Structural Clay Products: Applications, Production and Benefits

Ms. Anju Mathew
Assistant Professor, Department of Civil Engineering, Presidency University, Bangalore, India,
Email Id-anjumathew@presidencyuniversity.in

ABSTRACT:

Since ancient times, structural clay items including bricks, tiles, and pipes have been extensively employed in building. Ceramic materials designed for use in building construction, such as structural clay products. Building brick, paving brick, terra-cotta face tile, roofing tile, and drainage pipe are examples of structural clay materials. An overview of structural clay products, their production method, characteristics, and uses is given in this chapter. The chapter provides a quick overview of the main ideas covered in the paper as well as an introduction to the subject.

KEYWORDS:

Clay, Clay Classification, Mechanical Properties, Physical Properties, Type.

I. INTRODUCTION

For thousands of years, structural clay products have been an essential component of human civilization. Bricks, tiles, and pipes, among other things, have been essential building materials because they give structures strength, longevity, and aesthetic appeal. Ancient civilizations like Mesopotamia, Egypt, and China used clay as a building material and shaped it into a variety of shapes to create wonders of architecture that are still standing today. Clay must first be extracted and refined, then shaped, dried, and fired in order to produce structural clay products. Clay is a naturally occurring substance made up of tiny particles that are the result of rocks being weathered, and it has certain qualities that make it perfect for building. Clay may be molded into a variety of shapes and sizes when combined with water to create a plastic mass. The clay becomes a strong, resilient substance that can survive varied climatic conditions after drying and burning. One of the most popular structural clay products is brick, which has seen significant use throughout history. They are square clay blocks that have been fired to make them more durable. Bricks are a great choice for building because of their high compressive strength, excellent thermal insulation, and resilience to fire and the elements.

They are often employed in the construction of foundations, walls, and other load-bearing structures. Another important category of structural clay product is tiles. They are often used to cover surfaces like roofs, walls, and floors. They are thin, flat pieces composed of clay or materials derived from clay. The variety of tile shapes, sizes, and colors allows for endless design and aesthetic possibilities. They add to the aesthetic appeal of buildings, offer protection from the elements, and aid in thermal insulation. Essential parts of drainage and sewage systems are pipes constructed of clay or clay-based materials. Due to its longevity, resistance to corrosion, and smooth interior surfaces that promote an efficient flow of liquids, clay pipes have been in use for millennia. These pipes are frequently employed for culverts, sewage lines, and subsurface drainage. There are various steps involved in the production of structural clay products. When clay is first mined from quarries or mines, it is refined to get rid of impurities and increase plasticity. The clay is then combined with water to create a workable mass, which is subsequently molded or extruded into the desired shape. The molded clay items are dried to eliminate extra moisture before being heated up in kilns [1], [2].

The clay is strengthened by firing, which changes both its chemical and physical characteristics. The characteristics of structural clay products help explain why they are so often used in building. Excellent thermal insulation is provided by clay-based materials, which helps control internal temperatures and lowers energy use. They also have a high compressive strength, which enables them to support large loads and endure stresses from the structure. Clay materials are resistant to fire, adding another level of protection to buildings. Additionally, the aesthetic value of their natural color and texture is added to architectural designs. The uses for structural clay materials are numerous and include both domestic and commercial building. Bricks provide structural stability and thermal efficiency when used to build walls, chimneys, and fireplaces. Tiles are used to cover walls, floors, and roofs, boosting the aesthetic appeal of structures. For effective drainage systems to function properly and dispose of wastewater, clay pipes are essential. Despite the development of substitute building materials, structural clay products continue to command a significant share of the market. Ancient constructions that have endured the test of time demonstrate the endurance and resilience of clay-based materials.

