

EXPERIMENTAL RESEARCH ON THE USE OF INDUSTRIAL WASTE AS ADDITION FOR THE PRODUCTION OF UNFIRED CLAY BRICKS

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ABSTRACT

Since ancient times we know the efficiency of the technology of building houses using clay soil in various forms: mixed, in the form of bricks, etc. Until now, there have been numerous studies to improve these technologies and to obtain structures that are as resistant, comfortable and durable, as well as for the recovery of industrial waste. This paper presents an experimental study on the possibility and efficiency of the addition of industrial waste in order to obtain suitable clay mixtures for making unfired clay bricks. For this purpose, 6 compositions based on clay and industrial waste have been made. The industrial waste was ash from Mintia (thermal power plant), limestone sludge, plaster sludge and dumped waste from the processing of imported ore. Analysing the followed physical-mechanical parameters, for the realized mixtures, it is confirmed that the industrial waste can be successfully used as an addition in the clay matrix destined to make bricks from unfired clay.

Keywords: sandy clay; waste; fly ash; limestone sludge; plaster sludge.

REZUMAT

Se cunoaște încă din cele mai vechi timpuri eficiența tehnologiei de construcție a locuințelor utilizând pământul argilos în diverse forme, bătorit, sub formă de cărămizi sau altele. Au existat numeroase studii pentru îmbunătățirea acestei tehnologii și pentru obținerea unor structuri cât mai rezistente, confortabile și durabile, precum și pentru valorificarea deșeurilor industriale. Această lucrare prezintă un studiu experimental privind eficiența adaosului de deșeuri industriale la argila și posibilitatea obținerii unui amestec optim pentru realizarea cărămizilor din argilă nearsă. S-au realizat 6 compoziții în proporții diferite de argilă și deșeuri industriale. S-a folosit cenușă de termocentrală de la Mintia, șlam de calcar, deșeu haldat provenit de la prelucrarea minereului importat și șlam de ipsos. Analizând concomitent toți parametrii fizico-mecanici urmăriți, pentru amestecurile argiloase utilizate, s-a ajuns la concluzia că deșeurile industriale pot fi folosite cu succes ca adaos la argilă, cu scopul de a obține cărămizi din argilă nearsă.

Cuvinte cheie: argilă nisipoasă; deșeu; cenușă termocentrală; șlam de calcar; șlam de ipsos.

1. INTRODUCTION

Increasing the CO₂ concentration in the atmosphere led to the depletion of the ozone layer and, consequently, to the global warming that led to the production of numerous fires worldwide. Portland cement manufacturing contributes with 4-8% of total greenhouse emissions, most notably CO₂, but also other, not at all negligible pollutants such as dust emissions and N₂O, CH₄, SO_x, NO_x, NH₃, CO emissions (Minke, 2006). Under these conditions, the elimination or substantial reduction of cement consumption is necessary.

The most important motivation for replacing, where possible, is represented by classic building materials with ecological materials, which could lead to the protection of the environment. In the context of sustainable development, the possibility of recycling, reuse, reintegration in nature, environmental protection and the efficient management of natural resources are essential indicators. The adobe bricks elements successfully meet these requirements. The lack of understanding of the importance of living in harmony with nature, another way of calling sustainable development, has led to different natural disasters.

Another important aspect of using environmentally friendly materials is the health and safety of users. The natural clay materials used in constructions allow natural and efficient ventilation of the walls, permeability to water vapor, thermal and humidity constancy of the interior environment, lack of toxic emissions, factors that play a very important role in reducing the risk of respiratory diseases, allergies and many others.

Currently, there are studies attesting the durability of the constructions made with local materials and with local techniques (Bui et al., 2009a; Hegyi et al., 2016; Călătan et al., 2016, 2017) in different geographical and climatic conditions. We have the intelligence and ingenuity necessary to adapt to the conditions of a changing world (Ciurileanu and Bucur Horvath, 2011).

The construction techniques using clay are known and attested 9000 years ago. The clay bricks found in Turkestan have been used from 8000-6000 B.C. The clay was used as a building material in all ancient cultures, not only for houses, but also for religious buildings, 5000-year-old foundations being discovered in Assyria. (Ciurileanu and Bucur Horvath, 2012).

