SOME PROPERTIES OF CONCRETE BASED ON RECYCLED BRICKS
UNELE PROPRIETĂȚI ALE BETONULUI CU AGREGAT RECICLAT DIN CĂRĂMIDĂ CERAMICĂ

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By using crushed brick as aggregate, the structure of concrete can be effectively modeled and materials with very different physical-mechanical characteristics can be obtained. Determination of the influence of polymer admixture on some modified concrete properties is shown in this paper. Experimental work included several types of concrete made with different cement content (250 or 350 kg/m^3), and same consistency (slump about 5 cm). Few types of concrete made with 4% admixture of polymer (dry material) by weight of cement. Recycled brick or combination of river sand and recycled brick were used as aggregates. Results of determination of concrete compressive and bending strength, modulus of elasticity, coefficient of thermal conductivity, resistance to freezing-thawing, water permeability, shrinkage and creep, and stress - strain diagram were observed.

Structura betonului poate fi modelată în mod efficient, obținându-se un material cu caracteristici fizico-mecanice foarte diferite, prin reciclarea, ca agregat, a cărămizilor concasate. În acest articol este prezentată influența cantitativă a adaosului de polimer asupra proprietăților betonului cu agregat reciclat din cărămidă ceramică. Partea experimentală include realizarea betoanelor cu diferite dozaje de ciment (250 sau 350 kg/m^3), la aceeași consistență în stare proaspătă (tasarea în jur de 5 cm). Câteva tipuri de beton au fost realizate cu adaos de polimer - 4 % (substanță uscată) din ciment. Ca agregat total s-a folosit cărămida reciclată sau nisip și cărămidă concasată. S-a examinat influența compoziției amestecului de beton asupra rezistențelor mecanice la compresiune și încovoiere, a modulului de elasticitate, a coeficientului de conductivitate termică, a rezistenței la gelivitate, a permeabilității față de apă, și a diagramei efort-deformație.

Keywords: *lightweight concrete, recycled bricks, polymer, mechanical-rheological properties*

1. Introduction

Fabrication of aggregate for concrete from industrial waste, helped transform waste material into raw material from which high quality of aggregate is obtained. It is very important for environmental protection [1].

Due to its chemical composition and physical properties, every waste material can not be used as raw material for production of aggregate (produced aggregate must be chemically inert and harmless in concrete) [2]. Every production of aggregate on the basis of industrial waste material is not economical. However, the produced aggregate must be competitive on the market regardless the type of process.

During industrial production of brick and tiles when the burning process is not adequately performed, waste can appear and it can successfully be used for production of concrete prefabricated elements with smaller sizes, mainly hollow blocks for building.

Collapse of buildings due to elemental and other catastrophes or by tearing down of buildings which can not be economically renewed leads to brick waste which may be possible for use for production of aggregate for concrete [3 - 6]. The production process comprises crushing, grinding, and separating crushed brick into fractions and removal of undesired materials [7].

Concrete on the basis of crushed brick has many possibilities regarding modelling the structure and physical-mechanical characteristics, so that it is possible to obtain materials with different bulk densities, compressive and tensile strength, insulation, and other features [8].

Concrete on the basis of crushed bricks aggregate has satisfactory compressive and tensile strength and thermal insulating properties but shows weaker resistance to water and freezing action and has greater shrinkage by 20-60% than ordinary concrete [9,10].

Polymer portland cement concrete (PPCC) is a composite consisting of two matrices: organic, which is a product of polymerisation, and inorganic, which is a product of cement hydration.

PPCC has improved properties when compared with non-modified concrete. This concrete has high tensile and flexural strength, good adhesion to various bases, high resistance to freezing and chemical agents and lower water permeability.

On the basis of characteristics of PPCC and concrete made on the basis of crushed bricks, it has been assumed that concrete, modified by polymer on the basis of recycled bricks, must be

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material which will preserve good properties of both types of concrete, i.e. , by using polymer lightweight concrete, with satisfactory compressive and tensile strength, thermal insulation properties, with decreased shrinkage and water permeability and resistance to freezing action.

The PPCC properties depend, not only on composition but also on the way of preparation, compacting, and curing of such concrete. PPCC curing differs from ordinary concrete because the humid condition of curing is suitable for hydration process and dry condition to polymer matrix forming. Optimum regime of curing and concrete technology fabrication is defined in the first phase of experimental work [11].