Flexibility in design and personalization are made possible by clay's capacity to be molded into a variety of forms and sizes. Additionally, clay is a plentiful and eco-friendly resource, making structural clay products a sustainable option for building. The effectiveness and sustainability of structural clay products have been substantially improved in recent years because to improvements in production processes and the creation of cutting-edge clay-based materials. The effectiveness of the manufacturing process has increased because to new fire technologies including tunnel kilns and sophisticated control systems. Additionally, clay compositions with additions and reinforcements have stronger, more durable, and more resistant to environmental influences. structural clay products have a long history and are now essential to the building sector. Clay-based pipes, tiles, and bricks have several benefits, including strength, sturdiness, thermal insulation, and aesthetic appeal. Clay is extracted, refined, shaped, dried, and fired throughout the manufacturing process to create durable products. These items are used in a variety of construction projects, from the development of infrastructure to residential constructions. Structural clay products have a long shelf life, and continual improvements in production processes and materials guarantee their sustained relevance and bright future in the building sector [3], [4].

Clay: Due to its special qualities and extensive variety of uses, clay is a versatile natural substance that has been utilized by humans for thousands of years. It is a fine-grained soil or silt made up of microscopic fragments that are the result of rock weathering. Minerals including kaolinite, montmorillonite, and illite make up the majority of clay, giving it its particular flexibility and cohesiveness when combined with water. Clay has been used for many different things since the dawn of human civilization, including making pottery, building structures, and creating artwork. Because of its fluidity, which enables it to be molded into many shapes and forms, clay is a perfect medium for constructing sculptures, ceramic containers, and other creative things. Clay may be made into a tough, long-lasting material by being fired at high temperatures, making it ideal for permanent buildings and useful objects.

Pottery is one of the most well-known applications for clay. Clay has traditionally been the principal material used by potters to make ceramic vessels. Because clay is malleable, potters may mould it by hand or on a potter's wheel to realize their creative ideals. After the clay object has taken on the appropriate form, it is often dried and fired in a kiln to create a ceramic product with improved strength and durability. Throughout history, clay pottery has been used for both practical and ornamental reasons, and diverse styles and techniques have been produced by many civilizations. Clay has been extensively used in building in addition to pottery. Buildings of diverse shapes and sizes have been constructed for ages using clay-based materials like bricks and tiles. Bricks, which are created by molding clay into rectangular blocks and then burning them, give walls and other load-bearing components in structures strength and stability.

They have great thermal insulation capabilities, exceptional compressive strength, and fire and weather resistance. On the other hand, clay tiles are flat, thin pieces that are used to cover floors, walls, and roofs. They defend against the weather while enhancing the beauty of structures. Even now, clay-based materials are still used in building, and contemporary methods and tools have further improved their efficiency and sustainability [5], [6]. There are several more uses for clay in numerous sectors outside pottery and building. Clay soils are prized in agriculture because they can hold onto moisture and minerals, making them appropriate for producing crops. Clay soil has finer particles that store water more efficiently than other types of soil, allowing plants to obtain rainwater even in dry areas. Clay soils also give plants a solid base, limiting erosion and encouraging the growth of strong roots. In the area of geotechnical engineering, clay is used extensively. Clay is a cohesive and impermeable material that may be used to build barriers like landfill liners, dams, and ponds. Clay has a low permeability, which stops water, dangerous chemicals, or toxins from seeping out and harming the environment or people.

In drilling operations, clay is also used to stabilize boreholes and stop them from collapsing. Beyond its original usage, clay has made its way into many different sectors. Due to its absorbent and purifying qualities, clay is used in the cosmetics industry to make face masks, cleansers, and exfoliants. It is renowned for its calming and rejuvenating properties and assists in cleaning impurities from the skin. Additionally, clay is used in the creation of ceramics, refractories, catalysts, and even as an addition in the manufacture of cement. Clay continues to be an important material with a variety of applications, from ancient pottery to contemporary purposes. It is an essential resource for the pottery, building, agriculture, geotechnical engineering, cosmetics, and many other sectors because of its flexibility, strength, durability, and thermal qualities. New uses and innovations are expected to appear as technology develops and as our knowledge of clay grows, further maximizing the potential of this extraordinary natural material.

