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Geopolymer materials in civil engineering

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Abstract: Geopolymers and alkali-activated materials are cement-free composites formulated by activating alumino-silicate materials, such as fly ash, meta-kaolin, and silica fume, and calcium-rich materials. The Geopolymer Materials Market grew from USD 12.48 billion in 2023 to USD 15.69 billion in 2024. It is expected to continue growing at a CAGR of 29.46%, reaching USD 76.07 billion by 2030. Today we found about 750 patents of USA, China, Japan and other countries. The selected last year patents have emerged on the usage of geopolymeric mortars for 3D printing, grouting, sewage lining, and wastewater treatment.
Keywords: geopolymers, alkali-activated materials, market of geopolymers, patents on geopolymers, application in in civil engineering.

Conventional cement-based composites, such as concrete and mortar, are ranked as the most used construction materials in the world. Concrete and mortar are mainly produced with ordinary Portland cement (OPC), coarse and fine aggregates, water, and additives. The widespread use of OPC by the construction industry is attributed to its impressive performance, affordability, availability, standardization, and compatibility with different types of materials and admixtures. Geopolymers and alkali-activated materials are cement-free composites formulated by activating alumino-silicate materials, such as fly ash, metakaolin, and silica fume, and calcium-rich materials, such as blast furnace slag or ladle slag, respectively, with a sodium, potassium, or carbonate hydroxide-based alkaline solution.

The Geopolymer Materials Market grew from USD 12.48 billion in 2023 to USD 15.69 billion in 2024. It is expected to continue growing at a CAGR of 29.46%, reaching USD 76.07 billion by 2030. The market for geopolymer materials is witnessing substantial growth driven by increased environmental regulations and a shift towards sustainable building practices. Industry-led government initiatives to lower greenhouse gas emissions and enhance the durability of construction materials further influence market growth. The upsurge in urbanization globally, alongside the inherent benefits of geopolymer materials

like reduced energy consumption and lower costs, also propels their demand. However, the high initial production cost and limited awareness about the technology pose significant challenges to market growth. Expanding research focusing on enhancing production methodologies and increasing the availability of raw materials might mitigate these limitations over time.

Companies that invest in research to improve the adaptability of geopolymers across various climates and their resistance to aggressive environments have significant opportunities. Innovation can focus on the development of geopolymer materials with enhanced capabilities such as increased optical properties for photovoltaic applications or higher conductive properties for electronic applications, potentially diversifying the application scope. Additionally, businesses that foster industry academia partnerships for R&D and pilot new applications could gain a competitive edge. The market is currently poised for steady growth, with increasing importance given to sustainable materials, supported by investments in infrastructure development and innovations aimed at reducing environmental impact. The selected last year patents you can see below.

US2025011236 (A1) - GEOPOLYMER PRODUCTION METHOD

A method of producing a geopolymer product having accelerated setting at a selected point in production includes providing a precursor, a reagent, and an accelerator; mixing the precursor and the reagent to form a geopolymerized binder; adding aggregate to the binder; mixing the aggregate and the binder until a mortar or concrete paste is formed; and applying the mortar or concrete paste. The mortar or paste is applied by extruding, casting, spraying, or brushing. The accelerator is added when providing the precursor; mixing the precursor and the reagent; or applying the mortar or concrete paste. The step selected for adding the accelerator is a function of selecting a setting time for the geopolymer product.

US2024417326 (A1) - Carbon-Absorbing Algae Concrete and Method of Production

A carbon-sequestering geopolymer concrete composition and method of manufacture is disclosed. The composition comprises a geopolymeric binder phase of aluminosilicate materials and an alkaline activator, coarse and fine aggregates, dried marine algae powder, and optional supplementary cementitious materials. This enables significantly reduced carbon dioxide emissions during production compared to standard concrete mixes. Additionally, the integrated algae powder facilitates direct capture and mineralization of atmospheric carbon dioxide as the concrete cures. Aspects of embodiments of the invention include the concrete composition; a sidewalk embodiment comprising said concrete; associated sidewalk construction methods; and alternate sidewalk embodiment claims. Compared to conventional concretes, the technology disclosed herein provides over 70% lower CO2 emissions coupled with enhanced carbon mineralization that progresses over the material lifetime. This enables various infrastructure applications to reach carbon-absorbing or carbon-negative performance credentials. The composition also exhibits excellent mechanical strength, freeze-thaw resilience, and extended durability properties.

