Improving elastic properties of bricks by polyurethane matrices mean

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Abstract. The usage of polyurethane was considered in order to obtain an innovative brick (polyurethane brick) for the envelope of reinforced concrete frame structures and also for partition walls. The following properties were studied: self-weight, compression strength and bending strength. In order to increase its mechanical properties, polyurethane materials can be reinforced with recycled or organic materials, reducing costs in this manner (crashed glass, straw, chopped rubber). Using these innovative infill materials, the heating costs are reduced and the execution time is decrease. The polyurethane bricks are easily adapted to any climatic condition and allow water vapour transfer from inside to the exterior side of the masonry, preventing condensation. Compressive strength, flexural strength and split tensile strength were experimentally determined. From the laboratory results it was observed that an increase of 32.6% occurred for the compressive strength for the sample with glass pieces. Overall improvements of the mechanical properties were noticed for the samples with smeared reinforcement.

1. Introduction

Buildings are intended to provide people the indispensable conditions for their activities. The society's degree of development is reflected by the technical level in construction. Each construction or construction component must meet a set of technical requirements and conditions, concerning durability, fire resistance, toughness and stability of the construction, architectural and economically-organizational ones. Every building has a well-established destination and satisfies a range of complex and varied functions.

Polyurethane is a resilient, flexible and durable material that can replace rubber, metal and wood in many applications. It can be produced in different colour, take any shape or size. The polyurethane properties depend on the type and percentage of the necessary components: isocyanate and polyols. A piece of polyurethane can be considered a giant molecule, as a consequence, typical polyurethanes do not soften or melt when heated. Isocyanates and polyols available options, compared to other additives and processing conditions, allow the polyurethane to have a wide range of properties that make it such a widely used polymer [4].

Polyurethane is used in construction since 1950 and its main destination is building insulation, in the shape of insulating roof panels, walls, ceilings and floors. One of the desirable attributes of polyurethanes is their ability to be converted to foam. Polyurethane foam sandwich panel is fit for projects which have requirements regarding constant high temperature or strict hygiene maintenance, because polyurethane core material is considered to be the best material in keeping warm and behaving as thermal insulation.

Metal-faced polyurethane sandwich panels are the system of choice today for large industrial buildings, office blocks, exhibition halls, schools etc. Prefabricated sandwich walls and lightweight roofing systems which consist of metal facings bonded tightly together by a core of rigid polyurethane foam. Polyurethane sandwich panels come complete with specially formed tongue-and-groove joints ensuring a perfect fit and maximum integrity [12].

Polyurethane bricks (PUB) are made using a mould and a special machine with a dosing device, in order to obtain the required mechanical characteristics. PUB can be produced in a variety of sizes, depending on the construction site, the destination of the building and the size of the frames structure [6].

Ventilated facades are currently made of: HPL tiles (High Pressure Laminate), cement, ceramics, clinker, terracotta, artificial stones, recomposed one (marble, granite, travertine), composite wood, aluminium, decorative glass, steel, natural stone.

By its insulating qualities, for both low and height temperature, a ventilated facade made of polyurethane, has the economic advantage of reducing the costs for air conditioner or heating. Using a ventilated facade, the building structure may represent the most modern and attractive line, its maintenance being simple, without major problems.

2. Material and method

2.1. Overview

The polyurethane brick is a mixture of chemical substances. The percentage of each component, the environment conditions and the technological process significantly influences the final product. Isocyanate is the functional group having the formula R – N = C = O.

Di-isocyanates are made from reactions with polyols in the production of polyurethanes. Isocyanates are electrophiles, so they are reactive among a variety of nucleophiles, including alcohols, amines or even water. The treatment with alcohols leads to a urethane bond. If a di-isocyanate is treated with a compound that contains two or more hydroxyl groups, such as a diol or polyol, a polymer chain called polyurethane is formed.

Monomeric polyols, made from the polymerization of ethylene oxide and propylene oxide, such as glycerol, pentaerythritol ethylene glycol, are often used as point of departure for polymer polyols and the initiation of the polymerization reaction. Polymer polyols are typically polyether or polyester. Hydroxyl terminated polybutadiene polyol is used to produce the polyurethane.

