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Analysis of equipment for thermoplastic molding artificial products of spatial form

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The study explores the innovative use of recycled plastic in brick production in the construction industry in Ukraine. It examines the production process, including the collection and processing of plastic waste, and the formation of bricks using methods such as plastic molding and semi-dry pressing. The research emphasizes the importance of pressure distribution in screw presses for the compaction of clay in construction ceramics production and highlights the significance of vacuuming the molding mass for improving the quality of molded products. Plastic-brick products are found to offer advantages such as altered strength, improved insulation properties, and lighter weight. Comparing technological schemes, the semi-dry method of brick production is noted to have higher metal capacity and lower labor intensity compared to the plastic method. The study aims to enhance the efficiency and results of thermoplastic molding in the construction industry, contributing to sustainable construction practices and reducing environmental impact.

Keywords: ecology; energy efficiency; equipment; plastic; plastic-ceramic products; press; thermoplastic molding; pressure; brick; quality

Аналіз обладнання для термопластичного формування штучних виробів просторової форми

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Будівельна галузь в Україні постійно розвивається, використовуючи сучасні технології та матеріали для підвищення стійкості та ефективності. Одне з таких нововведень передбачає використання переробленого пластику у виробництві цегли, пропонуючи багатообіцяюче рішення для боротьби з пластиковими відходами та сприяння переробці. Виробничий процес передбачає збір і переробку пластикових відходів, які потім змішуються з іншими компонентами та формуються в цеглу за допомогою таких методів, як формування пластику та напівсухе пресування. Ці методи мають явні переваги та недоліки, що впливає на загальну якість і властивості цегли. Критичним аспектом виробничого процесу є розподіл тиску в шнекових пресах, який відіграє ключову роль у пресуванні глини для виробництва будівельної кераміки. Проведено аналіз течії глини через прес на моделі в'язкопластичного матеріалу та розраховано характеристики шнека та формувальних тіл для визначення параметрів режиму роботи. Крім того, вакуумування формувальної маси визначено як вирішальний крок для підвищення якості формованих виробів. Отримані вироби з пластикової цегли демонструють ряд переваг, включаючи змінену міцність, покращені ізоляційні властивості та меншу вагу, що робить їх переконливою альтернативою традиційним цегляним матеріалам. Крім того, порівняння технологічних схем показує, що напівсухий спосіб виробництва цегли демонструє більшу металоємність і меншу трудомісткість на відміну від пластичного. Це дослідження має на меті зробити внесок у поточні зусилля щодо підвищення ефективності та результатів термопластичного формування в будівельній галузі. Досліджуючи інноваційне використання переробленого пластику у виробництві цегли та наголошуючи на важливості розподілу тиску та вакуумування в процесі формування, це дослідження спрямоване на просування екологічних методів будівництва та зменшення впливу на навколишнє середовище.

Ключові слова: екологія; енергоефективність; обладнання; пластик; пластико-керамічні вироби; прес; термопластичне формування; тиск; цегла; якість

Introduction.

The construction industry in Ukraine is one of the key sectors of the economy, which determines not only the socio-economic development of the country, but also contributes to the formation of modern infrastructure and maintains the stability of the national economy.

Technical progress and the introduction of innovations in the construction industry play an important role in ensuring high quality construction and energy efficiency of facilities.

One of the key trends in the construction industry is the active use of the latest building materials and technologies. Innovative building materials, such as high-strength concrete, environmentally friendly insulation materials and modern composite structures, ensure high strength and durability of structures.

The construction industry in Ukraine is constantly developing, using modern technologies and materials to achieve high quality and durability of construction projects. One of the key materials that is widely used is brick, which has the properties necessary for high-quality construction.

There are several basic methods of making bricks: plastic molding method (ceramic brick [7]) and semi-dry pressing method (silicate brick [8]). The plastic molding method is simpler in the technological process of making ceramic bricks. The method of producing bricks in this way is more economical and practical in our region, due to the use of local materials.

