

# **System and Process for Producing Construction Materials Using Contaminated Soft Clay and Clay-like Wastes through Geopolymerization**

## **TECHNICAL FIELD**

The present invention pertains to a robust system and a highly efficient process designed to effectively encapsulate pollutants and convert contaminated soft clay into superior-quality building materials by employing geopolymerization techniques. Specifically, the method and process disclosed herein significantly lowers the leachable fraction of soluble salts and effectively encapsulates heavy metals in the solid waste. This innovative approach results in the conversion of the treated solid waste into environmentally safe building materials, such as lightweight geopolymer slabs and geopolymer bricks, through the geopolymerization process.

## **BACKGROUND OF THE INVENTION**

Every day, 10,000 to 20,000 tons of soft clay is excavated in construction sites as part of development projects in Singapore. In some countries, this dredged soft clay is disposed of in open dumping. While some countries have abundant land, the open dumping of dredged soft clay occupies enormous precious space in land-scarce countries. According to data from the World Bank, at 7,919 people/km<sup>2</sup>, Singapore is among the world's most densely populated countries. For comparison, from the same source, the population density in Japan and the US is 346 people/km<sup>2</sup> and 36 people/km<sup>2</sup>, respectively. Therefore, generation of waste exerts enormous pressure on habitable land space-constrained countries. Countries may alleviate some of this pressure by reclaiming the ocean for more land space, however this practice may be disruptive to the ecosystem surrounding the reclamation site. Additionally, in some cases the dredged soft clay is contaminated with heavy metals as a result of the presence of the shipbuilding industry, potentially creating environmental pollution concerns.

Meanwhile, the cost of construction material is rising rapidly. It would be beneficial if the construction waste could be recycled back to the industry to help alleviate construction material cost pressures, thereby helping close the material loop. The construction industry faces a persistent challenge in dealing with a substantial volume of materials that are unsuitable for direct use in construction activities, including contaminated soil, soft clay, and sludge. Improper management and disposal of these materials not only occupy significant space but also pose severe environmental risks.

Various soft clay or clay-like materials, including contaminated soft clay, freshwater sludge, and wet incineration fly ash (IFA), possess distinct characteristics, such as high moisture content and high plasticity, which hinder the materials' dispersion and fragmentation. These materials exhibit a notable abundance of silica and/or alumina, making them particularly suitable for geopolymerization, which is a promising technique in sustainable material development. Geopolymerization offers a viable solution to transform such problematic materials into environmentally safe building materials, thereby mitigating the adverse impacts associated with their disposal.

Recognizing the urgent need for an efficient and eco-friendly process, the present invention introduces a novel method for treating contaminated soft clay and related materials, leading to their transformation into high-quality building materials. By leveraging the geopolymerization process, the invented technique ensures the conversion of contaminated soft clay and clay-like waste into environmentally safe construction materials, addressing the aforementioned challenges in the construction industry.

### Difficulty of Processing and Handling Soft Clay and Clay-like Waste

In the treatment of solid waste, especially one that is hazardous in nature, a mixing step is often involved. This is because some chemical agents, such as heavy metal immobilizers, are typically needed to be mixed in with the waste for the treatment effect to be realized. With soft clay and clay-like wastes, however, this mixing is difficult because of its high-viscosity nature. Furthermore, this problem is further complicated by the presence of stones, which usually are sieved out in non-clay waste and can jam other processing equipment if not removed.

### Waste Types

Soft clay and some clay-like wastes share some basic physical characteristics. They all present some difficulty in handling.

Contaminated Soft Clay: Soft clay refers to soil with large fractions of fine particles such as silty and clayey soils. Contaminated soft clay contains pollutants that exceed natural levels, posing risks to human health and the environment. Typically resulting from industrial, agricultural, or waste disposal activities, contaminated soft clay commonly contains heavy metals from industries and organic pollutants from fertilizer residues. Addressing the need for sustainable land management and environmental preservation, this invention focuses on transforming contaminated soft clay into environmentally safe building materials. By repurposing and utilizing this resource effectively, it mitigates the risks associated with improper disposal while providing a valuable solution for the construction industry.

Freshwater Sludge: Freshwater sludge, in the context of this invention, refers to the residual byproduct resulting from the water treatment process at water treatment plants, where raw water is treated to produce potable water. This sludge is characterized by its elevated alumina content, primarily derived from the use of aluminum-based coagulants during the primary sedimentation stage to remove suspended solids. While freshwater sludge is currently being landfilled, it presents an opportunity for effective management and repurposing. By developing innovative solutions to transform freshwater sludge into environmentally safe building materials, this invention aims to alleviate the environmental burden associated with its disposal and provide a sustainable alternative for its utilization.

Wet incineration Fly Ash: Incineration fly ash, specifically municipal solid waste incineration fly ash (IFA), refers to the ash residue obtained from the incineration of municipal solid waste. It is typically separated from exhaust flue gas. Unlike incineration

bottom ash (IBA), IFA is more hazardous, raising concerns about environmental contamination if directly landfilled. Many countries dilute IFA with less toxic IBA for disposal, but this approach becomes less feasible as IBA can be fully utilized as construction material. IFA is dry when it is produced in the incineration of municipal solid waste, but it is often sprayed with water in a quenching step, producing a wet IFA pile which exhibits qualities similar to soft clay and making wet IFA difficult to process for treatment. To overcome these challenges of handling and treating wet IFA, this invention proposes transforming wet IFA into environmentally safe building materials through the geopolymerization process, offering a sustainable solution that mitigates environmental risks associated with landfilling while enabling wet IFA's utilization in the construction industry.

### Geopolymerization

Geopolymerization is a chemical process employed in this invention that aims to convert contaminated soft clay or clay-like waste that contains pollutants exceeding natural levels and poses risks to human health and the environment into environmentally safe building materials. By activating soft clay and clay-like waste with alkaline solutions, geopolymerization forms a solid binder known as geopolymer. Using waste that has geopolymerization properties, this sustainable alternative to traditional cement-based binders addresses the need for sustainable land management and environmental preservation by repurposing contaminated soft clay effectively and mitigating the risks associated with improper disposal.

### Waste Powders

Waste powders in the present invention refer to fine powdery waste materials obtained as byproducts of various industrial processes. Waste powder can be used as a moisture absorbent. Examples of effectively used waste powders include coal fly ash, coal bottom ash, and dried concrete sludge. By incorporating these waste powders into the geopolymerization process, the mixing process of clay-like waste becomes more efficient. This inventive approach increases the resourcefulness of waste powders, resulting in the formation of environmentally safe building materials. By repurposing waste powders and reducing the environmental burden associated with waste disposal, this invention contributes to sustainable waste management practices and the preservation of our environment. However, the pollutive potential of waste powders must be controlled so as to not cause excessive leaching of pollutants to fail environmental standards.

### Microwave Curing

Microwave curing, a curing technique employed in this invention, harnesses electromagnetic waves in the microwave frequency range to generate heat within materials. By employing microwave curing, rapid and uniform curing can be achieved, benefiting various processes such as curing and drying. This technology greatly accelerates the curing process in solid materials and enables efficient and effective treatment of waste powders derived from waste streams, contributing to the transformation of waste into valuable building materials.

### Lightweight Geopolymer Slab

Lightweight geopolymer slab, an important industrial product produced by the present invention, offers significant advantages in the construction industry. Lightweight geopolymer slabs may incorporate commercial lightweight aggregates (LWA), such as expanded clay, shale, or slag, to reduce the weight of the concrete mixture. This reduction in weight not only enhances the cost-efficiency of transportation and construction but also improves thermal insulation, reduces deadload on structures, and enhances fire resistance. By utilizing lightweight concrete, this invention provides a valuable solution for sustainable and high-performance construction practices.

### Environmental Standards

Waste and wastewater disposal and reuse standards protect the environment and human populations against exposure to heavy metals and other pollutants. In biological systems, heavy metals have been reported to be associated with adverse effects in cellular organelles, cell membranes, mitochondria, lysosomes, endoplasmic reticulum, nuclei, and important enzymes. Heavy metal ions can interact with cell components, such as DNA and nuclear proteins, causing damage and structural changes that lead to carcinogenesis or apoptosis. According to the U.S. Environmental Protection Agency, some heavy metals are classified as either “known” or “probable” human carcinogens based on current epidemiological and experimental studies. In establishing disposal and reuse standards for wastes, risk assessment is conducted by regulatory bodies to promulgate rules to protect the environment and human health. Therefore, solid waste treatment outcomes are often compared to the criteria values in the applicable standard to determine compliance with disposal or reuse regulations. Examples of applicable standards that are cited are China’s type I common industrial solid waste standard, Singapore’s acceptance criteria for landfill disposal, and the Danish waste-to-resource standard from Statutory Order No. 1662 of 2010. Depending on the particular environmental standard that is set by a local authority, the criteria could be very stringent and meeting such criteria for solid waste disposal or reuse remains a challenge.

### Engineering Performance Standards

Similar to environmental standards, engineering performance standards must also be satisfied for waste material to be used in construction. Environmental standards are usually promulgated by a governmental authority specialized in the environment, engineering performance standards may be stipulated by government or industry. Usually engineering performance standards are satisfied to ensure safety of those near where the waste material is to be used.

### Artificial Intelligence

Artificial intelligence, in the context of this invention, refers to the utilization of advanced computer systems and programs that emulate human capabilities, including problem-solving, learning, perception, understanding, reasoning, and environmental awareness. In recent years, this technology has been demonstrated to work well in natural language processing. Other fields that can potentially exploit this innovative technology include weather forecasting, air pollution prediction, water contamination monitoring, waste sorting, and optimization of waste collection truck routes. In the present invention, artificial intelligence algorithm is trained to take soft clay

and clay-like waste characterization data to determine treatment method parameters. The customized algorithm also stores every treatment outcome, such as pollutant levels and physical characteristics of resulting slabs and bricks and performs statistical analysis to correlate initial soft clay and clay-like characteristics, treatment method parameters, and final outcomes to make decisions about future treatment methods.