II. DISCUSSION

Clay Classification: The most crucial raw element utilized to make bricks is clay. It is an earthy mineral mass or shard of rock that can combine with water to produce a plastic viscous mass that can be molded and dried while maintaining its shape. Such masses develop hardness and strength when heated to a reddish color. This is a chemical characteristic that results from microstructural modifications in clay. The purest clays are mostly made of kaolinite ($2SiO_2.Al_2O_3.2H_2O$), with trace amounts of other minerals such mica, calcite, quartz, felspar, and magnesite. Clays are separated into residual and transported clays based on where they come from. Clays that are left over after the underlying rocks have decomposed are used to make pottery and are referred to as Kaolin or China clay. Weathering agencies' actions lead to the transported or sedimentary clays. These are more dispersed, include contaminants, and are devoid of significant mother rock particle sizes [7], [8].

Clays are divided into three categories: refractory, high melting, and low melting clays based on their resistance to high temperatures (greater than 1580°C). The refractory clays are extraordinarily flexible and widely dispersed. These contain a high alumina concentration and a low impurity content, such Fe_2O_3, which tends to reduce the refractoriness. High melting clays have high refractoriness (1350–1580°C) and few to no impurities like calcium carbonate, magnesium carbonate, mica, quartz, or felspar. These are employed in the production of floor tiles, sewage pipes, and facing bricks. Low-melting clays range in composition and have refractoriness temperatures below 1350°C. They are employed in the production of bricks, blocks, tiles, etc.

If desired, clay can have additives added to it to enhance certain characteristics. For the addition of lean admixtures or non-plastic materials like quartz sand, chamottee, ash, etc., highly plastic clays that demand mixing water up to 28%, offer high drying and burning shrinkage, are used. By adding an admixture that burns off, items with decreased bulk density and high porosity are produced. Sawdust, coal fines, pulverized coal, and other materials are examples of burning out admixtures. Clay is made into acid-resistant products and facing tiles by adding waterglass or alkalis. By combining clay with fluxes like felspar, iron-bearing ores, etc., the burning temperature of clay products can be lowered. By adding surfactants like sulphite-sodium vinasse (0.1-0.3%), the plasticity of the molding mass can be enhanced [9], [10].

Physical Properties of Clay: Physical characteristics like as plasticity, tensile strength, texture, shrinkage, porosity, fusibility, and color after burning are crucial in assessing the value of clay. A chemical analysis is less helpful in determining the quality of the raw material than knowledge of these features. The ability of moist clay to be permanently distorted without cracking is referred to as plasticity. Between 15% and 35% of water is needed by various clays to provide the most plastic state. Although clay's plasticity is its most significant physical characteristic, there are no completely accurate ways to measure it. Feeling the damp clay with the fingertips is the quickest and most common test available. Naturally, a significant portion of this assessment is based on personal equation. A high tensile strength is preferred because clay pottery is put under a lot of strain throughout the molding, handling, and drying processes. The test is performed by measuring the strength of specimens that have been meticulously dried and molded into briquette shape.

The degree of grain fineness in clay serves as a gauge for its texture. The percentage of a No. 100 sieve that passes is calculated in rough work. There is no specified numerical limit for the grain size or desirable relationship between sizes. Extremely fine-grained clays devoid of sand are more flexible and experience more shrinkage than clays that contain coarser particles. To generate a product of the specified size, knowledge of shrinkage during drying and burning is necessary. Additionally, the degree of burning may be determined by the quantity of shrinkage. The amount of mixing water and the pore space in the clay both affect how much the clay will shrink after drying. Sand or crushed burned clay can be used to reduce shrinkage, enhance porosity, and speed drying. Fire shrinkage is influenced by the ratio of volatile components, texture, and clay's ability to burn.