Today, a new innovative technology has emerged aimed at reducing the consumption of traditional building materials and the use of recycled plastic, which helps to reduce the negative impact on the environment [20].

Review of the research sources and publications.

Ukrainian and foreign researchers were engaged in research in the preparation of bricks using plastic, which made it possible to use plastic waste, which usually becomes a problem for the environment. The use of plastic in brick production can help reduce the amount of plastic waste and promote recycling.

Plastic-based brick manufacturing processes that use less energy compared to traditional brick production methods have also been described [6].

Studies have also shown that the use of plastic materials in construction can be an innovative solution that develops the construction technology industry. This can open up new possibilities for architectural solutions and structures, expanding the possibilities for the design and efficiency of buildings. The use of plastic in brick production can create a demand for recycled materials and contribute to the development of efficient recycling systems [17, 18].

Definition of unsolved aspects of the problem

It requires in-depth research on the properties and capabilities of new thermoplastic materials, namely the study of their resistance, mechanical characteristics and recycling capabilities.

There is insufficient theoretical justification for studies of the properties of plastics and their impact on the quality and strength of bricks and the types of plastic that are most suitable for use in bricks and can be combined with other materials.

It is also important to study and take into account production safety issues, as well as to determine the appropriate standards for thermoplastic molding. Consideration of the impact of thermoplastic molding on other production processes and the development of integrated approaches to production.

Problem statement

Research of promising technologies in the field of thermoplastic molding and their possible impact on production, analysis of modern brick forming equipment, including its specifications, efficiency and capabilities and the study of technological aspects and parameters, affecting the quality of thermoplastic molding, in order to improve efficiency and results.

Basic material and results

The production of plastic-ceramic products includes several key stages. The first stage is to collect and process the recycled plastic. Plastic waste is used, such as plastic bottles, bags, containers, and others. This plastic is placed in special containers and can be cleaned and shredded. The shredded plastic is mixed with other components such as sand, cement, water, and additional additives that improve strength and insulation properties. The resulting mixture is fed into special molds, which give the brick product the required shape and size. Products can be compressed or pressed to obtain the required density [16]. The formed bricks are subjected to a drying and hardening process, which can take place at room temperature or at elevated temperatures in special drying chambers or ovens [10]. Finished bricks are packed in bundles or on pallets for easy transportation and delivery to construction sites.

When assessing the plastic-ceramic mass's ability to form, first of all, the quantitative relationships between the solid, liquid and gaseous phases of the mixture are considered. The liquid phase (water) is an essential component of the ceramic mass for all practically used molding methods. Water, on the one hand, tightens clay particles, on the other hand, causes significant mobility of clay particles, providing them with the ability to slide relative to each other. The required amount of the liquid component for the formation process in one way or another depends on many different factors: the method of formation, the mineral composition of the clay component, its amount in the plastic-ceramic mass, the content of the air component, etc. One of the main requirements for the formed semi-finished plastic and ceramic product is a sufficient and constant degree of its compaction, which is characterized by an indicator of relative density or porosity, which largely determines the behavior of the semi-finished product in drying and especially in firing.

To assess the quality of the semi-finished product, not only the density values are important, but also its uniformity in different parts of the body of the formed product. Insufficient even density of the semi-finished product leads to unequal shrinkage during sintering, accompanied by deformation and even cracking [5].

This indicator is decisive for transportation, processing, installation of the semi-finished product in dryers and furnaces without damage and violation of its integrity.

The main requirements proposed for the semi-finished product after its formation also include the absence of structural defects – internal cracks, sinks and the absence of significant internal stresses, which in the process of subsequent technological operations can cause the formation of various defects and destruction of the finished product.

Based on these technical and economic requirements for the semi-finished product, as well as taking into account the physical and mechanical properties of the feedstock, it is possible to choose one or another method of forming the semi-finished product. In the production of building ceramics, the following methods are most common: plastic molding from masses with a moisture content of 14...20%, pressing from powdered masses with a moisture content of 5... 7% and casting of semi-finished products in gypsum molds from foundry masses with a moisture content of 30... 33%.