### Solid Materials Reuse

Solid materials reuse, within the context of this invention, focuses on the imperative of maximizing the utilization of major solid waste streams. The generation of vast amounts of solid waste not only occupies precious land resources but also poses significant risks of soil, water, and air pollution. To address this challenge, promoting the reuse of solid materials has emerged as a paramount priority. Current approaches include the use of waste material in the production of construction materials, utilization in roadbed construction, and backfilling of mined-out areas. By embracing the principle of solid materials reuse, this invention strives to minimize waste and environmental impact by transforming various waste streams into valuable resources. By repurposing and reintegrating solid materials, cities can promote resource efficiency, reduce the demand for virgin materials, and foster sustainable practices in the construction industry.

## **PATENT LITERATURE**

US Patents 2,758,010 and 3,439,802 describe chemical methods in which soft clay is treated to increase brightness.

US Patent 8,225,935 B2 describes a non-chemical method in which contaminated soft clay is suspended with water to remove suspension of soft clay and residue of low-clay content.

In all cases above, the patents referenced do not address the issue of reuse of processed or treated soft clay and clay-like waste in construction. In addition, the patents referenced do not describe in detail how stones are removed from soft clay or clay-like waste or how heavy metals are immobilized.

## **SUMMARY OF THE INVENTION**

### Summary of Invention

Throughout this specification and beyond, unless the context requires otherwise, “comprise,” or variations such as “comprises” or “comprising,” shall be understood to imply the inclusion of a stated component or components or integrated components but not the exclusion of any other components. In addition, as they appear in the specification and claims, the singular forms “a,” “an,” and “the” include the plural referents unless otherwise stated.

The present invention has been accomplished under a context described in previous sections. It is, therefore, the main objective of the present invention to provide a system and method for transforming contaminated soft clay, freshwater sludge, and wet IFA, or similar wastes into

building materials using geopolymerization. To achieve these and similar objectives of the present invention, the system comprises:

- a) A unit that performs mixing and slurry making of soft clay and clay-like waste;
- b) A unit that performs particle size sieving function;
- c) A unit that performs stone and sand size reduction through crushing and ball milling;
- d) A unit that performs intense washing using ultrasound energy and solid-liquid separation through centrifugation;
- e) A washing water treatment system;
- f) A unit that performs mixing of washed contaminated soft clay or clay-like waste, waste powders, filter cake, and alkaline activators in vacuum setting; and
- g) A microwave tunnel curing unit that cures slabs and/or bricks.

#### Problems solved by the invention

The global construction industry generates an overwhelming volume of waste, posing a pressing environmental challenge. The conventional waste management practice around the world is predominantly landfilling, which is unsustainable due to the escalating demand for habitable space. Furthermore, the construction industry is a major source of consumption of natural materials, such as sand and stone, exacerbating concerns regarding resource depletion. However, by treating and repurposing some construction waste, a circular economy can be achieved, improving the efficient utilization of resources for future generations.

Existing solid waste treatment technologies, such as simple washing, thermal treatment, and chemical methods, have been explored to address the issue of waste-to-resource. However, these approaches have largely overlooked the specific treatment requirements of contaminated soft clay and clay-like waste. The unique challenge presented by contaminated soft clay and clay-like waste lies in its high viscosity, low permeability, and difficulty of being mixed and dispersed in achieving thorough mixing and dispersion using conventional equipment. Conventional methods often involve mixing soft clay with dry powdery materials to facilitate dispersion, but this approach has limitations in terms of efficiency and homogeneity. Existing machines designed for de-airing soft clays used in high-value ceramic production are not suitable for large-scale treatment of soft clays encountered during the piling process, as they have limited capacity and are unable to handle foreign objects, such as hard stones.

Recognizing the need for a comprehensive solution, the present invention pioneers the utilization of geopolymerization as an efficient and sustainable method to address the issue of clay-like waste materials in the construction industry and clay-like waste materials. By employing this novel approach, the invention enables the conversion of such waste into high-quality building materials, thereby mitigating environmental impact, minimizing resource consumption, and fostering circular economy.

## Means for Solving the Problems

The present invention provides a robust and highly efficient system for converting soft clay and clay-like waste materials, such as contaminated soil, sludge, freshwater sludge, and wet IFA, into superior-quality building materials using geopolymerization techniques.

Before the soft clay or clay-like waste enters the treatment system, its moisture content, leaching potential, and alumina:silica ratio are measured. All this characterization information is used by a processor of the treatment system to help inform itself to determine treatment method parameters, such as how much water to add to the system, how much sodium dimethyldithiocarbamate (SDMC) to use, and how much waste powder should be added. The main process encompasses several essential components for effective waste treatment. A washing system is utilized to pre-mix the waste with water, followed by wet size sieving using a vibrating sieve to separate out stones and sand. An intensive washing process is utilized to enhance mixing and to dissolve soluble salts. The washing process also uses SDMC to chemically immobilize heavy metals and prevent pollutant leaching. The resulting slurry undergoes solid-liquid separation through a centrifuge, enabling the separation of soft clay or clay-like waste and liquid.

Concurrently, the stones and sand segregated by the vibrating sieve undergo size reduction. These materials are subjected to size reduction to below 500  $\mu\text{m}$  through a jaw crusher and ball mill, resulting in waste powders.

To address wastewater management, a dedicated washing water treatment system of coagulation, flocculation, and sedimentation is integrated into the overall process, treating the washing water, and enabling its recycling. The system also includes a mechanical vapor recompression unit to remove soluble salts. The wastewater treatment system generates filter cake as a byproduct.

The dosage of alkaline activators, such as  $\text{NaOH}$ ,  $\text{Na}_2\text{SiO}_3$ , and  $\text{Ca}(\text{OH})_2$ , is determined by the processor. Together the solid waste material and alkaline activators are mixed in a vacuum mixer until a homogeneous mixture is achieved. The resulting mixture is then poured into slab molds and brick molds. Subsequently, the molds undergo microwave curing at 100-200°C, facilitating the conversion of the materials into lightweight geopolymer slabs and geopolymer bricks.

The operational parameters, such as the use and dosage of SDMC, the dosage of alkaline activators, and the curing temperature, are essential specifications of the invention, ensuring the effective conversion of contaminated clay and clay-like waste into environmentally safe building materials.

## Advantages of the Invention

The invention offers significant advantages in addressing the environmental and resource challenges posed by the global construction industry. Firstly, it provides a robust solution for effectively treating and repurposing contaminated clay and clay-like waste, thereby promoting circular economy and reducing reliance on unsustainable landfill practices. This approach contributes to environmental sustainability by reducing the overall impact of waste generation.

Moreover, the invention addresses natural resource depletion concerns by providing an additional source of building and construction materials from waste-derived products, enabling the conversion of clay and clay-like waste into superior-quality building materials using geopolymerization techniques. By maximizing the efficient utilization of resources, including waste, the present invention significantly reduces the demand for virgin materials and promotes resource conservation within the construction industry.

A key advantage of the invention is its innovative approach to waste management. While existing solid waste treatment technologies have explored various methods such as washing, thermal treatment, and chemical processes for general solid waste, the specific treatment requirements of clay and clay-like waste have often been overlooked. Recognizing this gap, the present invention pioneers the use of geopolymerization as an efficient and sustainable method tailored specifically for clay and clay-like waste materials commonly encountered in the construction industry. This represents a significant advancement in waste management practices, addressing the unique challenges associated with clay and clay-like waste.

Another noteworthy aspect of the invention is the integration of a processor with artificial intelligence technology. This unit incorporates state-of-the-art algorithms and machine learning techniques to statistically analyze characterization information of clay or clay-like waste. With comprehensive information about the clay or clay-like waste, which is obtained before the clay or clay-like waste enters the treatment system, the processor enables the formulation design of targeted treatment strategies, thereby optimizing the efficiency and effectiveness of the overall waste treatment process.

Furthermore, the geopolymerization process employed in the invention leads to the production of high-quality building materials. Clay and clay-like waste materials, which often contain silica and alumina, undergo a chemical reaction with alkaline activators (alkaline solution) to form geopolymer. This geopolymer exhibits superior properties compared to traditional concrete, including higher early strength, higher ultimate compressive strength, lower reduced shrinkage, improved thermal insulation, enhanced fire resistance, and increased resistance to chemical attack. Additionally, geopolymerization reduces the risk of alkali-silica reaction, thus enhancing the durability of structures constructed using the geopolymer building materials.

In summary, the invention's advantages lie in its ability to address critical environmental and resource challenges in the construction industry. It provides an innovative and comprehensive solution for the effective treatment of construction waste, while harnessing the benefits of geopolymerization to produce high-quality building materials. The incorporation of an artificial intelligence-based processor further enhances the efficiency and precision of the waste treatment process. Overall, the invention represents a significant step towards sustainable waste management practices and the utilization of clay and clay-like waste materials in construction.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

The invention is graphically illustrated in an exemplary manner, with the understanding that the overall purpose of the invention is not restricted by the specific configuration, shape, or scale of

any elements depicted in the drawing. The drawing serves as a reference for exemplary embodiments, and any undisclosed details regarding the invention can be found within the schematic drawings.

FIG. 1 is an overview of the soft clay or clay-like waste treatment system.

FIG. 2 shows the ultrasonic washing and centrifuge dewatering system.

FIG. 3 shows the vacuum mixer system.

FIG. 4 shows the molds and microwave curing process.

## **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

### **Best Mode for Carrying out the Invention**

The main objectives of the present invention are to treat contaminated soft clay, including but not limited to solid waste with clay texture and poor mechanical properties. The treated materials are then transformed into beneficial construction materials with high strength and low leaching of heavy metal contaminants through geopolymerization. Treatment by the present invention is beneficial for solid waste utilization in civil engineering applications since the high contamination of heavy metals can be reduced and the resulting geopolymer has increased strength. The present invention gives contaminated soft clay and clay-like waste a second life, diverting them from disposal in landfills.