CN118955026 (A) – Recycled concrete micropowder-slag-based geopolymer cementing material and preparation method thereof

The invention relates to the technical field of solid waste resource recycling and green low-carbon cementing materials, in particular to a recycled concrete micro powder-slag based geopolymer cementing material and a preparation method thereof. The material comprises 50-80 parts of recycled concrete micro powder, 20-50 parts of blast furnace granulated slag, 11-26 parts of an exciting agent, 38-44 parts of a solvent and 12-19 parts of bacillus. The preparation method comprises the following steps: preferentially preparing the exciting agent, then mixing the exciting agent with the recycled concrete micro powder and the blast furnace granulated slag, finally inoculating bacillus, and fully stirring and mixing to form the recycled concrete micro powder-slag based geopolymer cementing

material. The method has the advantages that cement is partially replaced; the economical problems of solid waste resource storage and resource application can be effectively solved; a high-performance material with condensation flow characteristics and mechanical strength characteristics is simple and economical in material taking, rapid and convenient to construct and reliable and stable in curing effect; microorganisms are introduced, so that the impermeability is better improved; the curing effect is good.

CN118930137 (A) - Geopolymer grouting material for rapid recovery of bearing capacity of semi-flexible pavement as well as preparation method and fixed-point repairing process of geopolymer grouting material

The invention discloses a geopolymer grouting material for rapid recovery of bearing capacity of a semi-flexible pavement as well as a preparation method and a fixed-point repairing process of the geopolymer grouting material. The grouting material is at least formed by mixing the following raw materials in parts by weight: fly ash, blast furnace slag, sand, an additive, water and an alkali activator. The preparation method comprises the following steps: uniformly dry-mixing the fly ash and the blast furnace slag to obtain powder; weighing sand, uniformly dry-mixing the powder and the sand to obtain a solid mixture, and pre-weighing water; preparing an alkali activator; adding the waterborne polyurethane emulsion, the water reducing agent, the shrinkage reducing agent, the alkali activator and the remaining water into the solid mixture, and slowly stirring to obtain a gel material; and quickly stirring the cementing material to obtain the concrete. The construction process comprises the following steps: preparing grouting materials; base layer cleaning, drill hole layout, static pressure grouting and grouting pressure control in the construction process are carried out; grouting real-time monitoring in quality control, pavement deflection value measurement and geological radar detection after grouting are completed, and construction area

maintenance; and construction safety management and environmental protection are realized.

US2024352756 (A1) - INNOVATIVE TECHNIQUE TO CONSTRUCT A ROBUST DURABLE SEISMIC PROTECTIVE DEVICE

The invention is an innovative technique to construct a robust durable protection device for structures against dynamic loadings such as earthquakes, wind, or mechanical vibrations. The technique utilizes friction between a sliding material such as PTFE and Cementitious Material (CM) (not metal) to protect structures. The invention controls the surface roughness of the CM by employing a designed mix with small size to no aggregates and cast it in molds with different roughness to produce a friction coefficient ranging from 0.3% to 40%. The CM mix preferably has a ultimate strength higher than 3,000 psi. The CM includes, but is not limited to, polymer concrete, high performance concrete, geopolymer and ultra-high-performance concrete. The resulting sliding material and the specially molded CM can be used in several forms to protect structures against dynamic loading such as dampers or base isolators.

NZ781905 (A) - System and method for making and applying a non-portland cement-based material

Sewer refurbishing and concrete restoration and construction may involve the application of shotcrete, which may be pneumatically projected towards the surface in need of repair or construction. This shotcrete includes materials found in basic concrete, such as, sand, Portland cement, and liquid. Previous methods have attempted to alter the material composition of the shotcrete in order to obtain certain benefits. Accordingly, some approaches have involved the use of geopolymers. However, these materials are often subject to corrosion as a result of the organic material inherent in these products. The present invention provides a system and method for applying a construction material. The method may include mixing blast furnace slag material, geopolymer material, alkali-based powder, and

sand at a batching and mixing device to generate a non-Portland cement-based material. The method may also include transporting the non-Portland cement-based material from the mixing device, through a conduit to a nozzle and combining the transported non-Portland cement-based material with liquid at the nozzle to generate a partially liquefied non-Portland cement-based material. The method may further include pneumatically applying the partially liquefied non-Portland cement-based material to a surface. The construction material includes volcanic rock flour, blast furnace slag, sand and alkali.