In the second phase of experimental work, the concrete with various composition were designed by varying cement quantity, polymers, and use of natural and recycled sand. The influence of concrete composition on its bulk density, compressive and tensile strength, module of elasticity, shrinkage and creep, coefficient of heat conductivity, resistance to freezing-thawing and water permeability, were observed.

2. Experimental work

Experimental work included several kinds of concrete consisting of different cement content (250 or 350 kg/m^3) and few of them with 4 % admixture of polymer, by weight of cement.

Curing of polymer modified concrete is different compared to normal concrete, because hydration needs wet conditions, but formation of organic (polymer) matrix needs dry conditions.

Accordingly, it is necessary to determinate combination of wet and dry conditions that produces the best polymer modified concrete's properties. Concrete was cured 1 day in wet conditions, 6 days in water and after that in dry conditions [11, 12].

2.1 Component materials and concrete mixtures

Concrete mixtures were made using ordinary Portland cement (CEM I 42.5R). Four types of concrete (A, B, G and H) had 350 kg/m^3 and two (D and J) 250 kg/m^3 cement content.

Crushed bricks were separated into fractions 0/4, 4/8, 8/16 and 16/32 mm. Three kinds of concrete (A, B and D) were made using recycled bricks as aggregate. Other kinds of concrete (G, H and J) were made using combination of river sand and recycled bricks. Grain size distribution for mixtures with recycled bricks as aggregate are shown in Figure 1, for mixtures with combination of river sand and recycled bricks are shown in Figure 2.

Concrete mixtures B and H were made using polymer. It was latex BSR, with 47.4 % of dry materials in dispersion.

Information about composition of concrete are shown in Tables 1- 2. One part of water providing the required consistency (slump about 5.0 cm) of the mixture (free water i.e. effective water). Quantity of absorbed water is equivalent average value of water absorbed by aggregate after 30' [12].

Concrete was placed by vibration on vibro - table.

3. Results of investigations

Bulk density of concrete (after 28 days) with recycled brick was about 1850 kg/m^3, and for concrete with combination river sand and recycled brick was about 2050 kg/m^3.

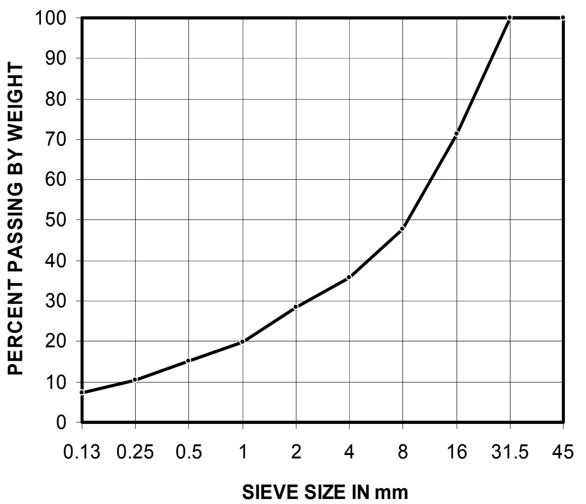

Fig. 1 - Grain size distribution for concrete with recycled brick *Curba granulometrică a agregatului din cărămidă reciclată pentru beton.*

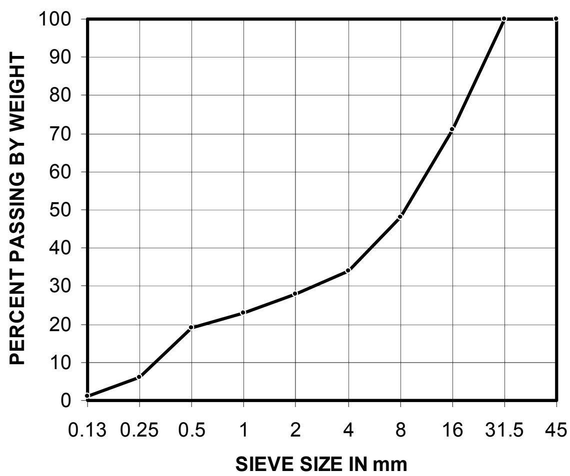

Fig. 2 - Grain size distribution for concrete with combination of river sand and recycled brick */ Curba granulometrică a agregatului pentru beton - nisip de râu şi agregat grosier din cărămidă reciclată.*

Table 1

Quantities of component materials of concrete with recycled brick aggregate / *Compoziția betonului cu agregat din cărămizi reciclate*