In Romania, clay houses have started to become more and more popular and pleasant, so more and more specialists are interested in this type of construction (Suciu and Suciu, 2007; Moquin, 1994). A contemporary representative example of clay construction in Romania is the Clay Castle in Fairy Valley, Porumbacu de Sus, Sibiu County, built with the help of the architect Ileana Mavrodin, which is made exclusively of natural materials.

The results of some research, presented in the literature indicate the possibility of realizing the constructions made of unfired clay bricks (adobe bricks) but also some shortcomings of the method (Minke, 2006; Suciu and Suciu, 2007; Kiroff and Roedel, 2010; Vural et al., 2007). The main disadvantages would be that, in order to reach minimum conditions of mechanical and thermal resistance in operation, a large wall thickness is required; there is a high risk of cracking during drying, and axial contractions are significant. The literature shows that the main raw material, the clay soil,

to be ideal for use for the proposed purpose must contain at least 15-16% clay because it has plasticity and workability suitable to obtain a quality finished product. Water is needed to obtain the delaying phenomenon of clay sheets and, therefore, to obtain a workable mixture. However, the water should be dosed so as not to damage by inducing significant axial contraction and cracks occurring during drying. Thus, a linear contraction between 3 and 12% is accepted for bricks from soft mixtures or between 0.4 and 2% in case of drier mixtures (Minke, 2006; Bui et al., 2009; Kiroff and Roedel, 2010; Jayasinghe and Kamaladasa, 2007). Also, in order to obtain a good thermal insulation, the literature indicates a density of the material within the limits 1600 – 2000 kg/m³ (Minke, 2006; Bui et al., 2009b; Jayasinghe and Kamaladasa, 2007; Lăzărescu et al., 2020).

On the other hand, literature does not fully cover, through specific studies and researches, the influence of the different additions, on the physical-mechanical characteristics of the elements made of clay (mechanical resistance, thermal resistance, behavior to water and water vapor, etc.).

Every year, large quantities of ash are generated, because for the production of energy the process of burning coal is used - the share of coal for the production of electricity globally remains over 38%, the consumption of coal increasing in recent years after a short period of annual decrease (Lăzărescu et al., 2020; Feuerborn et al., 2019). As a result of coal burning, two types of ash result: fly ash, evacuated with combustion gases and coarse ash, collected and dumped, both with major impact on polar growth, the first polluting the air, the second occupying huge areas of land. In Romania, over 80% of the industrial waste is deposited, this being the main way of so-called disposal. Only in 2017, a single Romanian power station produced almost 650,000 tons of ash, 50,000 tons of slag and 50,000 tons of gypsum and, out of the total industrial waste produced nationally, only 0.06% of these wastes are capitalized (Lăzărescu et al., 2020).

Within the technological process from the processing of natural stones and marble (limestone blocks), significant quantities of sludge result, 20 tones / day - consisting of limestone suspension (Lazarescu et al., 2020). The limestone sludge resulting in the technological process of processing natural stones and marble, partially dried is deposited in the form of a cake, drying naturally (Figure 1). Also, when processing the imported ore, it results a large quantities of mixed waste and plaster sludge.



Fig.1. Naturally dried limestone sludge

Therefore, studies and research are needed on the possibility of recovering industrial waste by using them as additives in clay mixtures intended for the manufacture of bare clay bricks. The aim of this research is to establish optimum mixtures intended for the production of bare bricks using four types of industrial waste, used in pairs, as follows: fly ash and limestone sludge on the one hand, respectively waste from processing imported ore and plaster sludge, on the other hand.

2. MATERIALS AND METHODS

The clay extracted from Valea Drăganului locality, Cluj Napoca County, was used to make the experimental mixtures. Clay mixes with fly ash from the Mintia power plant and limestone sludge, as well as clay mixtures with added waste dump from the processing of imported ore and plaster sludge were produced in the current research.

The clay soil used was characterized by the particle size distribution, as shown in Figure 2 (Călătan et al., 2015, 2016) and by the oxide composition, as shown in Table 1.

Industrial waste used as an additive was characterized according to the data presented in Tables 2-5.

