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Climate-Adaptive Environment and Cost-Efficient Ceramics and Concrete-Like Construction Materials from Hazardous Industrial and Municipal Wastes

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raw construction materials
amorphous new formations
high mechanical properties
strong chemical bonding
heavy metals leaching/solubility
environment-friendly ceramic materials
economic efficiency

ABSTRACT

The purpose of this study was to develop new environment clean and economi efficient composites of concrete and ceramics construction materials fror hazardous industrial and municipal wastes. All the raw and the develope materials were analyzed by XRF, XRD, DTA and TGA, SEM, AAS, an LAMMA methods. The ceramics showed very high axial and flexural resistanc and low values of linear shrinkage, water absorption, and bulk density. Th solubility and leaching of heavy metals from the developed composites wit high content (till 75 -100%) of industrial wastes were far below Brazilia standards, which makes them eco-friendly materials. Such properties allow th use of the industrial and municipal wastes for the production of concrete bricks facing tiles, roof tiles, blocks, and bricks with high economic and ecologi efficiency.

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1. Introduction

Through all modern methods of communication, one can see an increase in the awareness of the high contribution of industrial and municipal waste to the increase of the Earth's serious environmental problems.

Billions of tons of different waste contaminate the air, land, surface water and groundwater of every country in the world. Residues from these industries usually contain high levels of heavy metals, such as Ni, Zn, Cr, Sn, Cu, Pb, Sb. About 4000 industries in EU countries produced 150,000 tones/year of galvanic sludge [1]. Infamous technological catastrophes are constant in different scales in different parts of the world, most famous among them as the rupture of the aluminum ore sludge in Hungary (2010) and iron ore in Brazil (2015, 2019). Industrial waste dumps pollute the environment, including groundwater [2,3].studied a number of shallow aquifers in industrial regions polluted by toxic Cr (VI) and spontaneous reduction of dissolved Cr (VI) to insoluble Cr (III). The studies of [4] were the first attempt to apply a combination of electromagnetic measurements and mineralogical investigations to pyrometallurgical heavy metals slags of the Upper Silesia region of Poland. The main part of FS is thrown into the factory industrial dumps [5]. It was studied [6] new ceramic composites from sewage sludge, foundry sand, glass waste, and acid neutralization salts.

They happen frequently and on an increasingly high scale with greater numbers of victims and economic loss [7]. realized that the inclusion of 9% of galvanic sludge affects the thermophysical characteristics, reducing the thermal conductivity and mechanical resistance. It was studied by [8] applicability and viability of galvanic sludge in composites with oil-contaminated diatomite waste and glass waste in red ceramic fabrication.

In order to assist enterprises in addressing their environmental problems the author for more than 60 years developed new methods (compositions and technologies) for more than 100 types of industrial and municipal wastes utilization as raw materials to produce new compositions of construction materials, such as the materials of roads and airports bases, ceramics, municipal and industrial waste dumps, concrete-like and refractory materials, plaster, thermal and sound insulator, new types of fuel with high calorific value, hard core of dams, etc.

As a result of industrial and field tests, conducted in different regions, including Brazil, Spain, and former USSR, methods of the roads base construction were included in the norms of the countries, and are used in industrial level. The author carried out projects for branches of international companies like Renault, Volvo, VALE, BOSCH, Odebrecht, Petrobras in Brazil for the use of hazardous industrial waste to produce new sustainable and economically attractive materials.

2. Research Objectives

1) Assistance to industrial enterprises to solve their environmental problems.
2) Development of new methods with maximum content of industrial and municipal wastes.
3) Development of new methods for the transfer of heavy metals of wastes in practically insoluble environmentally clean new formations, much below of the national standards' demands.
4) Studying of physical and chemical processes of new materials structure formation to enable control of their properties.
5) Development of new or adapt existing technologies of new materials production.
6) Development of materials and technologies of its productions with a very high economic efficiency.

3. Lists of Wastes and of Final Costruction Materials

3.1. List of Developed Construction Materials

Conventional ceramics; 2. Refractory ceramics; 3. New composites of building materials with high strengths (bricks, boards, blocks, etc.) without preliminary drying, without heating and without Portland cement; 4. Bonding materials (Portland or lime cement type) for the production of road bases, airports, municipal and industrial landfill bases, dam core, etc.; 5. Thermal and acoustic insulation; 6. New types of fuel with high calorific value; 7. Compositions with plastics;8. Decorative materials.

3.2. List of Industrial and Municipal Wastes Used as Raw Materials (With Numbers of the Above List of Final Construction Materials)

1) Metallurgical Wastes

All types of ferrous slag as binders (blast-furnace, Martin, converter, electric-steel, etc.) – 1, 2, 3, 4; All types of slags of non-ferrous metallurgy (Ni, Al, Cu, Zn, Pb, etc.); Electric-ark filter dust (EAFD) – 1, 3, 8; Dust of non-ferrous metals (Pb, Ni, Zn, Cr, V, Fe, etc.) – 1, 3, 8; Heavy metal sludge - 1,3,8.