Type of concrete *Tip beton*		A	B	D
Cement/ *Ciment* (kg/m^3)		350	350	250
	0/4	469	458	504
Aggregate *Agregate* (kg/m^3)	4/8	161	157	173
	8/16	214	210	230
	16/32	496	485	533
Water / *Apă* (kg/m^3)	Absorp.	224	219	240
	Free	79	51	40
Polymer / *Polimer* (kg/m^3)		-	29.6	-

Table 2

Quantities of component materials of concrete with river send and recycled brick aggregate / *Compoziția betonului cu nisip de râu şi agregat grosier din cărămizi reciclate*

Type of concrete *Tip beton*		G	H	J
Cement / *Ciment* (kg/m^3)		350	350	250
	river sand 0/4	535	532	574
Aggregate *Agregate* (kg/m^3)	4/8	184	182	197
	8/16	245	243	262
	16/32	566	562	607
Water / *Apă* (kg/m^3)	Absorp.	165	164	177
	Free	85	61	33
Polymer / *Polimer* (kg/m^3)		-	29.6	-

Air content of fresh concrete is shown in Table 3.

Table 3

Air content of fresh concrete
Conținutul de aer în betonul proaspăt

Type of concrete *Tip beton*	A	B	D	G	H	J
Air content *Conținut aer* (%)	3.0	3.5	2.9	2.3	2.6	3.0

3.1. Compressive strength

By testing the specimens of cube having 15 cm long edges compressive strength of concrete was established. The obtained strengths of concrete without polymer examined after 7, 28, 90, and 180 days are shown in Figure 3. The values of compressive strength after 28 days were 20.9 MPa for mixture B and 27.0 MPa for mixture H.

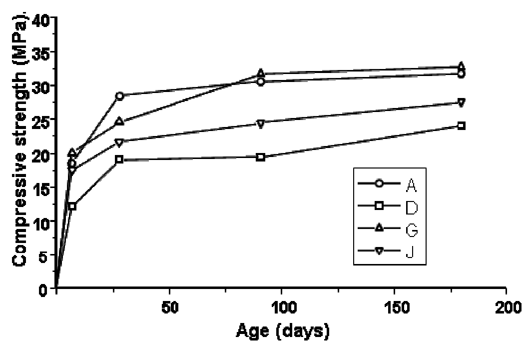

Fig. 3 - Time dependent compressive strength of concrete without polymer / *Evoluția rezistenței la compresiune a betonului fără polimer.*

3.2. Bending strength

This property of concrete was tested on prismatic specimens of dimensions 15 x 15 x 60 cm. One concentrated force on half of specimen span (l = 50 cm) was taken as the loading. The obtained strength of concrete without polymer examined after 7, 28, 90 and 180 days is shown in Figure 4. The value of bending strength after 28 days was 2.2 MPa for mixture B and 3.1 MPa for mixture H.

3.3. Modulus of elasticity

Modulus of elasticity has been examined for all kinds of concrete after 28 days on cylindrical specimens d/h = 15/30 cm. The results are shown in Table 4.

Table 4

Modulus of elasticity / *Modulul de elasticitate*

Type of concrete *Tipul betonului*	A	B	D	G	H	J
E (GPa)	14.5	11.1	13.6	17.7	17.6	16.4

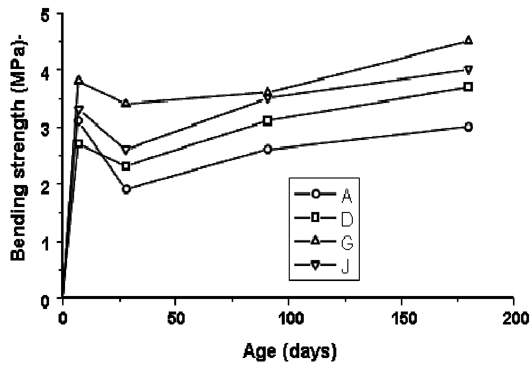

Fig. 4 - Time dependent bending strength of concrete without polymer / *Evoluția rezistenței la încovoiere a betonului fară polimer.*

3.4. Stress - strain diagram

Dependence of stress and deformation in course of short-term loading was obtained on the basis of testing prismatic specimens size 12 x 12 x 36 cm 28 days old. The specimens were axially subjected to pressure. The force was gradually increased up to rupture.

The stress-strain diagrams of concrete is shown in Figure 5 and values of stress and strain are shown in Table 5.