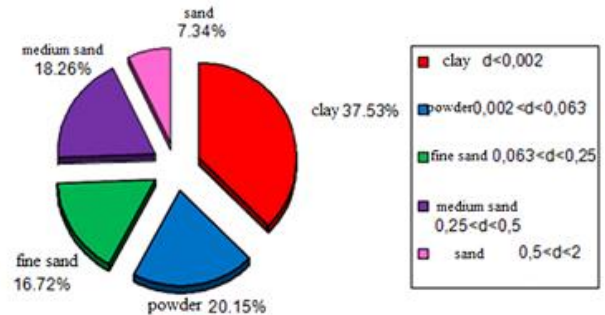


Fig. 2. Sandy clay granulometry

Table 1. Clay oxide composition

Oxides	[%]
SiO ₂	74,17
Al ₂ O ₃	12,74
Fe ₂ O ₃	4,38
CaO	0,7
MgO	1,0
K ₂ O	1,43
Na ₂ O	0,73
TiO ₂	0,05
PC	4,78

Table 2. Fly ash chemical composition

Oxides	[%]
SiO ₂	53,75
Al ₂ O ₃	26,02
Fe ₂ O ₃	7,91
CaO	2,54
MgO	1,54
SO ₃	0,35
Na ₂ O	0,59
K ₂ O	2,57
P ₂ O ₅	0,12
TiO ₂	1,02
Cr ₂ O ₃	0,05
Mn ₂ O ₃	0,09
ZnO	0,04
SrO	0,02

Table 3. Physical characteristics of the ash samples – Fineness $R_{0,045}$

Mintia Fly ash	Fineness $R_{0,045}$ (%)	Apparent density (Mg/m^3)
	39,20	1,67

Table 4. Particle size distribution

The size of the sieves (mm)	0,063	0,125	0,250	0,500	1
Through the sieve (mm)	69	93	95	99	100

Table 5. The apparent density of the additions

Addition material	Waste	Sludge of paste	Limestone sludge
Apparent density (Mg/m^3)	1,26	1,26	1,78

Within the experimental program, six mixtures with different ratios of clay, fly ash and limestone sludge, respectively clay with dumped waste from the processing of imported ore and plaster slurry, were produced (Table 6) and a control mixture, without additions (Mixture 1). The following parameters were determined on 40 x 40 x 160 mm prismatic specimens which were dried until humidity equilibrium was reached:

- shrinkage, according to STAS 2634;
- apparent density hardened state, when the equilibrium humidity is reached, according to EN 1015-10;
- mechanical strength, according to EN 1015-11.

From previous experience, it is known that the equilibrium humidity can be considered to be obtained after 40 days of keeping the samples in laboratory conditions and is signaled by reaching a constant mass level between successive weighing at 24 hours intervals.

3. RESULTS AND DISCUSSIONS

The experimental results obtained are shown in Figs. 4 to 6.

As seen in Figure 3, it was found that, from the point of view of the shrinkage, all the tested mixtures fall within the limits indicated as being admissible in the specialized literature (Minke, 2006; Moquin, 1994; Lăzărescu et al., 2020). Analyzing the aspect of the samples at equilibrium humidity and the values of their shrinkage, we can observe a contraction of the samples, but at the same time the lack of cracks (Figure 3). However, the small dimensions of the specimens must be taken into account. Therefore, it can be said that in order to make the bricks in these compositions, in order to avoid the occurrence of cracks, even if the obtained results regarding the drying contractions and the evolution of the cracks are satisfactory; the dimensions of the elements should not exceed certain values. Establishing the correlation between the maximum allowable dimensions of the masonry elements made from clay mixtures with industrial waste additives and the lack of cracks requires further experimental study.

Based on the results presented in the graph in Figure 4 it can be said that the additions introduced into the mixture have little influence on the axial contractions, compared to the blank test made only of clay. At the addition of fly ash and limestone slime, there is a lower decrease in shrinkage than at the addition of waste mixture and plaster slurry. The largest decrease of shrinkage can be seen for the mixture with 50% clay, 25% waste and 25% plaster sludge that is 8.6 mm / 100 mm from 9.4 mm / 100 mm of the Mixture 1.

