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APPLICATION OF GREEN CLAY MATERIALS IN SUSTAINABLE CONSTRUCTION: AN OVERVIEW

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This article provides an overview of current trends in sustainable environmental development in the production of building materials. The first part of the article is devoted to the comparison of the most popular building materials in terms of their impact on the environment by the parameters of their life cycle assessment (LCA). The second part presents some options for improving the mechanical and operational properties of unfired clay material, as the most perspective material from the point of view of sustainability. A hypothesis about the further prospects for the study and use of non-fired clays has been made.
Keywords: *eco-friendly, life cycle assessment (LCA), embodied energy, carbon emission, unfired clay, modification, industrial wastes, bio-polymers.*

ИСПОЛЬЗОВАНИЕ ГЛИН В ЭКОЛОГИЧНОМ СТРОИТЕЛЬСТВЕ: ОБЗОР

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Данная статья представляет обзор современных тенденций устойчивого экологического развития в сфере производства строительных материалов. Первая часть статьи посвящена сравнению наиболее популярных строительных материалов с точки зрения их влияния на окружающую среду по параметрам оценки их жизненного цикла (ОЖЦ). Вторая часть представляет варианты улучшения механических и эксплуатационных свойств необожжённого материала из глины, как наиболее перспективного материала с точки зрения экологичности. Выдвинута гипотеза о дальнейших перспективах исследования и использования необжиговых глин.
Ключевые слова*: экологичный, оценка жизненного цикла, вовлеченная энергия, выбросы углекислого газа, необжиговая глина, модификация, промышленные отходы, биополимеры.*

Introduction. Nowadays, the construction industry has one of the most impaction on environment among other socio-economic sectors. One of the common-used methods to determine the evaluating of a product's impact on the environment during its exploitation is Life Cycle Assessment (LCA). This method helps to analyze the ecological impact of the building material over all its entire life cycle from production to utilization. The main problem of its detailed assessment is the accurate audit of every processing aspect including the quantification of the relevant transport, energy, environmental (emissions) and the any other inputs into the final product [6].

Focus on the life cycle also helps to make a right decision when selecting the production technology and minimizing the environmental impact of the building materials through their manufacturing, using or recycling. As was mentioned in the work [14], most of the building materials may be quite harmless during their exploitation, but at the stage of their production or recycling they may emit a huge amount of toxic agents. As an example, author used a case concerns PVC. It was concluded that LCA models can also accompany to a product design. Producing an eco-friendly product, we should pay attention to its whole reusing in the future, or at the recycling of its components in the waste management stage.

Speaking about sustainable construction development we should consider on so-called "sick building syndrome" (SBS). This phenomenon is characterized by acute consequences for the health or comfort of people inside the building and associated with the time spent in it. The main trouble is the specific disease or cause cannot be determined, but after leaving the building complainants feel relieved soon. The main causes of SBS are: i) inadequate ventilation, ii) chemical or biological contaminants from indoor/outdoor sources [1]. The materials around us, for example, adhesives, carpeting, upholstery, manufactured wood products may emit volatile organic compounds (VOCs), including formaldehyde.

The comfort of the occupants and the quality of indoor air are becoming important parameters in the selection of building materials for use inside buildings [8, 9]. Unfired clay material is a green material that to meet all the requirements, essentially because of its low environmental impact and strong hygroscopic properties. The popularity of green clay or soil-based materials is also increasing due to their great potential for sustainable production. The green clay, earth materials (bricks, mortars, plasters) are generally held to have good environmental characteristics.

For example, green clay porous materials can absorb a certain quantity of the humidity contained in the environmental air. Green clay materials are known for its high capacity to balance air humidity (sorption and desorption property) in room, it is a very good property. It has been shown that clay materials moisture content increases when the ambient relative humidity increases and decreases when ambient temperature increases [19-21]. Natural clay plasters are breathable, non-toxic, release no VOCs into the atmosphere and are 100% biodegradable. The incorporation of bio-aggregates within clay plasters has potential to improve indoor environment quality through passive humidity buffering [15]. The earthen material also may store heating and cooling energy inside. It allowed 69 % savings of heating energy in winter and 57% savings of cooling energy in summer [22]. Results obtained in [9] indicated that the place from earth brick provided a preferable indoor climate than in the fired brick room because of a lower air temperature maximum and smaller fluctuations of air temperature that are better for a people's comfort.