Table 5

Stress and strain values for concrete G,H and J
Valorile efortului şi deformaţiei pentru betoanele G,H şi J

G		H		J	
Stress (MPa)	Strain (mm/m)	Stress (MPa)	Strain (mm/m)	Stress (MPa)	Strain (mm/m)
2.1	0.115	2.1	0.105	1.7	0.078
4.2	0.235	4.2	0.212	3.5	0.162
6.2	0.355	6.2	0.325	5.2	0.258
8.3	0.472	8.3	0.442	6.9	0.360
10.4	0.600	10.4	0.565	8.7	0.468
12.5	0.748	12.5	0.698	10.4	0.588
14.6	0.908	14.6	0.848	12.2	0.715
16.7	1.095	16.7	1.010	13.9	0.875
18.8	1.290	18.8	1.192	15.6	1.040
20.8	1.542	20.8	1.420	17.4	1.255
0.0	0.180	0.0	0.118	0.0	0.130

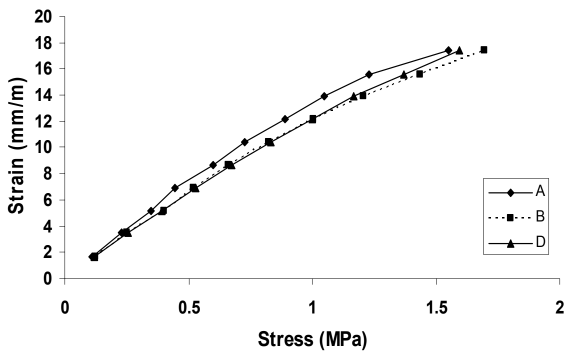

Fig. 5 - Stress-strain diagram of concrete with recycled brick aggregate / *Diagramele efort-deformaţie ale betonului cu agregat din cărămizi reciclate.*

3.5 Shrinkage

Shrinkage of concrete was determined by testing prismatic specimens size 12 x 12 x 36 cm, age 4, 7, 14, 21, ..., 91, 120, 150 and 180 days. The specimens were stored on temperature of 20° C and humidity of 65 %. Obtained results are shown in Figures 6 and 7.

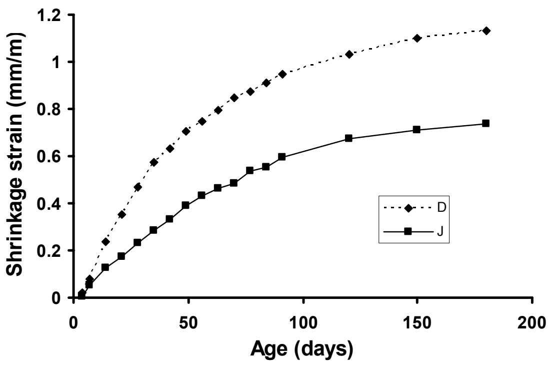

Fig. 6 - Dependence of shrinkage strain versus time for concrete with cement content of 250kg/m^3 / *Evoluţia în timp a contracţiei betonului cu un dozaj de ciment de 250kg/m^3.*

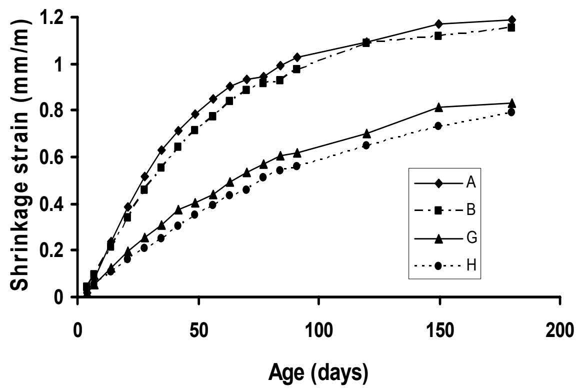

Fig. 7 - Dependence of shrinkage strain versus time for concrete with cement content of 350kg/m^3 / *Evoluţia în timp a contracţiei betonului cu un dozaj de ciment de 350kg/m^3.*

3.6. Creep

Concrete creep was determined by testing prismatic specimens size 12 x 12 x 36 cm. The specimens were loaded when 28 days old, and the creep deformations were measured after 7, 14, 21 (for concrete B), 28, 56, 91 and 150 days after loading. Dependence of creep strain and age in stress equal to one third of compressive strength is shown in Figure 8.