**Fig.3** The surface of the hardened specimen

As seen in Figure 5, the tested mixtures have a density between 1600 kg / m^3 and 1690 kg / m^3 . As with the shrinkage, the density variation is insignificant. The sample with the highest apparent density is Sample no. 4, which has the largest amount of added waste (40% clay and 60% other additions). These density values indicate a good thermal resistance of the material, as specified in the literature (Minke, 2006; Moquin, 1994; Karim et al., 2011). Probably, this sample has the highest density due to the addition of the largest sludge of limestone, which has the highest density in bulk, compared to the other raw materials.

The mechanical strength determined on the hardened prisms and reached the equilibrium humidity is shown in Figure 6.

From the graph, we observe an increase of the mechanical resistance to compression and bending to all mixtures with added waste, compared to the control sample. The highest resistances are obtained at different percentages of addition depending on the type of waste used. The sample with addition of thermal ash and limestone sludge, Sample no. 3, shows the highest resistance to compression. This sample has 25% ash, 25% limestone sludge and 50% clay. At the addition of 20%

ash and 20% limestone sludge, as well as at the addition of 30% ash and 30% limestone sludge, there is a slight decrease of the strength in compared to Sample no. 3, but nevertheless the strengths of these mixtures are greater than the strength of the clay without addition. In the case of the addition of dumped waste and plaster slurry, the sample with the highest strength is the sample no. 6, which has 40% added of waste. (20% hald mixture waste and 20% plaster slurry). The samples with the addition of 30% and 50% waste of the same type have the mechanical strengths with approx. 6% lower than the sample with 40% added waste. In this case too, all the samples with waste addition have higher resistance than the control sample.

Mixture 3, with 50% clay, 25% ash from Minutia and 25% limestone sludge, has the compression strength with 50% higher than the control sample, and the mixture 6, with 60% clay, 20% dumped waste and 20% plaster sludge has a compression strength 40% higher than the test specimen. These are the optimal mixtures from the point of view of the mechanical strengths. Figure 7 shows the specimens after breaking.

Table 6. Composition of experimentally tested mixtures

Materials / Mixtures	Clay (%)	Fly ash (%)	Limestone sludge (%)	Ore waste (%)	Plaster sludge (%)
1	100	0	0	0	0
2	60	20	20	0	0
3	50	25	25	0	0
4	40	30	30	0	0
5	70	0	0	15	15
6	60	0	0	20	20
7	50	0	0	25	25