Characteristics of the mixture are:

- mixture ratio: 100:120
- free density: 100 ÷ 350 Kg/m3
- working temperature: 25 ° C
- time to expand: 16-18 sec
- moulding time: max. 15 minutes.

Polyurethane bricks are made using a mould filled in by a special machine with a dosing device, in order to obtain the essential density. During the manufacturing process it is desired to use the best quality of the material components, compliance with technological parameters and quality of finished products, in order to ensure proper operating behaviour [11].

Various sizes of polyurethane bricks can be produced, depending on the construction site, the destination of the building and the size of the reinforced concrete frame structures. In figure 1 it is shown a model for a polyurethane brick that has fibre cement boards on the lateral sides, in order to increase the mechanical strength [6].

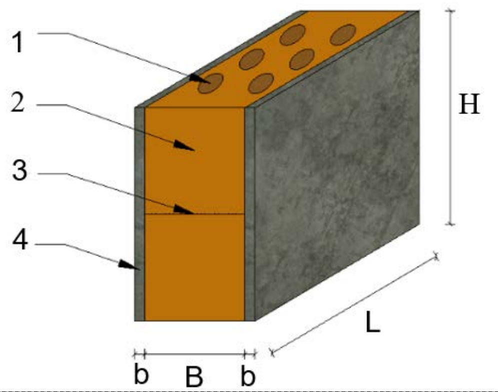

Figure 1. PUB: 1. Gaps (ceramic, extruded polystyrene, wood); 2. Rigid polyurethane; 3. Reinforcement mesh; 4. Cement slabs

The gaps presented in this prototype can be left empty or filled with various materials – ceramics, polystyrene, and wood, in order to reduce the costs and increase the mechanical strength.
Considering the available size of a classic bricks that are already on the market – ceramic, lightweight concrete, Table 1 presents some suggestions for PUB possible dimensions. For each case the polyurethane and the cement dimensions are presented. Models 11 and 12 are proposed for implementing new dimensions.
Large size products are possible due to the low density of the polyurethane, meaning as well as low weight.

Table 1. Possible dimensions for polyurethane bricks

Crt. No.	Brick	L [mm]	H [mm]	B [mm]	b [mm]
1	Module 1*	240	115	43	10
2	Module 2*	240	115	68	10
3	Module 3*	240	115	118	10
4	Module 4*	240	115	168	10
5	Module 5*	240	115	158	15
6	Module 6*	290	140	68	10
7	Module 7*	290	140	118	10
8	Module 8*	290	140	168	10
9	Module 9*	380	250	168	10
10	Module 10*	380	250	158	15
11	Module 11 (Concept)	500	250	150	10
12	Module 12 (Concept)	500	250	150	20

As said previously, if creating appropriate moulds, polyurethane can even take the shape of a round section as half log, figure 2. Polyurethane concrete block can represent a proper replacement for logs used for the construction of country houses, the environmentally friendly properties being a major advantage for this brick. Table 2 presents three different possible dimensions that could be used for moulds, but these are not necessarily the only ones. Their dimensions can be adapted according the owner request or the construction requirements.

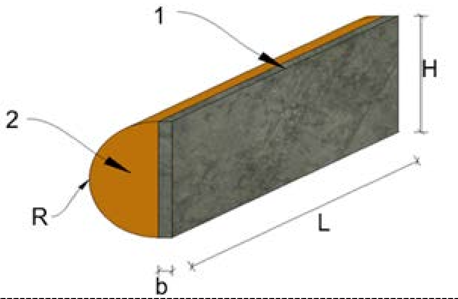

Figure 2. PUB: 1. Cement slabs; 2. Rigid polyurethane

Table 2. Possible dimensions for polyurethane bricks

Crt. No.	Brick	L [mm]	H [mm]	R [mm]	b [mm]
1	Module 1	2000	200	150	20
2	Module 2	2000	150	100	20
3	Module 3	1000	100	50	20

2.2. Reinforcement

Fibre reinforcement of construction materials has been used for a long time in order to increase the tensile capacity. Unburned bricks (adobe) were reinforced with chopped straw or animal hairs are considered, in order to prevent cracking and to provide a high strength to tearing and moisture represent a novelty. The extrapolation was made from clay to cement and from straw and animal hair to fibres. Due to the progressive increase of the steel – concrete price on the world market, and as a result to the technical and economic studies that were made, polymer fibres were chosen for dispersed reinforcement [3].

