PERFECTION OF OLD TECHNOLOGIES FOR THE PRODUCTION OF LARGE FORMAT TILES AND BRICKS

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Summary: *This paper provides some new information about old leading technologies and possibilities of large-format brick production in today's conditions. The production of masonry elements can be from clay that has been shaped and dried, or after drying, such clay has also been baked. The most sensitive phase in the production of clay products is the drying of the clay. In the drying phase, such stress states can occur in the clay that would lead to the appearance of cracks and warping. It is for these reasons that today the clay brick format has been reduced to the dimensions of 25 x 12 x 6.5 cm. The formats of bricks and baked bricks that were made thousands of years ago, until several hundred years ago, were several times larger than today's format, completely correct and without cracks and twisting. The old builders used micro-reinforcement in the form of fibers, which they mixed into the clay and thus prevented the appearance of cracks and warping. These technologies have been tested and confirmed in the works of students on the subjects of Traditional Materials and Masonry Structures for several years at the Faculty of Civil Engineering in Subotica. These projects were done in collaboration with the world leader in the production of baked clay products, Wienerberger d.o.o. Kanjiža.*

Keywords: *clay, adobe, brick, shrinking, baking*

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1. INTRODUCTION

Roman technology, like other old building technologies, represents the perfection that we, as builders and technologists, should strive for. Even after thousands of years we can still see and admire their buildings, because of how they were built. Roman bridges, Roman arenas, aqueducts, the Pantheon [1] [2] [4] ..., are for admiration, how long they last and captivate with their beauty and size. As elements for construction, they mostly used stone and baked clay, and as a binder, lime and pozzolanic materials, volcanic ash, baked clay, opal breccia, diatomaceous earth, fire ash... The building elements made of baked clay are of such surfaces and dimensions that today, with the current technology of clay preparation, we can hardly produce them. Clay is a plastic material, thanks to the plastic particles of kaolin and others, which are so fine and small that they require a large amount of water, so that they can perform shaping and retain their given shape. After molding, drying occurs and the occurrence of shrinkage is greater, the greater the amount of plastic particles and thus the amount of water in the material. The larger the dimensions of such product, the larger the ensuing shrinkage will be.

Picture 1. Photograph of Roman masonry brick measures 46 cm x 31.5 cm x 6.5 cm

The brick in the picture was obtained from the Sremska Mitrovica (Sirmium) site, it looks very well preserved, as if it was produced a couple of years ago. The age of this brick is at least 1500 years [1] [2] [4]. The brick has remnants of mortar on it, which means it was in the wall. The mortar is also of high quality, probably made of sand, lime and with the addition of pozzolana: firewood ash. The color of Roman bricks is basically bright red, only now it is superficially coated with "time patina". It is a product that is produced using excellent old technology, for great admiration and respect.

2. PRELIMINARY RESEARCH OF THE POSSIBILITIES OF PRODUCTION OF LARGE FORMAT TILES AND BRICKS

At the Faculty of Civil Engineering in Subotica, for several years now, in addition to all other subjects, students have been listening to the subjects Traditional Materials and Masonry Structures. Students in cooperation with the professor, a couple of years ago, successfully realized several new building ideas with traditional materials. Successfully

made tiles with larger dimensions: 34 x 16.5 x 8 cm. Completely regular and without cracks and bending, tiles are made with even larger dimensions: 40 x 20 x 10 cm. It was determined during the student works that the best clay for making large format tiles, is the so-called yellow clay, which is delivered from Kanjiža, from the world producer of rough ceramics, the company Wienerberger. Yellow clay has an optimal amount of plastic particles and very little shrinkage during drying which is less than 1%. Yellow clay can be plastically formed with much less water compared to "blue clay", which requires much more water, so it has a higher shrinkage of 6.7%. Yellow clay is great for making adobe but not baked bricks. For baking the so-called "blue clay", which is prepared for the production of tiles, the baking temperature is 1040 ^{0}C. The firing temperature of yellow clay, so that it is well baked, is much higher and amounts to 1150 ^{0}C. Graphic attachments show the shrinkage sizes of both clays after firing at a temperature of 1040 ^{0}C.