There are several ways in which plastic-ceramic mass is processed and products are formed. Based on the properties of the initial raw materials and the type of products that are manufactured, there are plastic and semi-dry methods.

Semi-dry pressing is based on pressing individual bricks from raw materials in the form of powder with a moisture content of 7...12% by sealing in closed molds. The low moisture content of the raw material with this method makes it possible to combine drying with firing in some complexes.

The advantages of semi-dry pressing are the ability to deploy the production of sufficiently high-quality bricks using clay raw materials of low conditions. The energy consumption for drying the loose clay before molding is much less than for the gentle drying of the wet raw material of plastic molding.

The main disadvantage, organically inherent in the method of semi-dry molding, is associated with the granular structure of raw materials and bricks, which loses in the homogeneity of plastic molded bricks. Quality indicators of semi-dry molded bricks (strength, frost resistance, durability), meeting the requirements of the standards, still have a significantly lower maximum limit. An inherent defect in semi-dry pressing of ceramic products is delamination cracks, which are located perpendicular to the pressing force. The main reasons for the appearance of such cracks are the growth of pressed air, segregation of the press powder when it is poured into the mold and elastic deformations of clay particles.

Plastic molding is characterized by the extrusion of solid timber and cutting it with strings into individual bricks. To implement this method, the raw material is prepared for formation in the form of a plastic charge with a moisture content of 17...25%, capable of defect-free extrusion, which is performed, as a rule, on screw presses. Depending on the pressure required for extrusion, a distinction is made between the so-called soft (pressure up to 1.6 MPa), semi-rigid (pressure 1.6...2.5 MPa) and rigid (pressure 2.5...4.0 MPa) extrusion. The power of the press motors also increases approximately in proportion to the pressure. Such presses are called belt presses, because they cut a beam (strip), which is then cut into products of the required size.

The main goal of the powder pressing process is to obtain the maximum pressing density. This indicator has the main impact on the completeness of the physicochemical processes in the mass during firing of products, as well as on the quality of the final product. It is for this reason that in the production of plastic-ceramic tiles, the insufficient density of the semi-finished product causes increased shrinkage, and therefore an increase in firing defects – cracks, warping, etc.

Uneven pressing also has a negative value. The main reasons for this may be the loss of pressure on the passage of friction against the walls of the mold, the dissimilar ratio between the depth of the layering and the thickness of the semi-finished product in different parts of the product, in addition, there may also be filling individual sections of the mold with powder of different granular composition and moisture content. A positive effect on the quality of pressing is made by stepped or repeated pressing, in which the die presses on the powder with the stages of unloading, namely, after a certain period of pressure, the die rises slightly and the pressing is released from the pressing pressure. This technique allows you to remove air from the presses as much as possible, causes less uneven density with a significantly lower maximum pressure than with one-stage pressing.

Presses that are used for plastic molding in relation to the design of the pressing device are divided into piston and screw presses [4].

The reciprocating press is simple in design and contains forming organs such as a press head with cavity formers, a mouthpiece and a cyclic operating piston blower. The cycle of operation of the piston blower consists of the working stroke for compaction of clay and extrusion of the beam and the return stroke to the original position after the next portion of clay [10]. The hydraulic piston drive allows to obtain significant pressure sufficient for rigid brick formation, and also ensures high piston speed in its reverse stroke and pre-sealing stroke, when the resistance force of the piston movement is negligible. Pauses in extrusion reduce productivity but significantly facilitate the cutting of fixed timber. It is advisable to use a reciprocating press in parallel with a powerful screw press as part of complexes for the production of facing bricks for the formation of relatively small batches of shaped bricks and other products of a wide range of shapes and sizes. In this version, the powerful screw press is used as efficiently as possible, without wasting time on frequent changeovers.

Screw presses use the principle of working with a screw shaft or screw squeeze, which moves plastic-ceramic raw materials and compresses them into a mold to obtain the desired shape and size of the product.