The preferred embodiment of the treatment system of the present invention comprises the following components that work together in synergy:

- a) A processor with artificial intelligence function;
- b) A double screw mixer that performs mixing and dispersion function;
- c) A vibrating sieve that performs particles size sieving function;
- d) A jaw crusher that utilizes compressive strength to break down stones and sand after sieving;
- e) A ball mill that crushes and grinds the materials into an extremely fine form;
- f) A unit that combines ultrasonic washing component and centrifuge dewatering component in series;
- g) A wastewater treatment system that treats the washing water to be recycled or safely discharged;

- h) A vacuum mixer that applies negative pressure while mixing; and
- i) A microwave tunnel curing unit that applies energy by microwave technology.

Characterization of contaminated clay or clay-like waste is done beforehand. The clay's or clay-like waste's moisture content, leaching potential, and alumina:silica ratio are measured by moisture meter, leaching procedure, and x-ray fluorescence analyzer, respectively.

This moisture content data is compared against an extensive experimental database, allowing the identification of the optimal liquid-to-solid (LS) ratio for the subsequent slurry making process. Through the analysis of the correlation between moisture content and washing efficiency, the processor enhanced by artificial intelligence gains valuable insights and continuously improves its understanding of the ideal LS ratio. The integration of moisture content data and washing efficiency data into the machine learning algorithms supports the system's ability to determine even more suitable LS ratios for future waste samples.

Leaching is the process by which solutes or contaminants are released from a solid material into a liquid phase by various chemical phenomena. Many batch leaching test protocols have been developed to simulate the leaching processes of waste materials in landfill or other disposal scenarios to evaluate potential risks to human and/or groundwater. The results of batch leaching tests are carefully evaluated before being used for regulatory or design purposes.

X-ray fluorescence (XRF) is a non-destructive technique for accurately analyzing the elemental composition of various materials. This device operates on the principle of XRF spectroscopy, utilizing a probe that emits a high-energy x-ray beam onto the sample surface. As a result, the atoms within the material emit characteristic fluorescent x-rays, which are detected and analyzed to identify the elements present in the sample, as well as measure their relative concentrations. The obtained elemental composition data is then compared to an extensive database, allowing the determination of the optimal dosage and formulation of alkaline activators required for achieving a high degree of polymerization during the subsequent process in the vacuum mixer. Similarly, by examining the relationship between the elemental composition and the degree of polymerization, the processor derives valuable insight and continuously improves its comprehension of the optimal dosage of alkaline activators. This knowledge significantly contributes to enhancing the overall efficiency and effectiveness of the geopolymerization process.

Characterization information of clay or clay-like waste is input into the processor of the treatment system. The processor seamlessly integrates the precise measurement of moisture content and the accurate determination of elemental composition. This powerful combination, bolstered by machine learning algorithms, optimizes the washing process by determining and setting the appropriate liquid-to-solid (LS) ratio based on the moisture content, and further determines the suitable dosage of alkaline activators based on the elemental composition. As a result, the processor equipped with artificial intelligence technology can make decisions concerning treatment method parameters, enabling efficient and effective waste treatment, as well as the conversion of clay and clay-like waste into high-quality building materials.

The double screw mixer **1** provides a thorough and homogenous mixing function of soft clay or clay-like waste with addition of water. As the screws rotate, it transports the slurry along the length of the mixing chamber. The intermeshing design of the screws ensures that the slurry is continuously pushed, lifted, and carried from one end to the other. This movement creates a cascading and kneading action within the mixing chamber. The screws' rotational motion and intermeshing configuration exert intense mechanical force on the slurry. The slurry is simultaneously compressed, stretched, and sheared as it passes between the threads of the screws. This vigorous agitation and interaction within the slurry result in thorough mixing and dispersion. The double screw mixer is particularly effective in achieving a homogenous mixture due to the continuous and repetitive action of the screws. The repeated contact and movement of the slurry between the screws' threads ensure that the slurry is well mixed. In addition, mixing parameters such as rotational speed or residence time can be adjusted to optimize the mixing process for different types of soft clay or clay-like waste. To create a slurry with good flowability, the liquid-to-solid (L/S) ratio, typically ranging from 2 to 5, is determined based on the moisture content of soft clay or clay-like waste.

The vibrating sieve **2** with aperture size of 0.5 to 1.5 mm sieves out the foreign materials, such as stones and sand, from the slurry. A vibrating sieve consists of a perforated surface or mesh that is vibrated to induce particle movement. When materials are fed onto the sieve, the vibrating motion causes the particles to move and separate based on their shape and size. The vibrating sieve utilizes vibration or oscillation to facilitate the separation based on size difference. Smaller particles tend to pass through the sieve mesh, while larger particles are retained on the surface. By adjusting the amplitude, frequency, and angle of the vibration, the vibrating sieve can effectively separate materials based on characteristics such as density or moisture content. This sieving process allows for efficient segregation and organization of materials for further processing or downstream applications.

The sieved stones and sand are introduced into a jaw crusher **3** which uses compressive force to break sand and stones down into smaller particles. These oversized materials are fed into the jaw crusher through a hopper. There are two jaws - a fixed jaw and a movable jaw inside of the jaw crusher. The movable jaw moves back and forth, exerting force on the material against the fixed jaw. This mechanical pressure crushes the materials, reducing them in size. The crushed material then exits the discharge opening at the bottom of the jaw crusher.

Next, the ball mill **4** contains a hollow cylindrical shell that rotates about its axis which crushes and grinds the materials into extremely fine particles of less than 500  $\mu\text{m}$ . This is accomplished by placing the materials into a rotating drum or cylinder filled with grinding media, such as steel or ceramic balls. As the drum rotates, the grinding media collides with the material, effectively crushing and grinding it. The continuous impact and attrition between the media and the material results in reduction of particle size. By controlling factors such as rotational speed or duration of milling, the ball mill can be optimized to achieve the desired level of particle size reduction.

The sieved slurry with added sodium dimethyldithiocarbamate (SDMC) is sent for ultrasonic washing **5**, followed by centrifuge dewatering (Figure 2). The ultrasonic washing compartment and centrifuge dewatering compartment are in a series. Firstly, the propellers provide a driving force which enables the slurry to pass the ultrasound washing chamber smoothly. Ultrasonic

washing works through high-frequency sound waves transmitted through liquid to scrub clean the surface of immersed materials. The high-frequency sound waves agitate the liquid solution of water or solvent and cause the cavitation of solution molecules. The presence of high concentration of soluble salts such as NaCl, CaCl<sub>2</sub>, and KCl can cause severe corrosion to the ultrasound generators, therefore it is advisable that the ultrasound generators be installed on the outer wall instead of inner wall of this chamber.

After ultrasound washing, the slurry then flows to the centrifuge dewatering chamber. It is a high-speed process that utilizes the force from rapid rotation of a cylindrical bowl to separate wastewater solids from liquid to produce centrifuge cake. Notably, centrifuge dewatering is preferred because centrifugation can operate in continuous mode and in high capacity. The expected moisture content of dewatered waste is around 30% to 40% on total mass basis. The process begins by loading slurry into a rotating cylindrical bowl or drum of the centrifuge. As the centrifuge starts rotating at high speed, typically 3000-4000 rpm, centrifugal force is generated. This force causes the heavier solid particles in the mixture to move towards the inner wall of the bowl, while the lighter liquid component moves towards the center. During rotation, the solids settle and form a sediment layer on the inner surface of the bowl, while the liquid forms a separate layer above the sediment. The sedimentation process is facilitated by the centrifugal force, which effectively separates the solids from the liquid. As the rotation continues, the sediment layer becomes more compacted, and the centrifugal force aids in squeezing out the moisture from the solids. This dewatering process results in the reduction of moisture content in the solids. Once the dewatering process is complete, the separated solids i.e., centrifuge cake with reduced moisture content, are discharged from the centrifuge. The liquid component, i.e., wastewater, which has been separated from the solids, can be collected separately and pumped into the wastewater treatment system. The efficiency of centrifuge dewatering depends on various factors such as rotational speed, bowl geometry, and characteristics of the slurry. By adjusting these factors, the dewatering process can be optimized to achieve the desired level of moisture removal from the slurry.

The wastewater discharged from the centrifuge dewatering process is sent to a wastewater treatment system 6. The wastewater treatment system comprises coagulation, flocculation, sedimentation, and pH adjustment processes. The wastewater treatment system also includes a mechanical vapor recompression unit to remove soluble salts in the washing water. The treated water can either be recycled into the process or safely discharged in accordance with local standards and regulations. The filter cake is combined into washed waste for further treatment.

Dry waste powders such as coal fly ash or coal bottom ash are utilized in the treatment of soft clay or clay-like waste to regulate the overall moisture content and modify the composition, with specific attention given to the silica:alumina ratio. The waste powders must not have contamination levels that are too high, however. It is desirable to maintain a moisture content below 20% and achieve a preferred silica:alumina ratio of 3.5 to 4.5. In addition, a solution containing NaOH and Na<sub>2</sub>SiO<sub>3</sub>, with a total concentration of 12 - 16 M and a silica:alkali ratio of 0 to 1 is employed. In cases where the waste mixture has a significantly higher silica content, pure NaOH solution prepared from NaOH pellets helps balance the silica:alumina ratio while optimizing operational costs.

The washed waste is then sent for vacuum mixing **7** with addition of dry waste powders such as coal fly ash or coal bottom ash, milled waste powders ( $< 500 \mu\text{m}$ ), wastewater filter cake, solution of NaOH, and  $\text{Na}_2\text{SiO}_3$ , and  $\text{Ca}(\text{OH})_2$  (Figure 3). The vacuum mixer helps by creating an environment devoid of air to prevent formation of bubbles in the materials that can lead to structural defects. The vacuum environment also aids in controlling the moisture content of the mixture. By reducing the pressure within the mixer, the evaporation point of water decreases, facilitating the removal of excess moisture from the waste. The output of the vacuum mixer is well mixed slurry, ready for further processing or shaping into desired forms, such as slabs or bricks.