Picture 2. The red and yellow bricks in the shaping phase had dimensions of 52cm x 25.8 cm x 8.8 cm, the yellow clay brick is the lower brick and the red brick from "blue clay" is the upper brick, where there is a big difference in dimensions after drying and baking.

Picture 2 clearly shows the difference in the shrinkage size of yellow clay bricks with less than 1% shrinkage, and "blue clay" bricks, upper bricks with 6.7% shrinkage. These two bricks are shaped in the same mold 52cm x 25.8cm x 8.8cm. The only way to avoid cracks and warping in the drying phase and the baking phase is to install micro-reinforcement in the clay. Clay with micro-reinforcement in the drying phase, which can be natural or artificial, gives the brick the correct shape and makes it impossible for cracks to appear. If we want to do larger formats of adobe or brick, in relation to today's usual dimensions of 25cm x 12cm x 6.5cm, is possible, as we have already pointed out, with the addition of suitable micro-reinforcement in clay. Micro-armature is especially needed if the shrinking of clay is large, which has "blue clay". The most suitable micro-reinforcement is natural, and that is ground straw. It used to be chaff that represents "shells" of cereal grains: wheat, barley, oats, rye and others... Since the chaff is not collected today, there are mills with which we can grind straw into a fine powder and fine fibers, even finer than the chaff itself. This is how large-format bricks were made of yellow clay and blue clay, where we

dosed ground straw with fibers smaller than 10 mm. The micro-reinforcement made of ground straw is so efficient that large formats of freshly shaped clay with mold dimensions of 52 cm x 25.8 cm x 8.8 cm, after drying and baking, remain completely regular, without bending and without cracks.

2.1. RECIPE OF PREVIOUS TESTS OF RECONSTRUCTION OF LARGE FORMAT BAKED ROMAN BRICK PRODUCTION TECHNOLOGY

Formulation of a preliminary test of technology with straw [3]**:**

Components:
- yellow clay
- ground straw as micro-reinforcement

$\gamma_{straw} = 250 \frac{kg}{m^3}$
Mold dimensions: $25{,}8 \times 52 \times 8{,}8\ \text{cm}$
Mold volume: $V = 0{,}258 \times 0{,}52 \times 0{,}088 = 0{,}0118\ \text{m}^3$
15% Ground straw : $0{,}15 \times 250 \times 0{,}0118 = 0{,}42\ \text{kg}$
85% Clay : $0{,}85 \times 1981{,}93 \times 0{,}0118 = 19{,}88\ \text{kg}$
The bulk density of ground straw in the dry state was determined by previous measurements. The mass of water absorbed by the straw is dosed into the mixer so that the clay retains its moisture content of 20%.

3. RECONSTRUCTION OF ROMAN BRICK PRODUCTION TECHNOLOGY FORMAT 46 cm x 31,5 cm x 6,5 cm

The Roman brick on the Picture 1., at least 1500 years old [1] [2] [4] , was tested in the laboratory of the Faculty of Civil Engineering in Subotica, with the most modern instrument, currently in the world, Isomet 2114, for this type of testing the thermal conductivity of the material λ (W / mK). The measurement showed a surprisingly good result of thermal conductivity resistance with measured thermal conductivity of incredible $\lambda = 0{,}1913\ \text{W/mK}$. This result of the measured thermal conductivity indicates that in Roman bricks there are micro pores with trapped air that provides high resistance to thermal conductivity (W/mK).

Picture 3. Instrument Isomet 2114 in the phase of measuring thermal conductivity (W/mK) on a Roman brick at least 1500 years old

It is now easy to prove that the walls of buildings built during the Roman Empire met today's regulations for the construction of energy efficient buildings in Europe and the world. If we assume that the Roman walls were only 80 cm thick, we use the formula to obtain the value of the heat transfer the $U = 0{,}29\,W/m^2K < 0{,}3\,W/m^2K$.
The bulk density of Roman brick is: $\gamma = 1660\,kg/m^3$
After preliminary tests and the obtained results of drying and baking large-format bricks, we moved on to a total reconstruction, which means that our bricks must have the same format and dimensions as Roman bricks 46 cm x 31.5 cm x 6.5 cm. Another condition that we have to match is the color, which means that we had to do the shaping of the brick with "blue clay".