The percentage of pore space to dry volume is referred to as the porosity of clay. Porosity will indirectly affect air shrinkage because it influences the amount of water needed to make clay plastic. Larger holes than small pores enable the water to evaporate more readily and, as a result, permit a greater rate of drying. The pace at which clay may be properly dried is crucial for creating clay goods, hence the impact of porosity on drying time should be taken into account. The ratio of fluxes, texture, homogeneity of the material, flame characteristics, and mineral composition all affect the temperature at which clay fuses. Because the composition of the clay body is not uniform, various portions melt at varying rates, causing the softening period to span a wide range of time and temperature. There are two stages of vitrification during this time: incipient and viscous.

Experiments generally show that the melting point decreases with increasing flow percentage. Clays with finer grain sizes and the same material content fuse more readily than clays with coarser grain sizes. The impact of various ingredients is greatly influenced by the homogeneity of the clay mass; for example, whereas tiny amounts of carbonate of lime in huge lumps might cause popping, 15% of it can be used to make brick or tile when it is finely ground. A useful flux is created when lime and feldspar are mixed. Iron that is present as ferrous iron, which is found in carbonates and magnetite, fuses more readily than ferric iron. The removal of carbon and sulfur will be delayed until the mass has decreased to a point where it can be stopped from doing so and the oxidation of iron if the kiln environment is not sufficiently oxidizing in nature in the early stages of burning. A product with a discolored core or bloated body is likely to be the result when this occurs. A clay's fusibility must be determined in order to gauge its refractoriness and determine how expensive it will be to burn.

Mechanical Properties of Clay: Different mechanical characteristics that clay possesses affect its behavior and applicability for diverse purposes. Factors including mineral composition, particle size, moisture content, compaction, and structural organization have an impact on the mechanical characteristics of clay. Here are some of clay's main mechanical characteristics:

a**. Plasticity:** High plasticity refers to clay's capacity to withstand deformation and molding without cracking. Due to the water concentration and existence of tiny particles in the clay matrix, this feature exists. For procedures like clay modeling and pottery shaping, plasticity is necessary.

b. **Cohesion:** The cohesive forces that hold clay particles together are quite strong. Due to this characteristic, clay is able to hold its form and resist collapsing or disintegrating under pressure.

c. **Compressibility:** Clay has a high compressibility, making it simple to compress it when a load is applied. This characteristic is a result of how clay particles are arranged and the presence of water in the pore spaces. Geotechnical engineering places a premium on compressibility since clay's behavior under stress affects settlement and foundation construction.

d. **Shear Strength:** The ability of clay to withstand deformation when subjected to shear stress is referred to as shear strength. Factors including moisture content, mineralogy, particle size, and compaction can affect the shear strength of clay. In slope stability analysis, retaining wall design, and other geotechnical applications, shear strength is an essential feature.

e. **Swelling and Shrinking:** Clay has volumetric changes in response to variations in moisture content. Clay expands as a result of water absorption, increasing volume. On the other hand, it shrinks and loses volume as it loses water. These swelling and contracting properties may have important construction-related ramifications since they may result in ground movements and possible structural damage.

f. **Permeability:** Clay has a poor permeability, which limits its capacity to let the flow of water. Clay has limited pore spaces due to its cohesiveness and fine particle size, which limits water movement. Clay is helpful for applications like landfill liners, retaining walls, and cut-off barriers to limit water seepage because of its low permeability.

g. **Elasticity:** Clay may distort when under tension but will revert to its original shape after the stress has been removed. However, compared to other materials, clay has very poor elastic behavior. The stability of slopes and the settling of clay soils under load are both impacted by this characteristic.

h. **Creep:** The slow deformation that takes place over time under a continuous strain is referred to as creep in reference to clay. The progressive deformation of clay can result in settlement and structural deformations, hence this trait may be important in long-term geotechnical engineering applications.

These mechanical qualities of clay are extremely important in many industries, such as geotechnical engineering, ceramics, building, and pottery. Engineers, potters, and designers may choose and work with clay more effectively for their unique applications by being aware of these qualities, assuring stability, durability, and the needed performance.