The blade of screw presses can be one-, two- and three-pass (Figure 1). Single-pass squeeze blades provide high press productivity and lower specific energy consumption for pressing. A press with a two-stroke squeeze blade has a much better pressing quality than a press with a single-pass blade, however, all other things being equal, the performance is less and the specific energy consumption is greater. Three-pass blades with and without overlap are rarely used due to a sharp decrease in the productivity of the press.

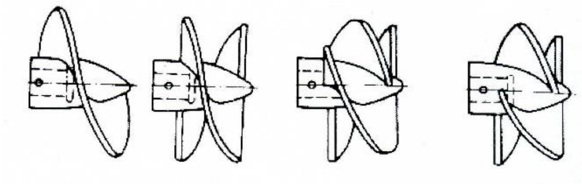

Figure 1 – Designs of pressing screw shaft blades

Belt screw presses are designed for the production of plastic-ceramic products with a moisture content of 14...25%. Also, according to technological characteristics, they are divided into presses with vacuuming and presses without vacuuming of plastic-clay mass. By design – for presses with discontinuous screw blades and for presses with cylindrical, stepped or conical bodies [3].

The speed of axial movement of the mass in the press cylinder is uneven: it is almost zero in the screw hub and maximum at the inner surface of the housing. As a result, in the mass moved in the press body, delaminations occur parallel to the axis of the press. With the further advancement of the mass in the press head, its individual sections also move at different speeds due to frictional forces along the outer perimeter of the mass beam, as well as the rotational motion, which continues partially, the mass and filling with it of the space previously occupied by the hub of the screw. As a result of such a complex movement of the mass, which depends on a large number of factors and is basically not suitable for theoretical calculation, the bar at the exit from the mouthpiece does not have a homogeneous structure, but is a sequential layering of empty cones of mass nested within each other.

To reduce and eliminate these shortcomings of plastic molding in screw presses of continuous action, it is necessary to observe the following technological parameters and measures: careful preparation of the plastic mass for the pressing operation; decrease in retention (in %) of the dusty part of the fireclay component of the mass; lengthening of the press head by inserting an intermediate ring 100...200 mm long between the body and the press head, reducing the gap between the screw blades and the press body to 2...4 mm; installation of peeling knives in the intermediate ring or head of the press; reducing the speed of the screw shaft to 20... 30 rpm; some increase in the moisture content of the mass.

Prior to the output of the timber formation and depending on the design, the presses are divided into vertical and horizontal. They are used in the production of special fine ceramics, building bricks, strip tiles, hollow ceramic blocks, socketless and drainage sewer pipes.

The screw aggregate press contains a press, a vacuum chamber and a mixer. Mixing the clay should take place without sucking in air. In this way, a screw and a working body are added to the paddle mixer to give resistance to the movement of the clay and its crushing by a grate or knives and cones [2]. While the pressure of the clay in the screw-sealed ring may be sufficient to maintain a high level of vacuum, it should not be excessive to reduce wear and energy intensity.

The press, which contains the forming organs, the screw blower (mouthpiece with cavity formers) and the press head, performs the main forming process.

The pressing process demonstrates the change in pressure in different areas of the auger, as shown in the Fig. 2. The highest pressure observed in the area of the mixer screw end blade is 0.4–0.5MPa. This is significantly less than the pressure of the main screw. Loading, pre-compaction, pressure build-up, and forming are all parts of the main screw. In the first section, the screw is filled with cut clay. During transportation, it constantly sucks out air, starting from the moment it falls. There's no pressure at this point, and it shouldn't be. In this region, the screw capacity must exceed the maximum possible with power fluctuations [1].