The slurry pushed out from the vacuum mixer is introduced into either one of the two different types of molds, slab molds or brick molds. The molds are specifically designed for easy de-molding, featuring two flat wings on either side, and intentionally omitting a bottom plate. It is crucial to select a material that meets the requirements of high durability, transparency to microwave radiation, and resistance to high temperatures. Alumina ( $\text{Al}_2\text{O}_3$ ) is a preferred choice for mold material. To prevent any undesired reaction between the slurry and alumina mold, a sacrificial layer of alumina powder is applied prior to casting the slurry into the mold. Usage of either slab molds or brick molds depends on the demand of users. If slab is applied, lightweight aggregates (LWA) can be added during the vacuum mixing step to produce a lightweight slab.

A heat-resistant conveyor belt delivers empty molds to designated locations underneath the vertical screw nozzle for filling and casting of slurry (Figure 4). The filled molds are then delivered to microwave tunnel **8** for curing. After the microwave tunnel is switched on, the slurry will be transported to the drying chamber. Throughout the entire process from the slurry entering the drying chamber to exiting the machine, water molecules inside of the slurry will rotate by trying to align themselves with the alternating electric field induced by the microwave rays. The rapid movement of the polar molecules creates friction and results in heat dissipation in the slurry exposed to microwave radiation. The moisture in the slurry is constantly evaporated due to continuous heat generated. During the drying process, the water vapor generated can be pumped away by the exhaust fan pipes with a proper dust elimination device. The whole drying process is continuous. New molds filled with slurry are continuously added at the feed entrance, and dried slurry can be continuously obtained at the exit. Upon the molds exiting the microwave tunnel, the slurry becomes hardened, resulting in formation of solid slabs or bricks. Due to water loss, the solid material shrinks, facilitating de-molding. De-molding is achieved by allowing free fall from a higher position onto a conveyor belt situated at a lower level. During the descent, rotating rollers support the mold's wings, ensuring stability and preventing any damage to the solidified material. Following de-molding, the empty molds are directed back onto the conveyor belt for subsequent use. To facilitate easy release of the slabs or bricks in future cycles, the molds are sprayed with alumina powder or a similar releasing agent. The coating prevents the material from adhering to the molds, ensuring a smooth and efficient de-molding process.

There are several advantages of microwave curing compared to drying in ambient conditions, including time saving, automated drying, balanced heat performance, consistent drying effect, and high product quality. The curing period of this slurry in ambient condition, i.e., without microwave curing, can take up to one to three months or even longer. Therefore, the application of the microwave tunnel can improve the efficiency of the curing process. Although the brick or slab from the microwave tunnel are hardened, it is advisable to cure them under ambient conditions for

another period of 7 to 14 days to enable them to achieve their final strength prior to any further applications.

## EXAMPLES

### Example 1: Production of construction bricks using contaminated soft clay, freshwater sludge, wet incineration fly ash, and coal fly ash

Representative contaminated soft clay, freshwater sludge, wet incineration fly ash, and coal fly ash samples were collected from a construction site, a water treatment plant, a municipal solid waste incineration plant, and a coal burning power plant respectively. The moisture content, heavy metals content, and silica:alumina ratio of the waste samples were measured, and the characterization results were input into the processor. Based on the instructions from the processor, the contaminated soft clay sample, freshwater sludge sample, and wet incineration fly ash sample underwent slurry making in a double screw mixer using L/S ratio, rotational speed, and residence time of 3, 20 rpm, and 1 minute, respectively. Afterwards, the mixture was wet sieved using a vibrating sieve with mesh size of 1 mm to separate out sand and stones. The separated sand and stones were subsequently grinded into waste powders < 500  $\mu\text{m}$  using a jaw crusher at 200 cpm for 5 minutes, followed by a ball mill at 45 rpm for 180 minutes. On the other hand, the sieved slurry from the vibrating sieve underwent intensive washing in an ultrasonic system with a treatment frequency of 20 kHz for 4 minutes, facilitated by the addition of 0.05 wt. % of SDMC based on the flowrate of slurry. The resulting slurry was then subjected to solid-liquid separation using a centrifuge at 3000 rpm for 2 minutes. The wastewater generated from the centrifuge dewatering process was subjected to a series of treatment steps including coagulation, flocculation, sedimentation, MVR evaporation to remove soluble salts, and pH adjustment to 8 with 50% (v/v)  $\text{H}_2\text{SO}_4$  in the wastewater treatment system. The treated water was reused as washing water in the slurry making step in the double screw mixer. Separately, moisture content of the washed waste of the centrifuge dewatering process was reduced to 31%. This washed waste together with wastewater filter cake produced from wastewater treatment, and waste powders < 500  $\mu\text{m}$  produced from crushing and milling were mixed with 30 wt. % coal fly ash and 8.0 wt. % sodium hydroxide solution based on the total weight of washed waste, wastewater filter cake, and waste powder in a vacuum mixer for 5 minutes at 50 rpm, based on the formulation determined by the processor. Consequently, the resulting slurry mixture possessed a moisture content of 15% and a silica:alumina ratio of 3.8. Following a thorough mixing process, the slurry mixture was poured into alumina brick molds. Before introducing the slurry mixture, a layer of alumina powder was applied to the mold's surface. The filled mold was then subjected to microwave curing at 160  $^{\circ}\text{C}$  for 20 minutes. Following the microwave curing process, the brick was left to cure under ambient conditions for an additional 7 days.

The untreated contaminated soft clay, freshwater sludge, wet incineration fly ash, and brick products were subjected to leaching and analytical tests to verify the treatment efficacy. The employed leaching test method was a batch leaching method that is specified in British Standard EN 12457-1EN12457-1:2022 (British Standards Institution). The leachates were analyzed, as described in Standard Methods for the Examination of Water and Wastewater that is published by the American Public Health Association (APHA), by inductively coupled plasma-optical emission

spectrometry (ICP-OES) for metals and metalloids including arsenic, barium, cadmium, chromium (total), copper, manganese, mercury, nickel, lead, selenium, and zinc.

Further, the brick product was also tested for its physico-mechanical properties including compressive strength according to EN 12390-3:2019, drying shrinkage according to EN 1367-4, thermal conductivity using heat flow meter according to ASTM C518, fire resistance according to ASTM E119, resistance to chemical attack according to BS EN771, and alkali-silica reaction (ASR) using mortar bar method according to ASTM C1260.

As shown in Table 1, the concentrations of all contaminants decreased after treatment with the system and process described herein and the concentrations of all contaminants in the product could meet the Danish WtR standard. The 28-day compressive strength, drying shrinkage, thermal conductivity, fire resistance, resistance to chemical attack, and expansion due to ASR of the geopolymer brick results were 63 MPa, 0.10 %, 1.6 W/m·k, 90 minutes, excellent chemical resistance, and 0.04% respectively.

**Table 1:** Leaching outcome

| Contaminants     | Danish WtR Standard (Cat. 3) (mg/kg) | Contaminated soft clay | Freshwater sludge | Wet incineration fly ash | Coal fly ash | Brick  |
|------------------|--------------------------------------|------------------------|-------------------|--------------------------|--------------|--------|
| Arsenic          | 0.1                                  | ND                     | 0.0051            | ND                       | 0.0103       | 0.0040 |
| Barium           | 8                                    | 0.0811                 | 1.6896            | 25.4670                  | 0.2474       | 1.6500 |
| Cadmium          | 0.08                                 | 0.1525                 | 0.0136            | 0.2845                   | 0.0029       | ND     |
| Chromium (total) | 1                                    | 0.0041                 | 0.0107            | 4.8957                   | 0.5796       | 0.0360 |
| Copper           | 4                                    | 0.0332                 | 0.3096            | 4.6159                   | 0.0179       | 0.0010 |
| Manganese        | 0.002                                | ND                     | 0.3148            | 0.00124                  | 0.0001       | ND     |
| Mercury          | 0.002                                | ND                     | 0.0007            | ND                       | ND           | ND     |
| Nickel           | 0.14                                 | ND                     | 0.0208            | ND                       | ND           | ND     |
| Lead             | 0.2                                  | 0.0713                 | 0.1468            | 256.3402                 | 0.1274       | ND     |
| Selenium         | 0.06                                 | 0.0565                 | 0.1734            | ND                       | 0.0628       | 0.0046 |
| Zinc             | 3                                    | 0.0238                 | ND                | 22.4256                  | 0.0360       | 0.0431 |

*ND: not detectable*

### Example 2: Production of construction lightweight slabs using contaminated soft clay, freshwater sludge, wet incineration fly ash, and coal fly ash

Representative contaminated soft clay, freshwater sludge, wet incineration fly ash, and coal fly ash samples were collected from a construction site, a water treatment plant, a municipal solid waste incineration plant, and a coal burning power plant respectively. The moisture content, heavy metals content, and silica:alumina ratio of the waste samples were measured, and the characterization results were input into the processor. Based on the instructions from the processor, the contaminated soft clay sample, freshwater sludge sample, and wet incineration fly ash sample underwent slurry making in a double screw mixer using L/S ratio, rotational speed, and residence time of 2.7, 20 rpm, and 1 minute, respectively. Afterwards, the mixture was wet sieved using a vibrating sieve with mesh size of 1 mm to separate out sand and stones. The separated-out sand and stones were subsequently grinded into waste powders < 500  $\mu\text{m}$  using a jaw crusher at 200 cpm for 5 minutes, followed by a ball mill at 50 rpm for 180 minutes. On the other hand, the sieved slurry from the vibrating sieve underwent intensive washing in an ultrasonic system with a treatment frequency of 20 kHz for 4 minutes, facilitated by the addition of 0.04 wt. % of SDMC based on the flowrate of slurry. The resulting slurry was then subjected to solid-liquid separation using a centrifuge at 3000 rpm for 2 minutes. The wastewater generated from the centrifuge dewatering process was subjected to a series of treatment steps including coagulation, flocculation, sedimentation, MVR evaporation to remove soluble salts, and pH adjustment to 8.5 with 50 % (v/v)  $\text{H}_2\text{SO}_4$  in the wastewater treatment system. The treated water was reused as washing water in the slurry making step in the double screw mixer. Separately, moisture content of the washed waste of the centrifuge dewatering process was reduced to 32.4 %. This washed waste together with wastewater filter cake produced from wastewater treatment, and waste powders < 500  $\mu\text{m}$  produced from crushing and milling was mixed with 29 wt. % coal fly ash and 8.6 wt. % sodium hydroxide solution based on the total weight of washed waste, wastewater filter cake, and waste powder in a vacuum mixer for 5 minutes at 50 rpm, based on the formulation determined by the processor. Consequently, the resulting slurry mixture possessed a moisture content of 14.8 % and a silica:alumina ratio of 3.5. The slurry mixture was then mixed thoroughly with 30 % LWA before being poured into alumina slab molds. Before introducing the slurry, a layer of alumina powder was applied to the molds' surface. The filled mold was then subjected to microwave curing at 160  $^{\circ}\text{C}$  for 20 minutes. Following the microwave curing process, the slab was left to cure under ambient conditions for an additional 7 days.