Type of Clay: There are several kinds of clay, and each has special qualities and attributes of its own. Based on elements including mineral content, particle size, and plasticity, clay kinds are categorized. Here are a few of the most typical kinds of clay:

1. **Kaolin Clay:** Kaolin is a white or almost white clay that is rich in the mineral kaolinite. It is often referred to as china clay. It is ideal for pottery and ceramics because of its great flexibility when wet and tiny particle size.

Due to its supple texture and capacity to increase opacity, kaolin clay is frequently used in the manufacture of porcelain, paper, paints, and cosmetics.

2. **Bentonite Clay:** A kind of clay called bentonite is produced when volcanic ash is altered. Montmorillonite, a mineral found in expanding clay, makes up a large portion of it. Bentonite clay has outstanding thixotropic behavior (becoming more fluid when stirred), which results from its exceptional water absorption and expansion characteristics. It frequently appears in drilling fluids, foundry molds, cat litter, and natural treatments for a range of skin issues.

3. **Illite Clay:** Muscovite, montmorillonite, and biotite are among the minerals that make up the illite clay mineral group. Illite clay, which is frequently found in sedimentary rocks, ranges in color from yellowish-green to brown. It has high flexibility and is frequently utilized in cosmetics, soil amendments to increase fertility and drainage, and ceramics.

4. **Montmorillonite Clay:** Clay having a layered structure known as montmorillonite is a form of swelling clay. It may take in a lot of water, which causes expansion and more plasticity. Due to its superior adsorption and ion exchange capabilities, montmorillonite clay is used in foundry molds, drilling fluids, wastewater treatment, and other applications.

5. **Ball Clay:** Ball clay is a fine-particle clay with a high degree of fluidity. It is frequently utilized in ceramics, especially for making porcelain and sanitaryware. Ball clay makes clay formulas more workable and flexible, facilitating simpler shape and molding.

6. **Fire Clay:** Fire clay is a type of clay that can sustain high temperatures without melting or deforming and has a high heat resistance. It is frequently used to make refractories, which are substances made to endure intense heat and are used as linings in furnaces, kilns, and industrial machinery.

7. **Stoneware Clay:** The temperature at which stoneware clay matures is higher than that of earthenware clay but lower than that of porcelain clay. It is frequently employed in the manufacture of tiles, tableware, and stoneware ceramics. The qualities of stoneware clay include sturdiness, strength, and heat retention.

These are just a handful of the numerous varieties of clay that may be found all over the world. The geographical and geological circumstances where clay is obtained might affect its individual characteristics and usage. The intended use, required properties, and processing needs all influence the choice of clay type.

Types of Clay Products: Clay, a resourceful and adaptable natural material, has been utilized historically to make a broad variety of goods for different uses. Products made of clay fill a wide range of demands in sectors including building, pottery, ceramics, and art, from practical things to creative masterpieces. Here, we look at some of the most popular clay product varieties and their uses.

1. **Bricks:** One of the oldest and most popular clay products is the brick. Clay is shaped into these rectangular blocks, which are then fired to increase their strength and longevity. Bricks are widely used in construction to make chimneys, fireplaces, walls, and foundations. They have great thermal insulation capabilities, exceptional compressive strength, and fire and weather resistance. Bricks' many sizes, hues, and textures enable a wide range of architectural styles.

2. **Roofing Tiles:** Clay roofing tiles are well-liked for its sturdiness, beauty, and capacity to survive severe weather. Clay is used to form these tiles, which are then burned to the necessary strength. Clay roofing tiles shield a roof from rain, wind, and sunshine, creating a durable and attractive roof. They give design freedom and attractive architecture because of their many profiles, which include flat, curved, and interlocking.