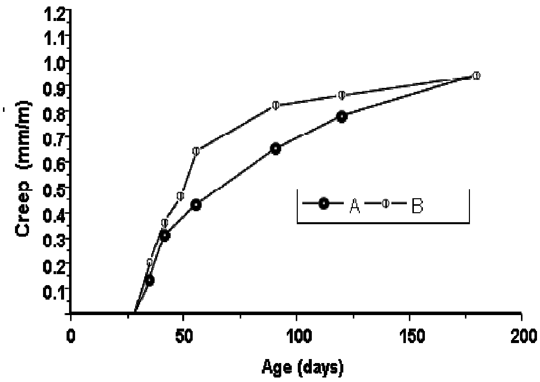

Fig. 8 - Dependence of creep strain versus time / *Fluajul în funcţie de timp.*

3.7. Water permeability

This property has been tested according to Serbian standard (on cylindrical specimens d/h = 15/15 cm; 8 hours at 1 bar, 8 hours at 2 bar, etc.).

Specimens of concrete D and J satisfied at water's pressure at 8 bar. Other concrete satisfied at water's pressure at 12 bar. Specimens of concrete with polymer had better results. Average water penetration after splitting of the specimens which satisfied at water's pressure at 12 bar is shown in Figure 9.

3.8. Freezing-thawing resistance

According to Serbian standard frost resistance was tested on prismatic specimens of the dimension 12 x 12 x 36 cm by nondestructive method (after 25,50.. freezing and thawing cycles

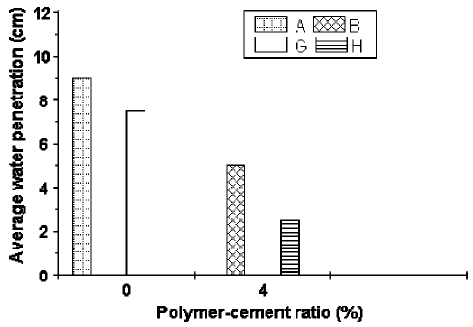

Fig. 9 - Average water penetration / *Penetrarea apei în beton*

Table 6

Number of freezing and thawing cycles
Numărul de cicluri de îngheț – dezgheț

Type of concrete *Tipul betonului*	A	B	D	G	H	J
Number of cycles *Numărul de cicluri*	125	125	50	75	75	50

decrease of dynamic modulus of elasticity was tested) [13]. Number of freezing and thawing cycles which satisfied decrease (25% related to inicial modulus at 0 cycles) of dynamic modulus of elasticity is shown in Table 6.

3.9. Coefficient of thermal conductivity

This property of concrete was tested for concrete A, H and J. Laboratory coefficient of thermal conductivity λ at the mean temperature t_M = 10 ^{o}C were:

- A - 0.556 W/ (mK)
- H - 0.652 W/ (mK)
- J - 0.703 W/ (mK)

4. Conclusion

Analyzing results of investigations it can be conclude that polymer modified concrete based on recycled bricks has approximately same value of compressive and bending strength, lower water permeability and freezing-thawing resistance, smaller shrinkage strains, worse modulus of elasticity and slightly greater creep strains than concrete without polymer.

Polymer modified concrete has lower absorption then unmodified concrete, so it is a composite with lower water permeability.

Polymer modified concrete has greater air content and less absorption than unmodified concrete. That is a reason why it has better frost resistance.

Measurement thermal conductivity values of lightweight concrete, without sand, with (or without) polymer, can be of opinion like as satisfied low. In addition to relative high bulk dry densities, here can be talking about concrete that have relatively small thermal conductivity, e.g. good thermal performances.

With polymer shrinkage of concrete was decreased. This can be explained by greater effect of retaining the water in concrete. Polymer membranes cover the micro-cracks which may appear due to shrinkage preventing their enlargement.

Comparing the kinds of concrete made with aggregate from crushed brick it can be noticed that with polymer inclination of σ - ε curve is decreased, i.e. that the modulus of elasticity is decreased. With polymer the strain during failure is also increased. The value of static modulus of concrete on the basis of recycled brick reaches up to one third of the value of static modulus of concrete made with natural aggregate.

Comparing kinds of concrete made with and without addition of polymer it can be noticed that modified concrete has larger creep than unmodified.

Comparing concrete with and without river sand we can conclude that concrete with river sand has: grater compressive and bending strength, greater modulus of elasticity, lower shrinkage, greater bulk density e.g. greater coefficient of thermal conductivity.

By modeling the structural characteristics of concrete, materials of various densities, mechanical and insulation properties can be provided.

Concrete based on recycled brick can be used for production of various solid and hollow construction blocks. Beside their function as thermal insulators, such blocks, with regard to their mechanical characteristics, can have an important role in the bearing walls of buildings.

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