The untreated contaminated soft clay, freshwater sludge, wet incineration fly ash, and lightweight slab products were subjected to leaching and analytical tests to verify the treatment efficacy. The employed leaching test method was a batch leaching method that is specified in British Standard EN 12457-1:2002 (British Standards Institution). The leachates were analyzed, as described in Standard Methods for the Examination of Water and Wastewater that is published by the APHA, by ICP-OES for metals and metalloids including arsenic, barium, cadmium, chromium (total), copper, manganese, mercury, nickel, lead, selenium, and zinc.

Further, the lightweight slab product was also tested for its physico-mechanical properties including density according to EN 12390-7:2019, compressive strength according to EN 12390-3:2019, drying shrinkage according to EN 1367-4, thermal conductivity using heat flow meter

according to ASTM C518, fire resistance according to ASTM E119, resistance to chemical attack according to ASTM C1202, and ASR using mortar bar method according to ASTM C1260.

As shown in Table 2, the concentrations of all contaminants decreased after treatment with the system and process described herein and the concentrations of all contaminants in the product could meet the Danish WtR standard. The density, 28-day compressive strength, drying shrinkage, thermal conductivity, fire resistance, resistance to chemical attack, and expansion due to ASR of the lightweight slab results were 1800 kg/m<sup>3</sup>, 42 MPa, 0.10 %, 1.1 W/m·k, 90 minutes, excellent chemical resistance, and 0.03% respectively. On the other hand, the density, compressive strength, drying shrinkage, thermal conductivity, fire resistance, resistance to chemical attack, and expansion due to ASR of normal weight slab results were 2385 kg/m<sup>3</sup>, 59 MPa, 0.06 %, 1.6 W/m·k, 60 minutes, moderate resistance to chemicals, and 0.03% respectively.

**Table 2:** Leaching outcome

| <b>Contaminants</b> | <b>Danish WtR Standard (Cat. 3) (mg/kg)</b> | <b>Contaminated soft clay</b> | <b>Freshwater sludge</b> | <b>Wet incineration fly ash</b> | <b>Coal fly ash</b> | <b>Lightweight Slab</b> |
|---------------------|---------------------------------------------|-------------------------------|--------------------------|---------------------------------|---------------------|-------------------------|
| Arsenic             | 0.1                                         | ND                            | 0.0065                   | ND                              | 0.0103              | 0.0003                  |
| Barium              | 8                                           | 0.0422                        | 0.3980                   | 31.3760                         | 0.2474              | 1.8900                  |
| Cadmium             | 0.08                                        | 0.0862                        | 0.0055                   | 0.3739                          | 0.0029              | ND                      |
| Chromium (total)    | 1                                           | ND                            | ND                       | 4.2925                          | 0.5796              | 0.0606                  |
| Copper              | 4                                           | 0.0123                        | 0.0085                   | 2.3282                          | 0.0179              | 0.0214                  |
| Manganese           | 2                                           | 0.3656                        | 0.8533                   | 0.00017                         | 0.0001              | 0.0020                  |
| Mercury             | 0.002                                       | ND                            | 0.0004                   | ND                              | ND                  | 0.00036                 |
| Nickel              | 0.14                                        | ND                            | 0.0006                   | ND                              | ND                  | ND                      |
| Lead                | 0.2                                         | 0.0532                        | ND                       | 318.8933                        | 0.1274              | 0.0075                  |
| Selenium            | 0.06                                        | 0.0462                        | ND                       | ND                              | 0.0628              | 0.0242                  |
| Zinc                | 3                                           | 0.0251                        | ND                       | 17.6175                         | 0.0360              | 0.0566                  |

*ND: not detectable*

### Example 3: Production of construction bricks using contaminated soft clay and coal fly ash

Representative contaminated soft clay and coal fly ash samples were collected from a construction site and a coal burning power plant, respectively. The moisture content, heavy metals content, and silica:alumina ratio of the waste samples were measured, and the characterization results were input into the processor. Based on the instructions from the processor, the contaminated soft clay sample underwent slurry making in a double screw mixer using L/S ratio, rotational speed, and residence time of 3, 20 rpm, and 1 minute, respectively. Afterwards, the mixture was wet sieved using a vibrating sieve with mesh size of 1 mm to separate out sand and stones. The separated-out sand and stones were subsequently grinded into waste powders < 500  $\mu\text{m}$  using a jaw crusher at 300 cpm for 5 minutes, followed by a ball mill at 45 rpm for 30 minutes. On the other hand, the sieved slurry from the vibrating sieve underwent intensive washing in an ultrasonic system with a treatment frequency of 20 kHz for 4 minutes, facilitated by the addition of 0.045 wt. % of SDMC based on the flowrate of slurry. The resulting slurry was then subjected to solid-liquid separation using a centrifuge at 3000 rpm for 2 minutes. The wastewater generated from the centrifuge dewatering process was subjected to a series of treatment steps including coagulation, flocculation, sedimentation, MVR evaporation to remove soluble salts, and pH adjustment to 8 with 50% (v/v)  $\text{H}_2\text{SO}_4$  in the wastewater treatment system. The treated water was reused as washing water in the slurry making step in the double screw mixer. Separately, moisture content of the washed waste of the centrifuge dewatering process was reduced to 30.8 %. This washed waste together with wastewater filter cake produced from wastewater treatment, and waste powders < 500  $\mu\text{m}$  produced from crushing and milling was mixed with 31 wt. % coal fly ash and 7.1 wt. % sodium hydroxide solution based on the total weight of washed waste, wastewater filter cake, and waste powder in a vacuum mixer for 5 minutes at 50 rpm, based on the formulation determined by the processor. Consequently, the resulting mixture possessed a moisture content of 13.6 % and a silica:alumina ratio of 3.78. Following a thorough mixing process, the slurry mixture was poured into alumina brick molds. Before introducing the slurry, a layer of alumina powder was applied to the molds' surface. The filled molds were then subjected to microwave curing at 160  $^{\circ}\text{C}$  for 20 minutes. Following the microwave curing process, the bricks were left to cure under ambient conditions for different durations: (1) 0 day; (2) 7 days; and (3) 14 days.

The untreated contaminated soft clay, coal fly ash, and brick products were subjected to leaching and analytical tests to verify the treatment efficacy. The employed leaching test method was a batch leaching method that is specified in British Standard EN 12457-1:2022 (British Standards Institution). The leachates were analyzed, as described in Standard Methods for the Examination of Water and Wastewater that is published by the APHA, by ICP-OES for metals and metalloids including arsenic, barium, cadmium, chromium (total), copper, manganese, mercury, nickel, lead, selenium, and zinc. As shown in Table 3A, the concentrations of all contaminants decreased after treatment with the system and process described herein and the concentrations of all contaminants in the product could meet the Danish WtR standard. The leaching of copper and chromium were reduced with curing age, but no evident effect of curing age on the leaching of arsenic, barium, cadmium, manganese, mercury, nickel, lead, selenium, and zinc was observed.

**Table 3A: Leaching outcome**

| Contaminants     | Danish WtR Standard (Cat. 3) (mg/kg) | Contaminated soft clay | Coal fly ash | Brick                                |                                                              |                                                               |
|------------------|--------------------------------------|------------------------|--------------|--------------------------------------|--------------------------------------------------------------|---------------------------------------------------------------|
|                  |                                      |                        |              | Microwave curing at 160°C for 20 min | Microwave curing at 160°C for 20 min + 7 days ambient curing | Microwave curing at 160°C for 20 min + 14 days ambient curing |
| Arsenic          | 0.1                                  | ND                     | 0.0103       | 0.0055                               | 0.0047                                                       | 0.0056                                                        |
| Barium           | 8                                    | 0.0401                 | 0.2474       | 0.0340                               | 0.0256                                                       | 0.0290                                                        |
| Cadmium          | 0.08                                 | 0.0743                 | 0.0029       | ND                                   | ND                                                           | ND                                                            |
| Chromium (total) | 1                                    | ND                     | 0.5796       | 0.0470                               | 0.0280                                                       | 0.0160                                                        |
| Copper           | 4                                    | 0.0124                 | 0.0179       | 0.0460                               | 0.0020                                                       | 0.0010                                                        |
| Manganese        | 2                                    | 0.1617                 | 0.0001       | ND                                   | ND                                                           | ND                                                            |
| Mercury          | 0.002                                | ND                     | ND           | ND                                   | ND                                                           | ND                                                            |
| Nickel           | 0.14                                 | ND                     | ND           | ND                                   | ND                                                           | ND                                                            |
| Lead             | 0.2                                  | 0.0236                 | 0.1274       | ND                                   | ND                                                           | ND                                                            |
| Selenium         | 0.06                                 | 0.0123                 | 0.0628       | 0.0327                               | 0.0586                                                       | 0.0530                                                        |
| Zinc             | 3                                    | 0.0016                 | 0.0360       | 0.0243                               | 0.0221                                                       | 0.0245                                                        |

ND: not detectable

Further, the brick products were also tested for its physico-mechanical properties including compressive strength according to EN 12390-3:2019, drying shrinkage according to EN 1367-4, thermal conductivity using heat flow meter according to ASTM C518, fire resistance according to ASTM E119, resistance to chemical attack according to BS EN771, and ASR using mortar bar method according to ASTM C1260. The 28-day compressive strength, drying shrinkage, thermal conductivity, fire resistance, resistance to chemical attack, and expansion due to ASR of the geopolymer bricks subjected to different durations of ambient curing were tabulated in Table 3B. The 28-day compressive strength of brick products increases with ambient curing duration. The strength gain was proportional to the curing period because hydration products that contribute to strength are formed as curing progress. However, extending ambient curing has negligible effect on drying shrinkage, thermal conductivity, fire resistance, resistance to chemical attack, and expansion due to ASR.