Within the past few years, there has been a significant increase in the use of natural fibres, such as leaves from flax, jute, hemp, pineapple, and sisal, for making a new type of environmentally-friendly composite. In general, two types of natural fibres are identified for making fibre-reinforcement polymer: plant-based and animal-based fibres. For the former, due to their abundant supply in the natural environment, the raw material cost is relatively low and can be completed with synthetic fibres [1].

The comparison between the physical and mechanical properties of this fibres and the steel ones have led to the exponential growth in the use and demand of this type of material in the construction world market.

To improve the quality of the polyurethane bricks and to increase compressive and flexure strength, reinforcement can be used for PUB, also. In addition to this, the amount of polyurethane will be reduced, and thus, the costs [2].

In order to find the ideal reinforcement material, bricks with different reinforcement type have been tested in three points to bending and compression tests. The materials used for this reinforcement are: fibreglass mesh, fibre rubber, Geogrid mesh, metal mesh, glass shards shape. Section 3 presents a synthesis of the laboratory tests and the conclusions.

2.3. PUB masonry

In order to do the infill of reinforced concrete structures, only bricks of good quality will be used, with no cracks. A polyurethane adhesive is recommended in order to obtain a homogenous infill wall. Wall thickness will correspond to the architectural drawings.

For execution, labour skilled workers will be used, along with masons and related masonry workers. Both, flatness and verticality will be watched; according to actual code. A deviation of ± 0.5 cm is allowed both vertically and horizontally, measured toward a straight edge of 3 m length.

The following operations must be strictly controlled:

- good adhesion between polyurethane bricks and adhesive;
- horizontal and vertical joints shall be well filled with adhesive all over;
- in the vertical joints reinforcing mesh fibreglass can be placed by geogrid etc.;
- vertical joints will be weave so that the height superposition of two successive rows, both in the field and at the corner's intersection, to make the minimum of ¼ from the brick length, and ½ of its thickness. Weaving is required in each row;
- the horizontality of the brick's rows will be watched;
- the interruption of the masonry work will be done in steps;
- the connections between walls, corners, junctions and branches will be made alternatively;
- the anchoring of the infill masonry is made with steel whiskers of 8 mm diameter and 50 cm long or creating strep to achieve weaving ancient masonry;
- corrosion protection of the anchors will be provided;
- partition walls (bricks edge) are stiffen by weaving and anchoring steel bars of 6 mm diameter every 3-4 rows in horizontal joints, according to the P2-85 Standard.

3. Laboratory test and results

3.1. 3 point bending test

To sustain the efficiency of polyurethane masonry, laboratory tests were performed in order to obtain and compare the physical and mechanical characteristics of four types of materials: autoclaved aerated concrete (AAC), brick, wood, and respectively polyurethane brick.

For the bending tests, a simple scheme of loading is considered. The test tube, having the shape of a circular or rectangular section bars, will be simply supported, and the load will be applied in the midway of the supports, until the time of rupture, as shown in figure 3. Tension in the test tube it is not even, due to the variation of the bending moment in the longitudinal axis, and because of a given cross-section in elastic areas, tension varies linearly.