Discussion. *1.1 Construction materials life cycle assessment*

Nowadays, LCA has become the most common way to quantify the (un)sustainability of building materials. Based on the environmental management standards EN ISO 14040 (2006) and BS EN 15978 (2011) a large number of LCA databases are still developing and updating [3-5]. Also, the “cradle-to-grave” methodology should be applied in the design and manufacturing of new building materials to assess its environmental impact beforehand [2,6].

Thus, to compare the most popular building materials in terms of their impact on the environment in terms of their life cycle assessment parameters, overall data from different sources were collected in the Table 1.

To further evaluation of the various building materials sustainability, it was decided to compare these materials by the two main criteria: embodied energy or carbon. To clarify this definitions: *embodied energy* is the total energy requirements of the final material connected with its delivery (including raw ingredients), production and further exploitation; *embodied carbon* is the equivalent carbon emissions incorporated in the energy of used materials. In general, the higher values of these two indicators, the more environmental damage is caused.

Table 1. – Environmental impact of typical building materials - comparative data

#	Material	Density, (kg/m^3)	Thermal Conductivity, (W/mK)	Embodied energy, (MJ/kg)	Embodied carbon, (kg CO_2/kg)	Ref.
1	Concrete (heavy-weight)	1800 – 2500	~1,5	0,9 – 1,2	~0,14	[3,7]
2	Cement	~1300	~1,4	2,4 – 9,3	0,25 – 0,82	[3,7]
3	Cement mortar	~1500	~0,7	1,1 – 2,2	0,04 – 0,24	[3,7]
4	Cement plaster	1600 – 1800	~1,0	~17,2	~6,0	[4]
5	Fired clay brick	1400 – 2200	~0,9	1,2 – 6,5	0,06 – 0,24	[2,3,7]
6	Unfired clay brick	1200 – 2000	~0,65	~0,09	0,002 – 0,02	[2,3]
7	Clay plaster	~1700	~1,0	~11,7	~1,4	[4]
8	Wood products	500 – 1000	0,12 – 0,16	8 – 16	0,12 – 0,24	[3,7]
9	Wood wool	180	0,07	~20,3	~0,14	[3,7]
10	Cellulose fiber	50	0,04	~10,5	~1,8	[3]
11	Rock wool	60	0,04	~26,4	~1,5	[3]
12	EPS foam slab	30	~0,04	~105,5	~7,4	[3]

It is important to understand, that comparative data from the Table 1 is not absolutely accurate and not in full agreement, the data can vary in different sources: articles or databases. For example, in the work [5] authors presented a comparative study of ten different LCA databases of building materials to help researchers to define the most suitable one in a certain case. It was also pointed that each LCA database is created by an organization located in a specific territory with its own manufacturing characteristics. Some key data such as energy consumption and total amount of emissions during production create major challenges. Incorporation of the recycled materials with a long-processing history can also be a problem [6]. In fact, to obtain the most adequate results, each material should be considered separately, as a combination of many factors, taking into account all its specific features.

According to the Table 1 we can draw the following conclusions:

Concrete is not the most "dirty" material in terms of kilograms, but steel reinforcement necessity and huge total amount in the final building's structure are the main factors making concrete one of the most unsustainable material.

Ceramic bricks, for example, are more energy intensive than concrete due to the high-temperature burning treatment needed for its manufacture process. Moreover, the high quantity used in a building, makes ceramic bricks one of the most impacting materials in the whole building process [5]. Unfired or green clay systems has the far higher environmental credentials than other materials. Of course, the unfired brick is inferior to concrete or ceramic brick in some aspects, but it is only stimulating its further development and improvement of properties such as compressive/tensile strength, water resistance and etc.

Involved energy of the wood products is related to their biomass, which is more than half of the total primary energy requirement. Carbon dioxide emissions are almost zero due to the low level of industrial processing, and with further reuse or recycling it will be generally negative [3].

It can be considered, insulation materials in a whole are the most impacting group comparing with others. As expected, materials with a high degree of processing, such as expanded polystyrene, are the most unsustainable, which in some cases would be more expedient to replace with natural analogs, such as rock, wood wool or some recycling products such a cellulose fiber.