**Table 3B:** Physico-mechanical properties

| Properties                    | Brick                                |                                                              |                                                               |
|-------------------------------|--------------------------------------|--------------------------------------------------------------|---------------------------------------------------------------|
|                               | Microwave curing at 160°C for 20 min | Microwave curing at 160°C for 20 min + 7 days ambient curing | Microwave curing at 160°C for 20 min + 14 days ambient curing |
| Compressive strength (MPa)    | 35                                   | 48                                                           | 56                                                            |
| Drying shrinkage (%)          | 0.05                                 | 0.10                                                         | 0.09                                                          |
| Thermal conductivity (W/m·k)  | 1.14                                 | 1.12                                                         | 1.13                                                          |
| Fire resistance (min)         | 90                                   | 90                                                           | 90                                                            |
| Resistance to chemical attack | Moderate                             | Moderate                                                     | Moderate                                                      |
| Expansion due to ASR (%)      | 0.04                                 | 0.03                                                         | 0.04                                                          |

Example 4: Production of construction bricks using contaminated soft clay, wet incineration fly ash, and coal fly ash

Representative contaminated soft clay, wet incineration fly ash, and coal fly ash samples were collected from a construction site, a municipal solid waste incineration plant, and a coal burning power plant, respectively. The moisture content, heavy metals content, and silica:alumina ratio of the waste samples were measured, and the characterization results were input into the processor. Based on the instructions from the processor, the contaminated soft clay sample and wet incineration fly ash sample underwent slurry making in a double screw mixer using L/S ratio, rotational speed, and residence time of 5, 20 rpm, and 1 minute, respectively. Afterwards, the mixture was wet sieved using a vibrating sieve with mesh size of 1 mm to separate sand and stones. The separated sand and stones were subsequently grinded into waste powders < 500 µm using a jaw crusher at 250 cpm for 5 minutes, followed by a ball mill at 40 rpm for 180 minutes. On the other hand, the sieved slurry from the vibrating sieve underwent intensive washing in an ultrasonic system with a treatment frequency of 20 kHz for 4 minutes, facilitated by the addition of 0.025 wt. % of SDMC based on the flowrate of slurry. The resulting slurry was then subjected to solid-liquid separation using a centrifuge at 3000 rpm for 2 minutes. The wastewater generated from the centrifuge dewatering process was subjected to a series of treatment including coagulation, flocculation, sedimentation, MVR evaporation to remove soluble salts, and pH adjustment to 8 with 50% (v/v) H<sub>2</sub>SO<sub>4</sub> in the wastewater treatment system. The treated water was reused as

washing water in the slurry making step in the double screw mixer. Separately, moisture content of the washed waste of the centrifuge dewatering process was reduced to 33.8 %. This washed waste together with wastewater filter cake produced from wastewater treatment, and waste powders < 500 µm produced from crushing and milling was mixed with 32 wt. % coal fly ash and 6.4 wt. % sodium hydroxide solution based on the total weight of washed waste, wastewater filter cake, and waste powder in a vacuum mixer for 5 minutes at 50 rpm, based on the formulation determined by the processor. Consequently, the resulting slurry mixture possessed a moisture content of 13.8 % and a silica:alumina ratio of 3.79. Following a thorough mixing process, the slurry mixture was poured into alumina brick molds. Before introducing the slurry, a layer of alumina powder was applied to the molds' surface.

The filled molds were then subjected to different curing conditions: (1) microwave curing at 160 °C for 30 minutes followed by curing under ambient conditions for 7 days; (2) microwave curing at 160 °C for 20 minutes, followed by curing under ambient conditions for 7 days; and (3) curing under ambient conditions for 7 days.

The untreated contaminated soft clay, wet incineration fly ash, coal fly ash, and brick products cured under different conditions were subjected to leaching and analytical tests to verify the treatment efficiency. The employed leaching test method was a batch leaching method that is specified in British Standard EN 12457-1:2022 (British Standards Institution). The leachates were analyzed, as described in Standard Methods for the Examination of Water and Wastewater that is published by the APHA, by ICP-OES for metals and metalloids including arsenic, barium, cadmium, chromium (total), copper, manganese, mercury, nickel, lead, selenium, and zinc. As shown in Table 4A, the concentrations of all contaminants decreased after treatment with the system and process described herein and the concentrations in the product could meet the Danish WtR standard. The leaching of arsenic, barium, chromium, copper, and zinc were reduced with microwave curing duration, but no evident effect of curing age on the leaching of cadmium, manganese, mercury, nickel, lead, and selenium has been observed.

**Table 4A:** Leaching outcome

| Contaminants        | Danish<br>WtR<br>Standard<br>(Cat. 3)<br>(mg/kg) | Contaminated<br>soft clay | Wet<br>incineration<br>fly ash | Coal<br>fly ash | Brick                                                                              |                                                                                    |                                    |
|---------------------|--------------------------------------------------|---------------------------|--------------------------------|-----------------|------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|------------------------------------|
|                     |                                                  |                           |                                |                 | Microwave<br>curing at<br>160°C for<br>30 min +<br>ambient<br>curing for<br>7 days | Microwave<br>curing at<br>160°C for<br>20 min +<br>ambient<br>curing for<br>7 days | Ambient<br>curing<br>for 7<br>days |
| Arsenic             | 0.1                                              | ND                        | 0.0183                         | ND              | 0.0040                                                                             | 0.0077                                                                             | 0.0120                             |
| Barium              | 8                                                | 0.0326                    | 27.4470                        | 0.2034          | 1.2100                                                                             | 1.4500                                                                             | 1.8900                             |
| Cadmium             | 0.08                                             | 0.0768                    | 0.2573                         | 0.0276          | ND                                                                                 | ND                                                                                 | ND                                 |
| Chromium<br>(total) | 1                                                | ND                        | 6.3462                         | 0.4134          | 0.0264                                                                             | 0.0360                                                                             | 0.0910                             |
| Copper              | 4                                                | 0.0126                    | 4.2836                         | ND              | 0.0060                                                                             | 0.0084                                                                             | 0.0130                             |
| Manganese           | 2                                                | 0.1568                    | 0.0004                         | 0.00024         | ND                                                                                 | ND                                                                                 | ND                                 |
| Mercury             | 0.002                                            | ND                        | ND                             | ND              | ND                                                                                 | ND                                                                                 | ND                                 |
| Nickel              | 0.14                                             | ND                        | ND                             | ND              | ND                                                                                 | ND                                                                                 | ND                                 |
| Lead                | 0.2                                              | 0.0564                    | 426.2136                       | ND              | ND                                                                                 | ND                                                                                 | ND                                 |
| Selenium            | 0.06                                             | 0.0135                    | ND                             | 0.0512          | 0.0049                                                                             | 0.0050                                                                             | 0.0048                             |
| Zinc                | 3                                                | 0.0549                    | 24.1254                        | ND              | 0.0263                                                                             | 0.0319                                                                             | 0.0334                             |

ND: not detectable

Further, the brick products were also tested for its physico-mechanical properties including compressive strength according to EN 12390-3:2019, drying shrinkage according to EN 1367-4, thermal conductivity using heat flow meter according to ASTM C518, fire resistance according to ASTM E119, resistance to chemical attack according to BS EN771, and ASR using mortar bar method according to ASTM C1260 and the properties of the brick produced different curing conditions were summarized in Table 4B. The 28-day compressive strength of brick products increases with ambient curing duration. The strength gain was proportional to the curing period because hydration products that contribute to strength are formed as curing progress. However, extending ambient curing has negligible effect on drying shrinkage, thermal conductivity, fire resistance, resistance to chemical attack, and expansion due to ASR.