2) Machin Production Wastes

Residues generated from the processes of the automobile industries: alkaline liquids, dust, pastes - 1,2,3; Foundry sands and slags - 1,2,3; Galvanic processes sludge - 1, 2; Acid battery neutralizing salts - 1; Wet and oily rejects of the grinder - 1; Rejected diatomite with high oil contamination and with galvanic slurry -1; Aluminum anodizing slurry - 1, 2, 3; Alkaline liquid aluminum anodizing waste - 1, 2, 3; Slags from the lead recovery process of automotive batteries - 1; Printed circuit manufacturing sludge – 1.

3) Municipal Wastes

Sludge of municipal sanitation stations - 6; Ash of sludge burning of municipal sanitation stations - 3, 4; Sewage sludge of municipal water treatment plant without burning and without.

Portland cement - 1, 3; Sea-water desalination sludge - 1; Sludge dredging of sediments of ports and rivers without burning and without Portland cement - 3; Ashes and slag from municipal wastes incinerators -1, 2, 3; Municipal garbage gasification ashes - 1, 3; Residual sludge from laundries - 1, 3; Tannery rejects - 1, 2; Slurry sludge from municipal landfills - 1, 2; Soil mixed with municipal landfills slurry - 1, 2; Ash of municipal landfill slurry burning - 1, 2, 3.

4) Construction and Demolition Wastes

Lime-producing wastes – 3, 4; Cement plant waste - 3; Construction and demolition debris - 3;

Rejection of production and use of mortars - 3; Concrete waste -3; MDF-3 production sludge; Glass waste (blasting dust, glass shreds, electric glass insulators and others) - 1; Porcelain waste (tableware, porcelain electrical insulators, etc.) -3; Portland cement and asbestos cement tiles (Eternity) - 1, 2, 3.

5) Pulp, Paper and Cardboard Industry Wastes

Cellulose production slurry - 1,3; Ash and Lime sludge from paper production - 1, 3; Sludge of different types of paper ink - 1, 2, 3; Rejected sludge from cardboard production and reuse - 1, 2, 6; Paper production sludge - 3; Toner dust waste – 1.

6) The Ore Mining and Processing Industry Wastes

Residual soils from mine roofs, clayey soils, etc. - 1, 3; Dredging sludge from canals and sea ports-3; Rock waste with high heavy metal content - 1, 2; Rejects of cutting, crushing, sifting and the remains of natural rocks (granite, marble, slate, serpentinite, etc.) - 3; Weathered rocks of mines - 3; Rejects of extraction of minerals (gold, diamonds, etc.) - 3; Mineral pickling soil - 3; Purification sludge from mines with high salt and mineral contents - 1, 3; Sawdust and wood shavings - 6, 7; Cuts and powder of asbestos rocks - 1, 2, 3; Acidic waste from Jarosite -1; "Alkaline red clay" of Bauxite from the Amazon and Spain - 1, 2, 3; Aluminum anodizing slurry - 1, 3; Liquid waste from the of aluminum production (Spain) - 3; Hydrated gypsum waste -3, 8; Phosphorus-gypsum waste -3,8; Fine and ultrafine mineral coal powder - 6; Charcoal powder - 6; Iron ore tailing materials -1, 3; Overburden soils of various fields - 1, 3.

7) Petrochemicals Wastes

Oily waste (as oily sludge) - 6; Liquid alkaline wastes from the petrochemical industry - 3; Rejections of catalysts of petroleum refineries - 1, 2; Oil spilled on soils - 6; Fine refuse of oil shale - 6; Burning ash from spilled oil soils - 1, 3.

8) Energy Production Wastes

ETA and ETE sludge from thermoelectric power plants - 1, 3; Ash of Oily Shale - 1, 3; Mix of ash with poorly burned wood - 6; Ash from wood burning, bituminous shale, coal, etc. - 1, 3; Wastes from the rectification process of metal-mechanical industries - 1; Boiler cleaning carbonates sludge from Thermoelectric Power Plants - 3; Ashes from the gasification processes of organic materials – 6.

9) Chemical Industry Wastes

Sludge from chemical industries: pastes, powders, alkaline liquid effluents - 1, 3; Rejects of rigid polyurethane foam from refrigerators, freezers, etc.- 5; Extrusion of aluminum sulphate - 1, 2; Rejected production of soda ash - 3; Industrial sludge from of different chemical production - 1, 2; Sludge of phosphoric fertilizers and nitrogen production - 3; Detergent production sludge - 3; Sludge for the production of cosmetics and perfumery (shampoos, conditioners, soaps, lipsticks, deodorants, beauty and depilatory creams, toothpastes, sun blockers, skin protectors against insects, etc.) - 3; Ethanol alcohol production catalyst sludge -1.