CN118754497 (A) - Low-alkali geopolymer concrete composite reinforced emulsion and preparation process thereof

The invention belongs to the technical field of concrete additives, and relates to a low-alkali geopolymer concrete composite reinforced emulsion and a preparation process thereof. The enhanced emulsion is prepared from the following components in parts by weight: 8 to 15 parts of sulfate, 5 to 8 parts of ferric chloride, 30 to 40 parts of polyvinyl alcohol, 5 to 12 parts of sodium thiosulfate, 1 to 5 parts of tertiary compound amine, 5 to 10 parts of alkali metal hydroxide, 3 to 8 parts of magnesium fluosilicate, 5 to 10 parts of fine silicon dioxide aerogel, 0.1 to 0.5 part of carboxymethyl starch ether, 1 to 3 parts of sodium tripolyphosphate, 1 to 5 parts of graphene nanosheet solution and 10 to 20 parts of water. The enhanced emulsion belongs to a weak base liquid additive, is green and environment-friendly, reduces the use amount of strong base, and improves the strength of the concrete in each age; the method has the advantages of good stability, low mixing amount and the like, and solves the alkali efflorescence problem; and the concrete has good adaptability with different cement, water reducing agents and admixtures, and has a wide application prospect in infrastructure construction engineering in China.

CN118703066 (A) - Radiation cooling coating based on solid waste-based geopolymer and preparation method of radiation cooling coating

The invention discloses a preparation method of a radiation cooling coating based on a solid waste-based geopolymer, which comprises the following steps: crushing and grinding waste concrete and fly ash to obtain a solid waste raw material; placing the obtained solid waste raw material in a beaker, sequentially adding water, an alkali activator, a functional filler and a surfactant, and mixing and stirring to obtain radiation cooling slurry; and spraying the obtained radiation cooling slurry on a standard plate by using a high-pressure spray gun, and curing to obtain the radiation cooling coating. The novel geopolymer-based radiation cooling coating is prepared by coupling the fly ash with relatively strong alkali-activated gelling activity and the waste concrete, so that the novel geopolymer-based radiation cooling coating is expected to be applied to reconstruction and upgrading of the outer wall of the existing building to realize the purposes of energy conservation and carbon reduction of the building, and the resource attributes of the waste concrete and the fly ash can be fully exerted; low-carbon, ecological, resource and high-value utilization of the solid waste is promoted, and good environmental benefits and wide market prospects are achieved.

CN118702441 (A) - High-adhesive-property geopolymer recycled concrete and preparation method thereof

The invention discloses geopolymer recycled concrete with high adhesive property and a preparation method thereof, and belongs to the technical field of concrete preparation. The recycled concrete comprises the following raw materials in percentage: 15%-20% of slag powder, 15%-20% of fly ash, 5%-10% of potassium silicate, 1%-5% of sodium hydroxide, 10%-15% of fine aggregate, 20%-25% of coarse aggregate, 0.5%-1% of nano SiO2, 1%-3% of steel fiber, 0.5%-1.5% of a microbial solution, 1%-2% of a composite solution, 0.5%-1.25% of microorganisms and the balance of water. Microorganisms and a solution generated by the microorganisms are used for filling tiny gaps in the concrete, so that the porosity can be reduced, and the compactness of the concrete can be

enhanced. In addition, the microorganisms can accelerate the deposition process of calcium carbonate, and in the process, calcium carbonate has high chemical reaction capacity and can chemically react with aggregate to generate chemical bonds. The chemical bonding not only can strengthen the bonding force between the aggregate and the geopolymer matrix, but also can further improve the contact surface between the aggregate and the geopolymer matrix, so that the bonding property of the concrete is improved.