**Table 4B:** Physico-mechanical properties

| Properties                    | Brick                                                            |                                                                  |                           |
|-------------------------------|------------------------------------------------------------------|------------------------------------------------------------------|---------------------------|
|                               | Microwave curing at 160°C for 30 min + ambient curing for 7 days | Microwave curing at 160°C for 20 min + ambient curing for 7 days | Ambient curing for 7 days |
| Compressive strength (MPa)    | 51                                                               | 47                                                               | 26                        |
| Drying shrinkage (%)          | 0.10                                                             | 0.10                                                             | 0.13                      |
| Thermal conductivity (W/m·k)  | 1.42                                                             | 1.38                                                             | 1.41                      |
| Fire resistance (min)         | 90                                                               | 90                                                               | 90                        |
| Resistance to chemical attack | Moderate                                                         | Moderate                                                         | Moderate                  |
| Expansion due to ASR (%)      | 0.03                                                             | 0.02                                                             | 0.03                      |

Example 5: Production of construction lightweight slabs using contaminated soft clay and coal bottom ash

Representative contaminated soft clay and coal bottom ash samples were collected from a construction site and a coal burning power plant, respectively. The moisture content, heavy metals content, and silica:alumina ratio of the waste samples were measured, and the characterization results were input into the processor. Based on the instructions from the processor, the contaminated soft clay sample underwent slurry making in a double screw mixer using L/S ratio, rotational speed, and residence time of 2.5, 20 rpm, and 1 minute, respectively. Afterwards, the mixture was wet sieved using a vibrating sieve with mesh size of 1 mm to separate out sand and stones. The separated-out sand and stones were subsequently grinded into waste powders < 500 µm using a jaw crusher at 200 cpm for 5 minutes, followed by a ball mill at 45 rpm for 180 minutes. On the other hand, the sieved slurry from the vibrating sieve underwent intensive washing in an ultrasonic system with a treatment frequency of 20 kHz for 5 minutes, facilitated by the addition of 0.1 wt. % of SDMC based on the flowrate of slurry. The resulting slurry was then subjected to solid-liquid separation using a centrifuge at 3000 rpm for 2 minutes. The wastewater generated from the centrifuge dewatering process was subjected to a series of treatment including coagulation, flocculation, sedimentation, MVR evaporation to remove soluble salts, and pH adjustment to 8 with 50% (v/v) H<sub>2</sub>SO<sub>4</sub> in the wastewater treatment system. The treated water was reused as washing water in the slurry making step in the double screw mixer. Separately, moisture content

of the washed waste of the centrifuge dewatering process was reduced to 31.6 %. This washed waste together with wastewater filter cake produced from wastewater treatment, and waste powders < 500 µm produced from crushing and milling was mixed with 22 wt. % coal bottom ash and 8.7 wt. % sodium hydroxide solution based on the total weight of washed waste, wastewater filter cake, and waste powder in a vacuum mixer for 4 minutes at 50 rpm, based on the formulation determined by the processor. Consequently, the resulting mixture possessed a moisture content of 14.8 % and a silica:alumina ratio of 3.5.

The slurry was then mixed with different dosages of LWA: (1) 20%; (2) 30%; and (3) 50%. Following a thorough mixing process, the mixture was poured into alumina slab molds. Before introducing the slurry, a layer of alumina powder was applied to the molds' surface. The filled molds were then subjected to microwave curing at 160 °C for 20 minutes. Following the microwave curing process, the slabs were left to cure under ambient conditions for an additional 7 days.

The untreated contaminated soft clay, coal bottom ash, and slab products were subjected to leaching and analytical tests to verify the treatment efficiency. The employed leaching test method was a batch leaching method that is specified in British Standard EN12457-1:2022 (British Standards Institution). The leachates were analyzed, as described in Standard Methods for the Examination of Water and Wastewater that is published by the APHA, by ICP-OES for metals and metalloids including arsenic, barium, cadmium, chromium (total), copper, manganese, mercury, nickel, lead, selenium, and zinc. As shown in Table 5A, the concentrations of all contaminants decreased after treatment with the system and process described herein and the concentrations in the products could meet the Danish WtR standard. Increasing LWA dosage was also found to reduce leaching of heavy metals.

**Table 5A:** Leaching outcome

| Contaminants     | Danish WtR Standard (Cat. 3) (mg/kg) | Contaminated soft clay | Coal bottom ash | Lightweight Slab |         |         |
|------------------|--------------------------------------|------------------------|-----------------|------------------|---------|---------|
|                  |                                      |                        |                 | 20% LWA          | 30% LWA | 50% LWA |
| Arsenic          | 0.1                                  | ND                     | ND              | ND               | ND      | ND      |
| Barium           | 8                                    | 0.0231                 | 0.1548          | 0.0110           | 0.0053  | 0.0030  |
| Cadmium          | 0.08                                 | 0.0763                 | 0.0741          | ND               | ND      | ND      |
| Chromium (total) | 1                                    | ND                     | 0.0413          | ND               | ND      | ND      |
| Copper           | 4                                    | ND                     | 0.0122          | ND               | ND      | ND      |
| Manganese        | 2                                    | 0.1562                 | 0.0030          | ND               | ND      | ND      |
| Mercury          | 0.002                                | ND                     | 0.0015          | ND               | ND      | ND      |
| Nickel           | 0.14                                 | ND                     | ND              | ND               | ND      | ND      |
| Lead             | 0.2                                  | 0.0238                 | ND              | ND               | ND      | ND      |
| Selenium         | 0.06                                 | 0.0281                 | 0.0243          | 0.0022           | 0.0021  | 0.0015  |
| Zinc             | 3                                    | 0.0186                 | 0.0178          | 0.0122           | 0.0103  | 0.0053  |

*ND: not detectable*

Further, the slab product was also tested for its physico-mechanical properties including density according to EN 12390-7:2019, compressive strength according to EN 12390-3:2019, drying shrinkage according to EN 1367-4, thermal conductivity using heat flow meter according to ASTM C518, fire resistance according to ASTM E119, resistance to chemical attack according to ASTM C1202, and ASR using mortar bar method according to ASTM C1260. The physico-mechanical properties of the slabs made with different percentage incorporation of LWA were summarized in Table 5B. The density, 28 days compressive strength, and thermal conductivity of the slab decreases with increasing LWA dosage while drying shrinkage, fire resistance, resistance to chemical attack, and expansion due to ASR are not affected by LWA dosage.

**Table 5B:** Physico-mechanical properties

| Properties                    | Slab with 20% LWA | Slab with 30% LWA | Slab with 50% LWA |
|-------------------------------|-------------------|-------------------|-------------------|
| Density (kg/m <sup>3</sup> )  | 1853              | 1805              | 1670              |
| Compressive strength (MPa)    | 73                | 64                | 59                |
| Drying shrinkage (%)          | 0.1               | 0.1               | 0.2               |
| Thermal conductivity (W/m·k)  | 1.5               | 1.1               | 0.9               |
| Fire resistance (min)         | 90                | 90                | 90                |
| Resistance to chemical attack | Moderate          | Moderate          | Moderate          |
| Expansion due to ASR (%)      | 0.03              | 0.04              | 0.03              |

Example 6: Production of construction bricks using freshwater sludge, wet incineration fly ash, and coal bottom ash

Representative freshwater sludge, wet incineration fly ash, and coal bottom ash samples were collected from a water treatment plant, a municipal solid waste incineration plant, and a coal burning power plant, respectively. The moisture content, heavy metals content, and silica:alumina ratio of the waste samples were measured, and the characterization results were input into the processor. Based on the instructions from the processor, the freshwater sludge sample and wet incineration fly ash sample underwent slurry making in a double screw mixer using L/S ratio, rotational speed, and residence time of 2.3, 20 rpm, and 1 minute, respectively. Afterwards, the mixture was wet sieved using a vibrating sieve with mesh size of 1 mm to separate out sand and stones. The separated-out sand and stones were subsequently grinded into waste powders < 500 µm using a jaw crusher at 200 cpm for 5 minutes, followed by a ball mill at 50 rpm for 180 minutes. On the other hand, the sieved slurry from the vibrating sieve underwent intensive washing in an ultrasonic system with different treatment frequencies (1) 20 kHz for 5 minutes; (2) 25 kHz for 5 minutes; and (3) 30 kHz for 5 minutes facilitated by the addition of 0.08 wt. % of SDMC based on the flowrate of slurry.

The resulting slurries were then subjected to solid-liquid separation using a centrifuge at 3000 rpm for 2 minutes. The wastewater generated from the centrifuge dewatering process was subjected to a series of treatment steps including coagulation, flocculation, sedimentation, MVR evaporation to remove soluble salts, and pH adjustment to 8 with 50% (v/v) H<sub>2</sub>SO<sub>4</sub> in the wastewater treatment system. The treated water was reused as washing water in the slurry making step in the double screw mixer. Separately, moisture content of the washed waste of the centrifuge dewatering process was reduced to 30.4 - 33.1 %. This washed waste together with wastewater filter cake

produced from wastewater treatment, and waste powders < 500 µm produced from crushing and milling was mixed with 24 wt.% coal bottom ash and 7.6 wt. % sodium hydroxide solution based on the total weight of washed waste, wastewater filter cake, and waste powder in a vacuum mixer for 4 minutes at 50 rpm, based on the formulation determined by the processor. Consequently, the resulting mixture possessed a moisture content of 12.4 - 12.9 % and a silica:alumina ratio of 3.5. Following a thorough mixing process, the mixture was poured into alumina brick molds. Before introducing the slurry, a layer of alumina powder was applied to the molds' surface. The filled molds were then subjected to microwave curing at 160 °C for 20 minutes. Following the microwave curing process, the bricks were left to cure under ambient conditions for an additional 7 days.

The untreated freshwater sludge, wet incineration fly ash, coal bottom ash, and brick products were subjected to leaching and analytical tests to verify the treatment efficacy. The employed leaching test method was a batch leaching method that is specified in British Standard EN 12457-1EN12457-1:2022 (British Standards Institution). The leachates were analyzed, as described in Standard Methods for the Examination of Water and Wastewater that is published by the APHA, by ICP-OES for metals and metalloids including arsenic, barium, cadmium, chromium (total), copper, nickel, lead, selenium, and zinc. As shown in Table 6A, the concentrations of all contaminants decreased after treatment with the system and process described herein and the concentrations could meet the Danish WtR standard. Increasing ultrasound frequency reduced leaching of heavy metals.