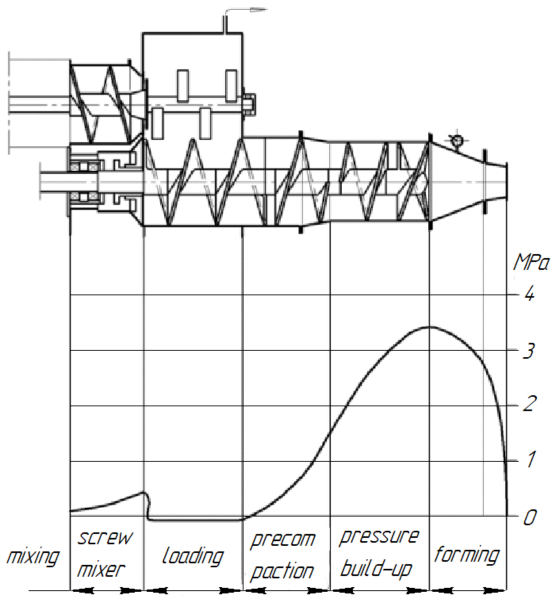

Figure 2 – Pressure distribution in the screw press

In the next part, preliminary compaction begins, and when the clay has already filled the entire turn-to-turn channel of the screw, air is squeezed out of the pores into the vacuum chamber. Reducing the channel area with auger taper and auger pitch helps to speed up compaction.

The increase in pressure is carried out by a screw in the following area. The presence of knives helps to stop the clay from turning along with the screw, in the gaps of the auger blades in this area. The pressure in the clay in the zones of action of the knives is balanced at a level sufficient to overcome the resistance of the forming organs. This means that when the supply fluctuates, these areas also help prevent overpressure inside the screw. Clay flows unevenly through the interturn channel of the auger. It flows faster in the periphery than in the hub. The cross-section that passes through the end blade at the inlet to the press head has the highest pressure. The level of this pressure is determined by the pressure losses that occur during the passage of clay through the channels of the organs that are being formed.

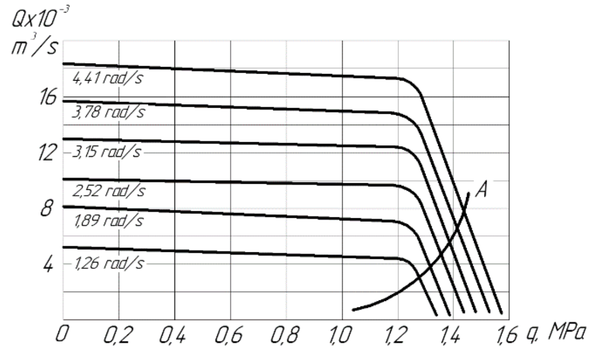

Figure 3 – Characteristics (performance as a function of pressure) of the screw and molding bodies at variable frequency

The new methods for measuring the pressure and capacity of the screw press are similar to those for aerodynamic and hydraulic systems. This method focuses on the interaction of the supercharger and the forming organs together, which means that their characteristics is *Q=f(q)*, i.e., the dependence of performance *Q* on pressure *q*. Figure 3 shows the characteristics of the screw at variable angular velocity (1.26 to 4.41 s^{-1}), as well as the characteristics of the forming organs (curve A). The operating mode parameters, Q_p and q_p, are identified as the points of intersection of the curves.

Models of Shvedov-Bingam visco-plastic material are used to describe the flow of clay through auger channels and forming organs:

$$\tau = \tau_0 + \mu \cdot \frac{dU}{dy} \quad (1)$$

where τ and τ_0 – effective and maximum stress shear;
μ – material viscosity;
$\frac{dU}{dy} = \gamma$ – velocity gradient.

This model demonstrates a class of materials in which the stress is proportional to the velocity gradient, as in a classical Newtonian fluid, but the flow begins only after the maximum shear stress is reached τ_0. In the clays used to make building ceramics using the plastic molding method, there is a feature known as the viscosity anomaly. Its essence lies in the fact that shear stress, or effective viscosity $\mu_e = f(\gamma)$, decreases significantly as the velocity gradient increases, rather than remaining constant [1]. The rheological curve, which is a mathematical description of dependence, has the form:

$$\mu_e = \mu_0 \cdot (\gamma)^{-\psi} \quad (2)$$

where ψ – the flow index, which depends in logarithmic coordinates on the angle of inclination of the rheological curve to the abscissa axis;

μ_0 – consistency index is an indicator that determines the effective viscosity at a unit velocity gradient, H·s/m^2.