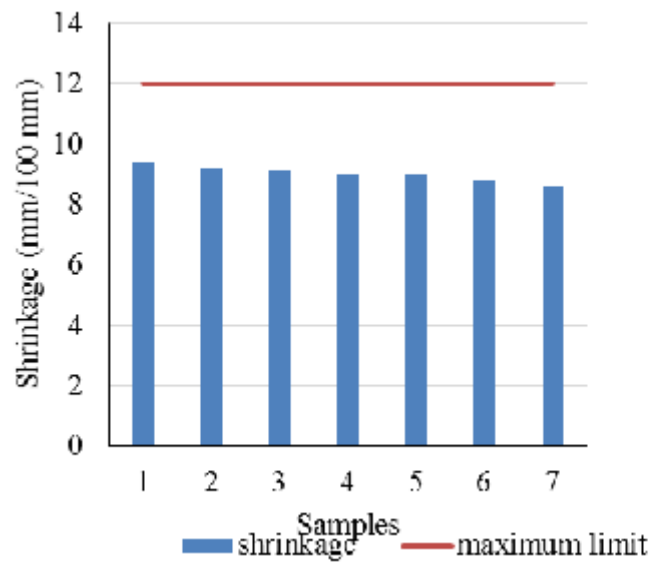


Fig. 4 Shrinkage of dry mixtures at equilibrium humidity

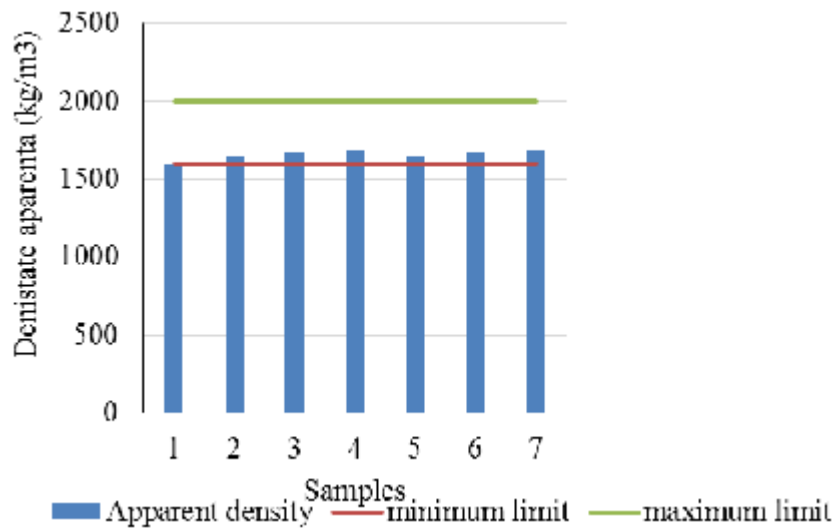


Fig. 5. The apparent density of the mixtures

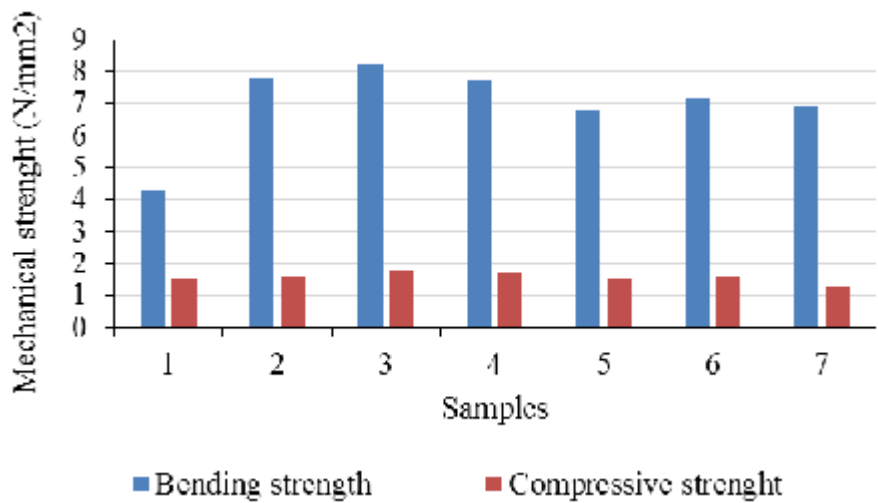


Fig.6 Mechanical strength of samples



Fig. 7 Specimens after breaking

4. CONCLUSIONS

As a result of the research carried out, the following conclusions are drawn:

- The workability of all clay mixtures with waste is very good, allowing an optimal homogenization;
- The addition of industrial wastes to the clay does not negatively influence the shrinkage. In the manufacture of small dimensions bricks, there is no crack, but probably in the bricks with dimensions of sides larger than 160 mm, cracks can be observed. This is due to the large contractions of the clay. These mixtures are not suitable for mortars, due to the large shrinkage that they present;
- The apparent density of the mixtures in strengthened state, dried at equilibrium humidity, is not significantly influenced by the additions of industrial waste used. The densities are in accordance with the specialty literature, satisfying the thermal efficiency, which indicates an apparent density range between 1600 and 2000 kg / m³, satisfactory for thermal efficiency. These mixtures are suitable for making heat-insulating bricks;
- The compressive strength is significantly positively influenced by the addition of industrial waste analyzed;
- The tensile strength is also influenced by the addition of industrial waste, increasing, in comparison with the con-

trol sample, for all 6 cases of clay compositions with industrial waste additions.

These conclusions confirm that the industrial waste can be successfully used as an addition to the clay matrix intended for the production of unfired clay bricks.

So, it can be affirmed that it is of interest to capitalize this industrial waste in this way, also resulting an ecological and healthy material.

These products can be successfully used to achieve an friendly environmentally, energy efficient construction, with a favorable impact on human health, protecting the nature of pollution, by reducing the consumption of cement, and also applying the basic principles of traditional vernacular architecture, modeled according to current technological progress (Călătan et al., 2015)

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