1.2 Methods of the clay/earth materials modification

Unfired clay brick is a composite construction material generally made of earth (clay) mixed with water and some additives. It is well-known, natural clays are hydrophilic materials and can absorb significant amounts of water. Their dimensions can also vary according to their moisture content, and change greatly during drying (20°C or 105°C temperature) of the sample. Shrinkage is a dimensional variation of the clay material caused by water evaporation. This volume decrease engenders internal stresses that can lead to shrinkage cracks or materials defects.

Thus, green clay bricks continue to present an environmentally sustainable cheap and wide alternative with low embodied energy and carbon, but still in need of improvement in its mechanical and performance properties. Speaking about the need of non-fired, green clays modifying, the most rational option seems to be the development of production in the way of modification with the help of natural products, industrial waste (as noted in the introduction) or some bio-components.

As was mentioned in the article [18] it is necessary to take into account not only the mechanical and hygrothermal properties of non-fired clays, but also their durability. The green clay material resistance to a water is extremely low, and the addition of bio-fibres may decrease its resistance even more. Also, adding of an organic matter, can decrease the composite's resistance to moulds. Therefore, studies on the stabilization of unfired clay materials with bio-additives (fibres or polymers) are still relevant.

Unfired clay material modification with natural fibers/industry wastes

It seems the most traditional way of the unfired, adobe clay modification is the usage of natural fibers. For example, the work [10] presents a critical analysis of various natural fibers wastes for unfired brick stabilization. The paper mentions 44 different types of fiber wastes aggregate, which indicates a variety of material for modification in different countries due to the industry based there. It was concluded, fiber waste in the unfired clay systems makes them more durable and stronger due to its reinforcement effect. In the most of the green clay bricks in question with increasing of compressive strength by adding fiber additives (at the optimal value) the water absorption also increased. This phenomenon caused to the absorbent nature of additives which creates pathway through the clay structure, thereby allowing more water to be absorbed by the bricks. Also, in the most of the considered studies the fibers addition are limited cracking of clay materials.

An example of green clay material modification by adding industrial waste can be found in the work [11]. This paper demonstrates the use of paper and pulp industry residues (PPR) as reinforcement with micro-fibers of unfired bricks with the aim of showing the feasibility of this construction material. It has been demonstrated that the use of PPR leads to produce lighter bricks with lower thermal conductivity and improved compressive strength, but water absorption test was not carried out.

Thus, the main concept of such modifications is the forming of an additional bonds inside the clay structure. The development of strength properties of such clay bricks mainly depends on the formation of “fiber-clay”, “clay-clay”, and “fiber-fiber” bonds. The strength of these bonds mainly depends on the dimension, surface conditions, and quantity of additives added to the soil. When additive content increased above the optimal value, the weakest bond "fiber-fiber" breaks, thereby reducing the compressive strength of the final material [10]. Increasing of water content can also leading to a bonds breaking in the clay material structure. There is a question not only the choice of optimal composition, but also protection of the adobe against the moisture ingress inside the material.

Unfired clay material modification with bio-polymers

The use of biopolymers, sourced from renewable materials are perspective way for construction materials modifying. There are a lot of bio-polymers like lignosulfonate, casein, derivatives of starch and cellulose and various water-soluble polysaccharides that can potentially been used as admixtures for masonry materials to improve the properties of final products. Natural biopolymers may play significant role as alternative stabilizers for earthen materials, and the question of the clay/biopolymer interaction should be more explored [16].

Authors, in the article [15] presents the novel bio-clay plaster with addition of a hemp powder. Results shows improving of the indoor building climate by additional moisture buffering and also providing a fire insulation. Addition of a hemp powder to the plaster also influences on its drying shrinkage, thermal conductivity. With increasing of the hemp powder content in the plaster the thermal conductivity and density were decreased. With a good moisture buffering capability, even for small thicknesses, and low thermal conductivity, the final product has potential to develop industrially viable products.