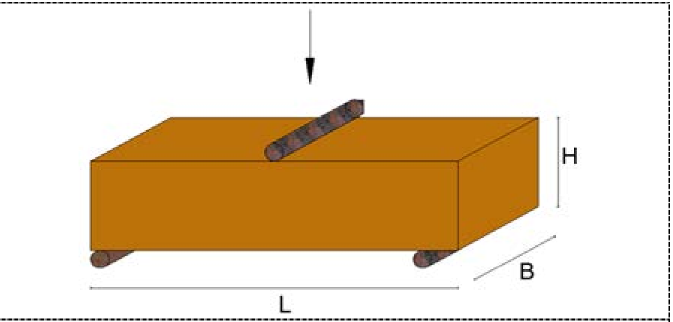

Figure 3. Testing specimen for 3 point bending test

Six testing tubes were considered – 2 made of autoclaved aerated concrete (A.A.C.), 2 made of clay (usual brick) and 2 of PUB. The samples had the following dimensions 40x40x160 all in mm. Traditional bricks and A.A.C. had behaved similarly, while polyurethane brick's behaviour was significantly different, see figure 4.

The displacements obtained for polyurethane brick were significantly higher than the other ones. Also, the maximum force was 1.15 kN for the most resistant traditional brick versus 1.35 kN for polyurethane brick. One of the PUB sample has been reinforced using fibreglass mesh. An increase of about 60% for the reinforced brick was reached, compared to the simple brick, concerning the maximum force, and an increase of 40% for the maximum displacement.

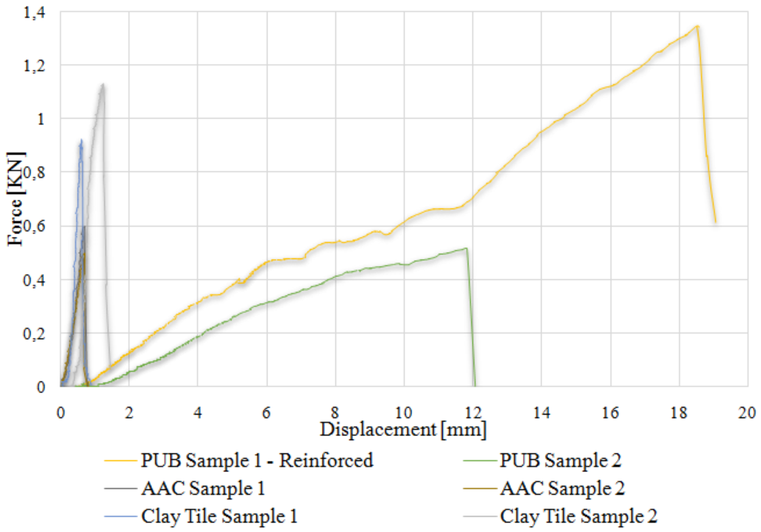

Figure 4. Results for 3 point bending test

From the 3-point bending test carried out in the faculty laboratory, it can be concluded that polyurethane brick has an adequate behaviour in comparison with current used materials. It was noticed that its capacity is significantly enhanced when reinforcement solutions are considered. figure 5 presents the sample taken during the testing.

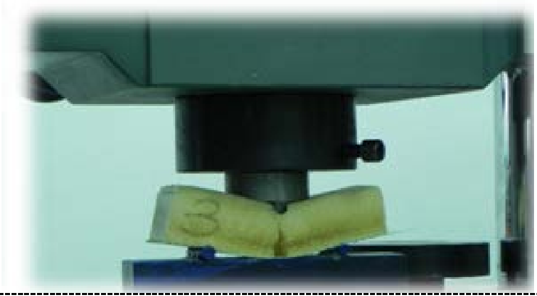

Figure 5. Photo from the 3 point bending test

3.2. Compressive test

The compression test is usually performed for determining the mechanical properties of brittle materials (when it is cold or warm), which present lower tensile strength (cast iron, metals or non-ferrous alloys etc.). This test allows to establish the compressive stress, according to STAS 1552-78 (STAS 1552-78).

The main issue that this laboratory test is facing is the homogeneous tension inside the test tube. Another problem is that tenacious materials cannot be damaged by this experiment, furthermore a plastic deformation can appear along with the increasing of the load. Rigid metals present an elastic deformation, followed by a plastic one that leads to damage. After deformation, the samples look like a barrel.