CN118702440 (A) – High-mechanical-property geopolymer recycled concrete and preparation method thereof

The invention discloses geopolymer recycled concrete with high mechanical property and a preparation method thereof, and belongs to the technical field of concrete production.The preparation method comprises the steps that the surfaces of natural coarse aggregate and recycled coarse aggregate are coated with an interface agent with the thickness of 3 nm, and composite natural coarse aggregate and composite recycled coarse aggregate are formed respectively; the interface agent forms a layer of compact film on the surface of the composite aggregate to effectively fill micropores on the surface of the aggregate, so that the surface of the aggregate is flatter and smoother, and the microstructure of the aggregate is improved. Due to the improvement, micropores and defects in the concrete are remarkably reduced, so that the overall mechanical property of the concrete is greatly enhanced, and the concrete has higher compressive strength and tensile strength and can better meet the requirements of various engineering applications.

US2024327287 (A1) - CARBON-FOOTPRINT-REDUCED CONCRETE SLAB ON GROUND SYSTEM AND METHOD FOR CONSTRUCTING SAME

A concrete slab on ground system includes a first slab portion and a second slab portion. The first slab portion is disposed on a ground substrate and includes geopolymer cement (GC) concrete. The second slab portion is disposed on the first

slab portion and consists of Portland cement (PC) concrete. The first slab portion may be mixed in-situ and left in an unfinished state such that only the top or exposed surface of the second slab portion need be finished.

MX2024008267 (A) - METHOD FOR PRODUCING LIGHTWEIGHT CONCRETE MIXTURES USING LIGHTWEIGHT AGGREGATES.

The invention provides a method for producing lightweight concrete mixtures using lightweight aggregates, comprising an at least two-stage mixing process, where first a suspension mixture comprising the binder composition is prepared by high-speed stirring with a cement or a geopolymer and water and then the suspension mixture is mixed by low-speed stirring with constituents including the lightweight aggregates. The invention also embraces lightweight concretes and lightweight concrete mixtures produced accordingly. Binder composition candidates include, for example: - 60-80 wt% finely ground slag sand cement, 10-60 wt% fly ash - 2-25 wt% alkali metal hydroxides/alkali metal silicates, 75-98 wt% finely ground slag sand - 2-20 wt% alkali metal hydroxides/alkali metal silicates, 60-78 wt% finely ground slag sand - 20-38 wt% fly ash cement, 30-50 kg/m (in the lightweight concrete mixture) microsilica cement, 10-60 wt% rice husk fly ash cement, 1-5 wt% caustic calcined CaO/MgO.

CN118684461 (A) Fly ash-based high-freezing-resistance geopolymer concrete and preparation process thereof

The invention discloses fly ash-based high-freezing-resistance geopolymer concrete and a preparation process thereof, and belongs to the technical field of concrete.The fly ash, furnace slag and desulfurized gypsum serve as raw materials, sodium silicate and cement are adopted to excite the raw materials at the same time, C30-C60 concrete is prepared, and the freezing resistance of the geopolymer concrete is improved. A proper cement mixing amount is adopted, high-activity materials such as fly ash and slag react with sodium hydroxide and water glass under the alkaline condition to form a compact C (A) SH gel structure, the freeze-

thaw cycle durability of the concrete can be effectively enhanced, and particularly in an extreme salt freezing environment, crack generation and expansion are effectively delayed, and the concrete has the advantages of being high in strength, good in durability and good in durability. And the long-term service performance of the material is further improved.

JP2024127258 (A) - GEOPOLYMER CONCRETE

To provide geopolymer concrete that satisfies desired strength and fluidity while suppressing costs.SOLUTION: Geopolymer concrete has a ratio of a volume of a fine aggregate to a mortar volume of 0.30 or more and 0.42 or less, a ratio of a volume of a coarse aggregate contained in a unit volume of geopolymer concrete to the volume when the coarse aggregate is filled to the maximum in the unit volume is 0.40 or more and 0.50 or less, a ratio of a total volume of a volume of water for mixing and a volume of water in an aqueous alkaline activator solution to a volume of fly ash is 0.87 or more and 1.02 or less, and a ratio of the total volume of fly ash, alkaline activator aqueous solution, water for mixing, and high performance water reducer to the entire volume of geopolymer concrete is 0.39 or more and 0.49 or less.