Research [16] proposed an unfired clay composite material with using of biopolymers obtained from different types of macro-algae (seaweed). Macro-algae are a renewable resource which contains alginate, the main structural polysaccharide of brown seaweeds may be suitable for the development of the new sustainable materials. Manufactured unfired clay bricks offering a low embodied energy and can be an alternative to other masonry systems such as fired brick or concrete structures. Results shows that some types of the alginate products improved both the compressive and flexural strength of the bricks, little reduction in shrinkage (2-4%).

An example of complex modification method, including fiber reinforcement and polymer addition, is presented in the work [17]. The authors have created a composite clay-based material using woolen fiber and alginate polymer. Separate tests show that the addition of wool fiber increases compressive strength by 37% and alginate polymer by almost 70%. By combining the two components, the authors obtained a result that exceeded the control sample by two times in compression and the tensile strength increasing by 30%. Unfortunately, no tests for water absorption / erosion were carried out, so the question of green clay modification with biopolymers and its effect to the performance characteristics of the final product remains open.

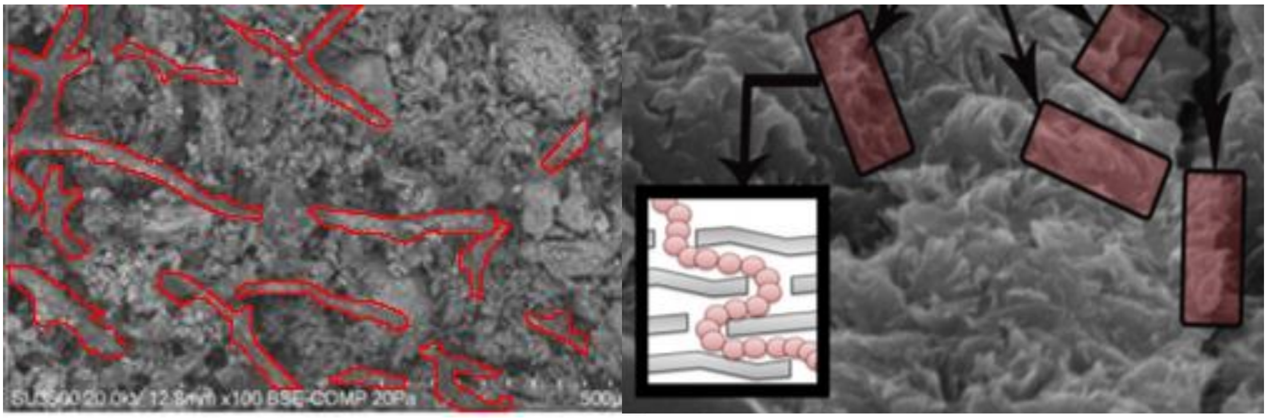
Thus, the main idea of the proposed modification type is the physical adsorption of polymers to the surfaces and interlayer spaces of the clay minerals. The physical adsorption can alter the nature of the clay mineral surfaces and improve their surface physical and chemical properties [13]. This property of polymers is most clearly demonstrated in the work [12]. Authors used acid-activated starch for investigation its influence on bentonite clay in tuning the responsiveness and rheological characteristics. Figure 1, b is demonstrated the clay surface with a starch skin in it. Such hydrogels are found to be quite effective in terms of swelling ability, water resistance and biocompatibility.

In the context of future research, it is promising to use a complex modification method of green clay materials. Combining the reinforcement of the clay structure with fibers, as well as adsorption of the polymer on the clay surface and interlayer space we may improve the strength and durability of final material.

Conclusions.

1. Nowadays, ecological sustainability is one of the most necessary way in social-economic development. Building materials industry as high-enviromentaly polluting sector should adaptate to the new trends, standarts and requirements. LCA is a useful and effective tool with different parametres which can be tuned to approve various aspects of manufactured products under different conditions for analysing technical, exploitation options and alternatives to minimise the ecological impact of any process or product.

a) b)



a) structure reinforcement with PPR, cellulose fibers [11];
b) surface, interlayer modification with acid-activated starch [12]

Figure 1. – Two approaches to unfired clay material modification

2. This overview shows a great potential of green clay or earth raw materials with different additions in the building industry. Stabilized unfired clay bricks may support the production of more durable and sustainable materials and may be an alternative to other building materials.

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МИНИСТЕРСТВО ОБРАЗОВАНИЯ РЕСПУБЛИКИ БЕЛАРУСЬ

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