3. **Floor Tiles:** Clay floor tiles are used often because of its sturdiness, maintenance-free nature, and aesthetic appeal. To accommodate differing design tastes, these tiles come in a variety of sizes, shapes, and finishes. Clay floor tiles are excellent for both indoor and outdoor applications because of its remarkable resistance to abrasion, stains, and moisture. They give rooms a warm, cozy vibe that improves the atmosphere in general.

4. **Sanitaryware:** Items like toilets, washbasins, and bidets are examples of sanitaryware made of clay. In order to obtain the necessary strength and impermeability, these goods are manufactured from a mixture of clay and other additives, which are moulded and burned at high temperatures. Clay sanitaryware is a common option in both residential and commercial structures because of its ease of upkeep, cleanliness, and durability.

5. **Pipes and Drainage Systems:** Clay pipes have been utilized in sewage and drainage systems for a very long time. They are created by shaping and firing clay or clay-based materials into hollow pipes with smooth inside

surfaces. Clay pipes are strong and long-lasting because of their exceptional resistance to corrosion, abrasion, and chemical assault. They are frequently used for culverts, stormwater management systems, sewage lines, and subsurface drainage.

6. **Pottery and Ceramics:** Pottery refers to a variety of clay goods that are shaped, dried, and fired. Items like bowls, plates, vases, cups, and ornamental accents fall under this category. Different clay varieties may be used to create pottery, and each one has unique properties and finishes. Pottery is very adaptable because to its aesthetic and practical qualities, having uses in everyday life, home design, and art exhibits.

7. **Sculptures and Artistic Creations:** Clay is a great medium for sculpting and producing creative works because of its flexibility and capacity to hold its shape. Different kinds of clay, including modeling clay or stoneware clay, are used by artists to mold and form sculptures, figurines, and other works of art. The clay piece is normally dried after achieving the required shape, and then fired to acquire the necessary hardness. Since ancient times, clay sculptures and works of art have played a crucial role in human aesthetic expression.

8. **Refractories:** Refractories are materials that can withstand high temperatures and are employed in industrial settings that need intense heat, such as furnaces, kilns, and reactors. Fire bricks, sometimes referred to as clay-based refractories, are made from unique kinds of clay that can resist high temperatures without melting or deforming. These refractory bricks offer insulation and safety in high-temperature settings, ensuring that industrial operations run smoothly.

9. **Clay-Based Additives and Fillers:** Clay-based additives and fillers are used in a variety of sectors to improve the characteristics of diverse materials. In paints, coatings, and plastics, for instance, kaolin clay is frequently employed as a filler to enhance the rheology, opacity, and mechanical qualities of these materials. Drilling fluids use bentonite clay, which has stabilizing and lubricating qualities. A wide variety of goods across sectors benefit from the performance and functionality of clay-based additives and fillers.

10. **Products for Cosmetics and Personal Care:** Clay is used in these industries because of its purifying and absorbent qualities. Face masks, cleansers, scrubs, and other skincare products are made from a variety of clays, including kaolin clay, bentonite clay, and French green clay. A clean and rejuvenated appearance is encouraged by the ability of clay to absorb extra oil, grime, and pollutants from the skin.

11. **Clay-Based Adhesives and Sealants:** Clay is used as a primary component in the formulation of clay-based adhesives and sealants. In order to improve performance, fillers and additives are frequently added to these materials, which have bonding and sealing capabilities. Clay-based adhesives are used to attach materials including ceramics, bricks, tiles, and stones in building, carpentry, and crafts. Clay-based sealants are used in a variety of applications, such as plumbing, building joints, and automobile parts, to form water- and airtight seals.

12. **Green building materials:** There has been an increase in interest in environmentally friendly and long-lasting building materials in recent years. Clay-based construction materials including compressed earth blocks, adobe bricks, and rammed earth have grown in prominence as green building substitutes. These materials are made from clay and other organic components, and their creation uses less energy. Green construction materials made of clay include benefits including durability, low environmental impact, and thermal insulation.