**Table 6A:** Leaching outcome

| Contaminants     | Danish WtR Standard (Cat. 3) (mg/kg) | Freshwater sludge | Wet incineration fly ash | Coal bottom ash | Ultrasonic washing conditions |                   |                   |
|------------------|--------------------------------------|-------------------|--------------------------|-----------------|-------------------------------|-------------------|-------------------|
|                  |                                      |                   |                          |                 | 20 kHz for 30 min             | 25 kHz for 30 min | 30 kHz for 30 min |
| Arsenic          | 0.1                                  | 0.0076            | ND                       | ND              | ND                            | ND                | ND                |
| Barium           | 8                                    | 0.2966            | 40.2840                  | 0.2812          | 0.1040                        | 0.090             | 0.0032            |
| Cadmium          | 0.08                                 | 0.0082            | 0.4202                   | 0.0867          | ND                            | ND                | ND                |
| Chromium (total) | 1                                    | ND                | 5.9802                   | 0.0729          | 0.0813                        | 0.0652            | 0.0421            |
| Copper           | 4                                    | 0.0075            | 2.1385                   | 0.0353          | 0.0102                        | 0.0072            | 0.0057            |
| Manganese        | 2                                    | 0.7321            | 0.00058                  | 0.0070          | ND                            | ND                | ND                |
| Mercury          | 0.002                                | 0.0001            | ND                       | 0.0094          | ND                            | ND                | ND                |
| Nickel           | 0.14                                 | 0.0008            | ND                       | ND              | ND                            | ND                | ND                |
| Lead             | 0.2                                  | 0.0327            | 309.134                  | ND              | ND                            | ND                | ND                |
| Selenium         | 0.06                                 | ND                | ND                       | 0.0650          | ND                            | ND                | ND                |
| Zinc             | 3                                    | ND                | 21.5912                  | 0.0487          | 0.0234                        | 0.0138            | 0.0096            |

ND: not detectable

Further, the brick products were also tested for its physico-mechanical properties including density according to EN 12390-7:2019, compressive strength according to EN 12390-3:2019, drying shrinkage according to EN 1367-4, thermal conductivity using heat flow meter according to ASTM C518, fire resistance according to ASTM E119, resistance to chemical attack according to ASTM C1202, and ASR using mortar bar method according to ASTM C1260. The physico-mechanical properties of the bricks subjected to different ultrasonic washing conditions were summarized in Table 6B. The ultrasonic washing conditions were found to have negligible influence on physico-mechanical properties of brick products.

**Table 6B:** Physico-mechanical properties

| Properties                    | Ultrasonic washing conditions |                  |                  |
|-------------------------------|-------------------------------|------------------|------------------|
|                               | 20 kHz for 5 min              | 25 kHz for 5 min | 30 kHz for 5 min |
| Compressive strength (MPa)    | 52                            | 56               | 54               |
| Drying shrinkage (%)          | 0.3                           | 0.1              | 0.2              |
| Thermal conductivity (W/m·k)  | 1.2                           | 1.3              | 0.9              |
| Fire resistance (min)         | 90                            | 90               | 90               |
| Resistance to chemical attack | Moderate                      | Moderate         | Moderate         |
| Expansion due to ASR (%)      | 0.04                          | 0.04             | 0.03             |

## CLAIMS

1. A system for processing contaminated soft clay or similar wastes comprising:

- (a) A processor with memory that stores treatment methods for different wastes to meet environmental standards or material utilization standards or both, and adopts artificial intelligence technology to execute instructions for selection of waste treatment methods and setting of equipment and process parameters based on information about solid waste and specific environmental standards or material utilization standards or both;
- (b) A mixer with two mixing axles and a continuous spiraling mixing blade attached to each mixing axle and the mixing axles rotates at 10 rpm to 20 rpm;
- (c) A vibrating sieve with aperture size 0.5 to 1.5 mm and a moisture meter;
- (d) A chamber with a central rotating axle that has mixing propellers extending perpendicularly from the axle, ultrasound generators lining the chamber exterior, and a centrifuge;
- (e) A jaw crusher;
- (f) A ball mill;
- (g) A wastewater treatment system with a mechanical vapor recompression unit;
- (h) A vacuum mixer comprising the following compartments:
  - (i) A vacuum mixing chamber with a single horizontal mixing shaft that has one part with perpendicular mixing blades and another part with single continuous plate attached that surrounds the horizontal mixing shaft in a spiraling fashion, and
  - (ii) A second conical chamber with a single vertical mixing shaft that has a single continuous plate attached that surrounds the vertical mixing shaft in a spiraling fashion;
- (j) Alumina slab molds;
- (k) Alumina brick molds;
- (l) A microwave tunnel curing unit; and
- (m) A slab/brick demolding system with a heat-resistant conveyor belt.

2. A method for processing contaminated soft clay or clay-like wastes using the system of claim 1 such that contaminated soft clay or clay-like wastes undergo steps of:

(a) Soft clay or clay-like waste is characterized by elemental composition, moisture content, and heavy metal content beforehand and all the characterization result information is sent to the processor of claim 1 (a);

(b) Slurry making;

(c) Particle size separation;

(d) Washing with ultrasonication and dewatering by centrifugation;

(d) Size diminution 1;

(f) Size diminution 2;

(g) Wastewater treatment;

(h) Vacuum mixing and extrusion;

(i) Microwave curing; and

(j) Slab/brick demolding.

3. The method for processing contaminated soft clay and clay-like wastes of claim 2 wherein for slurry making of claim 2 (b) contaminated soft clay or clay-like wastes are mixed with water in the mixer of claim 1 (b) at a liquid-to-solid ratio of 2 to 5 and the resulting slurry enters the vibrating sieve of claim 1 (c).

4. The method for processing contaminated soft clay and clay-like wastes of claim 3 wherein the particle size separation of claim 2 (c) separates out sand and stone by vibration, the separated-out sand and stone enter the jaw crusher of claim 1 (e), and the remaining slurry enters the chamber of claim 1 (d).

5. The method for processing contaminated soft clay and clay-like wastes of claim 4 wherein the size diminution 1 of claim 2 (e) and the size diminution 2 of claim 2 (f) take place inside the jaw crusher of claim 1 (e) and ball mill of claim 1 (f), respectively, to transform the sand and stone into powder that is <500  $\mu\text{m}$  in size.

6. The method for processing contaminated soft clay and clay-like wastes of claim 4 wherein for the washing and dewatering step of claim 2 (d) 0.01% to 0.1% on mass basis of sodium dimethyldithiocarbamate is added, the propellers inside the chamber of claim 1 (d) drive the slurry along the chamber, the ultrasound generators of claim 1 (d) emit ultrasound energy at a frequency of 20 to 40 kHz, the processor of claim 1 (a) instructs the centrifuge of claim 1 (d) to rotate at a speed of 3000 to 4000 rpm to separate out water and slurry until 30% to 40% moisture content by total mass of slurry basis is reached with information from the moisture meter of claim 1 (c), the

wastewater generated from the washing goes to the wastewater treatment system unit of claim 1 (g), and the slurry enters the vacuum mixer of claim 1 (h).

7. The method for processing contaminated soft clay and clay-like wastes of claim 6 wherein the wastewater treatment step of claim 2 (g) taking place inside the wastewater treatment unit of claim 1 (g) comprises

- (a) a flocculating or coagulating step using a chemical that is selected from group consisting of aluminum sulfate, ferric chloride, ferric sulfate, ferrous sulfate, polyacrylamide, polyaluminum chloride, polyaluminum chlorosulfate, polyaluminum silicate sulfate, sodium alginates, polyelectrolytes, and combinations thereof; and

- (b) a soluble salts removal step using the mechanical vapor recompression unit;

and the thus treated wastewater is reused as washing water in the slurry making step of claim 2 (a).

8. The method for processing contaminated soft clay and clay-like wastes of claim 6 wherein for the extrusion step of claim 2 (h) inside the vacuum mixer of claim 1 (h), the powder that is <500  $\mu\text{m}$  from size diminution 2 and dry waste powders such as coal fly ash and coal bottom ash are added based on instruction from the processor of claim 1 (a) such that the moisture content of the resulting mixture is <20% by total mass basis and that the silica-to-alumina ratio of the resulting mixture is 3.5 to 4.5.

9. The method for processing contaminated soft clay and clay-like wastes of claim 8 wherein for the extrusion step of claim 2 (h) inside the vacuum mixer of claim 1 (h) pressure of -10 kPa is applied to maintain vacuum and to de-air during mixing, the horizontal mixing shaft of claim 1 (h) (i) mixes the slurry first with perpendicular plates and then pushes the slurry to the vertical mixing shaft of claim 1 (h) (ii) and the vertical mixing shaft pushes the slurry out to the alumina slab molds of claim 1 (j) or alumina brick molds of claim 1 (k).

10. The method for processing contaminated soft clay and clay-like wastes of claim 9 wherein a layer of alumina powder is applied in the alumina slab molds or alumina brick molds before the slurry is pushed into the alumina slab molds or alumina brick molds, optionally up to 50% by weight of lightweight aggregates are added to the alumina slab molds to make lightweight slabs, the alumina slab molds or alumina brick molds holding the slurry go to the microwave tunnel curing unit of claim 1 (l) where for the microwave curing step of claim 2 (i) the curing temperature is 100 to 200°C and the curing duration is 20 to 30 minutes.

11. The method for processing contaminated soft clay and clay-like wastes of claim 10 wherein for the slab/brick demolding step of claim 2 (j) the heat-resistant conveyor belt in the slab/brick demolding system of claim 1 (m) transports empty alumina slab molds or alumina brick molds to receive slurry exiting the vacuum mixer of claim 1 (h), the thus filled alumina slab molds or alumina brick molds move to and through the microwave tunnel curing unit of claim 1 (l), demolding of slab or brick from the respective mold takes place by free fall to another heat-resistant conveyor belt, and an empty alumina slab mold or alumina brick mold is brought to the slurry exiting the vacuum mixer of claim 1 (h) for the next cycle.

12. The method for processing contaminated soft clay and clay-like wastes of claim 11 wherein after the microwave curing step of claim 2 (i) the slab or brick produced undergoes curing for 7 to 14 days in ambient temperature, the resulting products from the alumina slab molds are slabs or lightweight slabs and the resulting products from the alumina brick molds are bricks.