10) Agrarian Complex

Ash of husks and stems burning (coffee, rice and other cereals, coffee, sugar cane, etc.- 1,2,3; Animal waste after methane emission - 6; Ash after animal wastes incineration - 6; non-certified coffee - 6.

4. Methods of Industrial and Municipal Waste Disposal as Valuable Raw Materials

Most of the above-mentioned wastes were used mainly as principal components of building materials to produce cementless concrete and ceramics.

4.1. Concretes from Industrial and Municipal Wastes

Cementless concretes were developed by homogenization, hydration and compaction of mixtures with wastes that, by their chemical composition, have binding properties - slags from ferrous metallurgy (blast furnace, open hearth, electric steel and converter), ash, waste from limestone firing, etc.

The strength of concrete-type specimens from different clay soils, reinforced with 30% addition of different types of slags, activated with lime production waste 3% addition or 2% Portland cement as binding materials for their use as road and airfield foundations instead of traditional sand and crushed stone layers. The strength gain of concrete-type specimens was determined by uniaxial compression. At the age of 7 days of specimens they reached 3.9 MPa, by 28 days – 5.8 MPa, by 60 days – 10.3 MPa, by 90 days – 12.2 MPa at a rate of 4 MPa, by 1 year – 14.3 and 3 years – 19.6 MPa.

The morphological structures were studied by SEM, applying a Jeol JSM-6360 LV; micro-chemical composition – by EDS with a Jeol JSM-5410 LV. The LAMMA method was used to investigate the isotopic composition of the developed materials (with a LAMMA-1000, model X-ACT). The solubility and lixiviation of heavy metals were determined by AAS method, using a Perkin Elmer 4100 device.

The strengthening of these materials is ascribed to the appearance of new amorphous formations, which transform into a stone-like condition over time. The only new crystal formations, detected over a 3-year-long hardening process, were various crystalline carbonates in such amounts that they cannot be responsible for the materials’ highly significant strength (up to 19,6 MPa) at one year of age. Their long-term properties allow these types of slag to be used as traditional binders, in the preparation of materials for highway, airfield runway, dam and building foundation construction applications. More than 300 km of highways with road base from these materials have shown excellent performance indices in different parts of Russia, including Siberia and Russian North.

4.2. Ceramic Material from Industrial and Municipal Wastes

The author also developed a large number of ceramic building materials with a high content of industrial and municipal wastes. Galvanic processes plants are one of the most widely distributed industries all over the world. Residues from these industries usually contain high levels of heavy metals, such as Ni, Zn, Cr, Sn, Cu, Pb, Sb and therefore they are one of the most hazardous industrial wastes. One of them is given below as an example.

One of the objectives of the present research was also the development of ceramic building materials from hazardous Cr-Zn galvanic sludge (up to 30%), spent foundry sand (25%), glass rejects from metals surface cleaning (20%) and natural red clay (25%) to produce environmentally clean ceramics.

The basic physical properties of the ceramics after sintering at temperatures of 950-1200°C for 1h., such as flexural resistance, water absorption, linear shrinkage and bulk density of the ceramics in the heating temperatures, were also determined. The values of the ceramics flexural resistance strength were obtained in equipment for destructive mechanical tests model EMIC, DL-10.

The ceramics showed very high flexural resistance (up to 22.84 MPa) and low values of linear shrinkage (5.02%), water absorption (3.20%), and bulk density (2.00 g/cm^3). All the raw materials and the developed ceramics were analyzed by XRF, XRD, DTA and TGA, SEM, AAS, and LAMMA.

The solubility and leaching of heavy metals from the developed composites with 75% of industrial wastes were far below Brazilian standards, which makes them eco-friendly materials. Such properties allow the use of the ceramics for the production of facing tiles, roof tiles, blocks, and bricks with high economic efficiency.

5. Conclusions

All types of industrial and municipal wastes are extremely valuable raw materials. Their industrial use could significantly reduce the production costs of the most common building materials with very high economic efficiency. Their industrial recycling would inevitably lead to enormous environmental and planetary benefits due to: 1. A significant reduction in quarrying for traditional natural materials – clay, sand, and crushed stone – and the resulting disruption of our planet's natural connections; 2. An end to the pollution of air, natural soils, surface and groundwater with hazardous industrial and municipal waste; 3. A significant improvement in the quality of life and health of residents in areas where large numbers of industrial and municipal landfills are located; 4. The purification of our planet's atmosphere from dust and gases from industrial and municipal waste landfills, and the inevitable improvement of the Earth's climate; 5. A significant reduction in the cost of building materials by replacing expensive natural materials with industrial and municipal waste.

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Data Availability

Data supporting reported results can be found in the links to publicly archived datasets analyzed.

Conflicts of Interest

The author has no conflict of interest

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