For this test, six polyurethane bricks samples were considered, which differed by the reinforcement type. Two types of reinforcement were considered, horizontal, perpendicular to the loading action and smeared reinforcement. Samples 1 and 5 were longitudinally reinforced with fibreglass mesh, sample 2 was using geogrid mesh of 40 mm and dispersed rubber particles, sample 3 was reinforced with

broken glass, sample 4 was longitudinally reinforced with metal mesh of 5 mm, and sample 6 was simple, made at a specialized factory, with a special dosing machine [9].
Figure 6 shows photo take during the compression test on some of the samples.

Figure 6. Photo from the compressive test

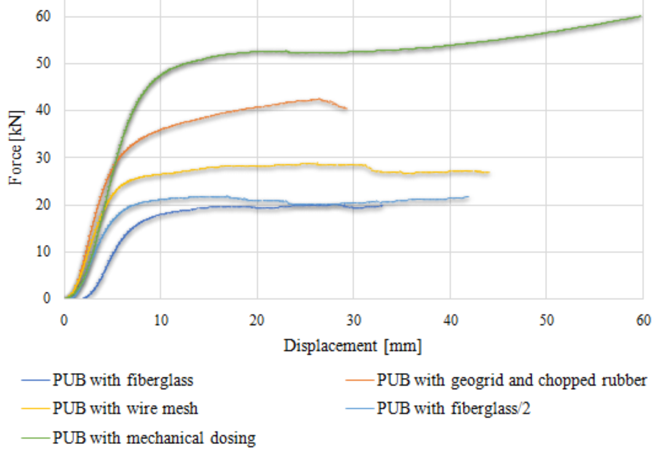

Figure 7. Compressive test results

Figure 7 is a synthesis of the results obtained in the compression test. The main conclusion of this test is that the use of mixed reinforcement – longitudinal and smeared one, lead to significantly better results. Although it was initially assumed that broken glass reinforcement would have a good behaviour, laboratory tests had shown otherwise.
It can also be concluded that the execution technology of the components is essential. Relatively large differences were observed between the samples hand made in our laboratory and those obtained by automatic dosing and mixing the components at constant pressure. This sustains the idea that the process is essential in reaching the top quality of polyurethane brick elements.

4. Conclusions
Polyurethane is not a new material, on the contrary is being widely utilized in different industries. In the construction field is generally used for sandwich panels, as building insulator, as adhesive, etc. The new use, that of masonry block, has numerous advantages. Firstly, good results obtained in the laboratory for the mechanical characteristics. Among the analysed properties were studied: self-weight, compression strength, bending strength and thermal strength. Also, it was established that in order to increase its mechanical properties, PUB can be reinforced with recycled or organic materials, reducing the costs in this way (crashed glass, straw, chopped rubber). The PUB masonry used as infill wall for reinforced concrete frame structures overcome the failure mechanism due to stiffness

differences between the components. Secondly, due to its good thermal characteristics, the masonry made of PUB elements lead to a superior thermal strength of the element in comparison with those frequently used (ACC, clay). A consequence of this property is represented by the cost reduction for the energy required to heat the interior spaces. The polyurethane bricks are easily adapted to any climatic condition and allow the water vapour transfer from inside to the exterior side of the masonry, preventing condensation. Thirdly, the technological process needed to put in place PUB elements is fast and requires minimum resources, to be exact only electric energy. According to the U.E. Directives on the classification, packaging and labelling of dangerous substances, there are no special requirements for this material. In addition to this, polyurethane corresponds to protocols relating to ozone layer in Montreal and Kyoto Summit. From the point of view of health, raw materials are treated in such a way that, under normal conditions, does not emit noxious fumes and are not toxic by touching. Environmentally speaking, the products do not emit harmful gases over their lifetime, nor degrade the environment. As one of the most effective insulators in construction, it actively contributes to energy saving, greatly reducing carbon dioxide emissions.
Last aspects which need to be considered are that this material can be recycled and used again in the construction field. Such an example is to mix small polyurethane pieces in the concrete in order to obtain thermal insulated slabs.
Further studies need to be performed in order to have a complete understanding on how the product behaves in particular situations, for example extreme weather conditions, fire, etc.

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