A complex equation that describes the properties of a screw takes into account the leakage of clay through the gaps between the screw and the cylinder jacket and through the turn-to-turn channel:

$$Q_{шн} = Q_{пр} - Q_{зв} - Q_{вит} \quad (3)$$

where $Q_{шн}$ – supercharger performance;
$Q_{пр}$ – direct flow, which occurs due to the pushing ability of the main front surfaces of the screw;
$Q_{зв}$ – the backflow that occurs when the forward flow is restrained;
$Q_{вит}$ – outflow through the gaps.

The characteristics of the forming organs (curve A in Figure 3) are calculated as *q=f(Q)*, moreover, the total pressure q_Σ is equal to the sum of the pressure losses in the press head $q_{гол}$ and mouthpieces $q_{мун}$: $q_\Sigma = q_{гол} + q_{мун}$. Each loss is calculated using the formula:

$$q_{гол}(q_{мун}) = \mu \cdot \frac{Q}{K_г} \quad (4)$$

where $K_г$ – A coefficient that describes the shape of a flow channel and is calculated using formulas for cylindrical, conical, slit, and wedge-shaped channels.

Effective viscosity μ_e for each channel, find by a chart $\mu_e = f(\gamma)$ after calculating the velocity gradient for each channel.

It should be noted that the rheological characteristics of different clays differ significantly from each other. In addition, experiments with the calculation of rheological curves on piston rheometers are quite complex and require special equipment [13]. For this reason, simplified methods for calculating screw presses are used in design practice.

Vacuuming molding is one of the best ways to improve the quality of molded products. As you know, the presence of air in the mass reduces the strength and molding properties of the ceramic mass due to the breaking of bonds between individual grains of clay minerals and water molecules. The presence of air in the ceramic mass also reduces the process of disaggregation of clay particles, reduces the molding ability of the mass, and leads to uneven compaction during molding, which leads to the formation of microcracks in the formed product. Stable vacuum, which depends on uniform press feed, as well as the power and reliability of the vacuum pumps, is important for effective vacuuming.

Unlike ordinary bricks, the characteristics of plastic-brick products differ and have a number of advantages. Plastic-brick products may have altered strength compared to traditional bricks depending on the type of plastic and the ratio of components in the mixture.

Plastic-brick products have better insulation properties, especially if they contain polystyrene foam, which helps to improve the energy efficiency of buildings and reduce heating and air conditioning costs.

Also, plastic-brick products are lighter compared to traditional bricks, which makes it easier to transport and process on the construction site.

The semi-finished product, which is pressed on vacuum presses, is not fully formed and undergoes pressing again on a pre-pressing press to give the semi-finished product the correct shape, as well as the necessary strength. At the same time, there are ancillary costs, which is inappropriate nowadays.

Comparing the technological schemes for the production of bricks by plastic and semi-dry methods of mass preparation, it should be noted that with almost the same indicators of energy consumption, the indicators of metal consumption of semi-dry pressing plants are about three times higher, and the labor intensity of making one thousand bricks is 30% lower compared to the semi-dry method.

Conclusions

The construction industry in Ukraine is adopting innovative technologies such as using recycled plastic to make bricks, tackling plastic waste, and promoting recycling. The production process involves collecting and recycling plastic waste, mixing it with other components, and shaping bricks using methods such as plastic molding and semi-dry pressing. To improve the quality of bricks, various equipment is used, for example, reciprocating and screw presses. The study aims to improve the efficiency and results of thermoplastic casting in the construction industry. In addition, the study highlights the importance of pressure distribution in screw presses to compact clay in the production of building ceramics. Vacuuming of the molding mass is emphasized as crucial for improving the quality of molded products. Plastic brick products have advantages such as altered strength, better insulation properties, and lighter weight. Comparing technological schemes, the semi-dry method of brick production has a higher metal consumption and less labor intensity compared to the plastic one. Overall, the study highlights the potential of recycled plastic bricks in promoting sustainable construction practices and reducing environmental impact.

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