requirements necessary for partition walls.

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