Recipe technology with ground straw as micro-reinforcement [3]**:**

Components:
- „blue clay“
- ground straw as micro-reinforcement
- lime

Mold dimensions: $49 \times 33 \times 7{,}2\,cm$
Mold volume: $V = 0{,}49 \times 0{,}33 \times 0{,}072 = 0{,}0116 m^3$
$\gamma_{lime} = 2250 \frac{kg}{m^3}$
$\gamma_{straw} = 250 \frac{kg}{m^3}$
$\gamma_{clay} = 1968 \frac{kg}{m^3}$
2% Lime : $0{,}02 \times 2250 \times 0{,}0116 = 0{,}52\,kg$
15% Ground straw : $0{,}15 \times 250 \times 0{,}0116 = 0{,}44\,kg$
83% „Blue clay“ : $0{,}83 \times 1968 \times 0{,}0116 = 18{,}95\,kg$

After manually installing the clay in the molds, we freed the mold by pulling the outer formwork of the mold upwards with our hands and holding the sample of shaped bricks on the floor, pressing down. After that, the samples were placed on their edge, to dry, which is shown in Picture 4.

The mass of water absorbed by straw and lime is dosed into the mixer so that the clay retains its moisture content of 20%.

Picture 4.The first phase of drying in the laboratory of the Faculty of Civil Engineering, next to the oven

Samples of bricks with "blue clay" and micro-reinforcement in the form of ground straw were taken for further drying and baking in Kanjiža to the Wienerberger factory. Along with large formats of bricks with blue clay, smaller samples were made with "blue clay" and straw as micro-reinforcement. The absorption of baked clay and the bulk density of baked clay were tested on one sample and on the other sample the thermal conductivity λ (W/mK) was measured. The straw burned and only pores remained at the place where the straw was, which affected the reduction of the volume mass and the increase of water absorption.

Bulk density of baked clay: $\gamma = 1414\ kg/m^3$
Absorbing water: $u = 24{,}3\%$

Picture 5. Displays the measurement of a sample of baked blue clay using the Isomet 2114 instrument

Due to the pores formed by the combustion of straw, we measured on samples of baked blue clay the values of thermal conductivity $\lambda = 0{,}2537\,W/mK$.

4. CONCLUSIONS

Measurements made on a sample of baked bricks format 52 cm x 25.5 cm x 8.5 cm, with yellow clay with the addition of 15% micro-reinforcement in the form of ground straw, can be solid evidence that we are completely right with the claim that the Romans mixed micro-reinforcement into the clay, which burned and left pores, which contributed to the thermal conductivity being very low.

Picture 6. Measurement of thermal conductivity in yellow clay bricks containing rigid horse feces

By measuring the thermal conductivity of yellow clay bricks, the result was $\lambda = 0{,}2053\,W/mK$, which is only 6.8% higher than the value obtained by measuring on Roman bricks, at least 1500 years old, which was $\lambda = 0{,}1913\,W/mK$.

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САВРШЕНСТВО СТАРИХ ТЕХНОЛОГИЈА ПРОИЗВОДЊЕ ЧЕРПИЋА И ОПЕКА ВЕЛИКОГ ФОРМАТА

Резиме: *Овај рад даје неке нове информације о старим врхунским технологијама и могућностима производње опека великог формата у данашњим условима. Производња елемената за зидање може бити од глине која је обликована и осушена или је након сушења таква глина и испечена. Најосетљивија фаза код производње призвода од глине је сушење глине. У фази сушења могу настати таква напонска стања у глини која би довела до појаве пукотина и витоперења. Управо из тих разлога данас је формат опеке од глине смањен на димензије 25 цм х12 цм х 6,5 цм. Формати черпића и печених опека који су рађени пре више хиљада година, па све до уназад неколико стотина година, били су неколико пута већи од данашњег формата, потпуно правилни и без пукотина и витоперења. Стари градитељи су користили микроарматуру у облику влакана, коју су умешали у глину и на тај начин спречили појаву пукотина и витоперење. Ове технологије су проверене и потврђене у радовима студената на предметима Традиционални материјали и Зидане конструкције уназад неколико година на Грађевинском факултету у Суботици. Ови пројекти су урађени у сарадњи сасветским лидером у производњи производа од печене глине, Wienerbergер д.о.о. Кањижа*

Кључне речи: *глина, черпиц,опека, формат, скупљање, печење*