These are but a few examples of the numerous clay products that are offered in a variety of sectors. Because of its adaptability, quantity, and special qualities, clay is a wonderful material for producing objects that are useful, aesthetically pleasing, and sustainable. Clay is still a vital material that meets a variety of demands, whether it is in building, pottery, ceramics, art, or other uses.

III. CONCLUSION

In conclusion, structural clay products are essential to the building sector because they provide strength, adaptability, and aesthetic appeal. Clay-based materials are used to create bricks, tiles, and pipes, which go through a number of processes including shaping, drying, and fire. These materials are suited for a variety of applications, including flooring, drainage systems, building facades, and more because of their outstanding thermal insulation, fire resistance, and load-bearing qualities. The vast historical usage of structural clay materials and the fact that they are still relevant in contemporary building speak to their enduring importance. The development of novel clay-based materials and continuous improvements in production processes bode well for the future of structural clay products, which will likely provide even better performance and sustainability.

REFERENCES

[1] H. Nasri, A. Azdimousa, K. El Hammouti, A. El Haddar, and M. El Ouahabi, Characterization of Neogene marls from the Kert Basin (northeast Morocco): suitability for the ceramics industry, Clay Miner., 2019, doi: 10.1180/clm.2019.50.

[2] M. P. Moreno Quintero, Y. A. Pabón Acevedo, L. Cely Illera, and J. Cely Niño, Influence of wet milling on the structural and mechanical behavior of ceramic products formed by extruding clay at Zulia (North de Santander, Colombia), Bol. la Soc. Esp. Ceram. y Vidr., 2019, doi: 10.1016/j.bsecv.2019.01.001.

[3] J. Entwistle, D. E. Latta, M. M. Scherer, and A. Neumann, Abiotic Degradation of Chlorinated Solvents by Clay Minerals and Fe(II): Evidence for Reactive Mineral Intermediates, Environ. Sci. Technol., 2019, doi: 10.1021/acs.est.9b04665.

[4] J. D. Wicochea-Rodríguez, P. Chalier, T. Ruiz, and E. Gastaldi, Active food packaging based on biopolymers and aroma compounds: How to design and control the release, Front. Chem., 2019, doi: 10.3389/fchem.2019.00398.

[5] L. F. de Castro, V. S. Brandão, L. C. Bertolino, W. F. L. De Souza, and V. G. Teixeira, Phosphate adsorption by montmorillonites modified with lanthanum/iron and a laboratory test using water from the jacarepaguá lagoon (RJ, Brazil), J. Braz. Chem. Soc., 2019, doi: 10.21577/0103-5053.20180236.

[6] H. Bu et al., Formation of macromolecules with peptide bonds via the thermal evolution of amino acids in the presence of montmorillonite: Insight into prebiotic geochemistry on the early Earth, Chem. Geol., 2019, doi: 10.1016/j.chemgeo.2019.02.023.

[7] J. Hadi, P. Wersin, V. Serneels, and J. M. Greneche, Eighteen years of steel–bentonite interaction in the FEBEX in situ test at the Grimsel Test Site in Switzerland, Clays Clay Miner., 2019, doi: 10.1007/s42860-019-00012-5.

[8] Y. Shi, X. Chen, J. Li, X. Li, and Z. Peng, Micro–macro properties of plastic concrete anti-seepage wall materials mixed with low-liquid limit clay, Adv. Mech. Eng., 2019, doi: 10.1177/1687814019849736.

[9] G. Yakovlev et al., Structural ceramics modified with technogenic isostatic nanographite, in IOP Conference Series: Materials Science and Engineering, 2019. doi: 10.1088/1757-899X/603/3/032070.

[10] Sariadi, Harunsyah, and Raudah, Effect of ZnO / Clay Nanoparticles Concentration Ratios to Improve the Mechanical Properties of Cassava Starch Bioplastics Film for Food Packaging Applications, in IOP Conference Series: Materials Science and Engineering, 2019. doi: 10.1088/1757-899X/536/1/012039.