CN118619600 (A) - High-durability recycled aggregate geopolymer concrete and preparation method thereof

The invention belongs to the technical field of concrete preparation, and provides high-durability recycled aggregate geopolymer concrete and a preparation method thereof. The product comprises the following components: 676-747 kg/m < 3 > of a cementing material, 930-940 kg/m < 3 > of coarse aggregate, 620-630 kg/m < 3 > of fine aggregate, 120-150 kg/m < 3 > of water, nano silicon dioxide and steel fibers, the mass ratio of the natural coarse aggregate to the recycled coarse aggregate in the coarse aggregate is (0-100): (0-100); the ratio of the total mass of the nano silicon dioxide and the cementing material to the mass of the nano silicon dioxide is 100: (0-3), and the volume ratio of the steel fibers to the

cementing material is (0-3): 100. On the basis that the utilization rate of the recycled coarse aggregate is increased, the nano silicon dioxide and the steel fibers with specific dosages are selected to be matched with the recycled coarse aggregate, and the obtained concrete has excellent anti-freezing, anti-carbonization and anti-permeation performance.

JP2024119386 (A) - GEOPOLYMER COMPOSITION AND CONCRETE STRUCTURE USING THE SAME

To provide a geopolymer composition capable of achieving a sufficient neutron ray shielding effect without increasing a thickness of concrete, and to provide a concrete structure using the same.SOLUTION: In a geopolymer composition containing an active filler, an alkali surfactant, and an aggregate as raw materials, at least a part of the aggregate is replaced with a boron-containing substance. Therefore, a geopolymer concrete having a sufficient load-bearing capacity as a structure as well as excellent neutron shielding can be produced without any hindrance to strength and solidification caused by mixing boron-containing substances, because the geopolymer is a solidified body that is hardened by the condensation-polymerization reaction between an alkali solution (GP solution) and the active filler and gains strength.

CN118609722 (A) - Modeling method of heterogeneous polymer recycled concrete mesoscopic numerical model

The invention discloses a heterogeneous polymer recycled concrete mesoscopic numerical model modeling method, which comprises the following steps of: establishing an MATLAB-PYTHON-ABAQUS joint simulation interaction platform, writing a cross-correlation variable three-moment quasi-normal transformation algorithm and a mesoscopic modeling program, and establishing a mesoscopic numerical model under the condition that cross-correlation random variable marginal probability density distribution or joint probability density distribution is unknown; and an integrated process of complex

operation and expansion of test data, software interaction and automatic processing of a calculation result is realized. According to the method provided by the invention, the problem that the heterogeneity and randomness of a unit material in space cannot be accurately represented by a traditional homogeneous mesoscopic model is solved, a comprehensive and complete numerical analysis framework is constructed, and the probability failure behavior of geopolymer recycled concrete can be accurately simulated; powerful support is provided for performance analysis and optimization of the geopolymer recycled concrete.

CN118598596 (A) - Repairing method using electrochemically compatible geopolymer concrete for repairing

The invention provides a repairing method using electrochemically compatible geopolymer concrete for repairing, and relates to the technical field of reinforced concrete. Comprising the following steps: mixing fly ash, slag powder and silicon powder, and carrying out dry mixing to obtain a first mixture; a mixed solution is added into the first mixture, the mixed solution comprises potassium silicate water glass, water and an additive, stirring is conducted after the mixed solution is added, and a second mixture is obtained; aggregate and PVA fibers are added into the second mixture to be stirred, and the electrochemically compatible polymer concrete for repairing is obtained; connecting the exposed old steel bars of the to-be-repaired part with the new steel bars for repairing by using stirrups to form an embedded steel bar structure; and the to-be-repaired part is poured with electrochemically compatible geopolymer concrete for repairing, the embedded steel bar structure is covered, and repairing is completed through maintenance. The geopolymer concrete is used for repairing the corroded structure, the macroscopic corrosion effect of steel bars in the new and old concrete can be reduced, and the electrochemical incompatibility and corrosion resistance of the new and old concrete are improved.

CN118598599 (A) - High-performance recycled concrete and preparation method thereof

The invention belongs to the technical field of recycled concrete preparation, and relates to high-performance recycled concrete and a preparation method thereof. The high-performance recycled concrete is prepared from the following raw materials: cement, an admixture, recycled aggregate, a PCA-I type polycarboxylic acid high-performance water reducing agent and a geopolymer additive. The particle size ratio of the recycled fine aggregate is limited, so that the recycled fine aggregate and the recycled coarse aggregate are subjected to gradient grading, and pores of part of the coarse aggregate are filled; the geopolymer admixture is mixed with the admixture, and pores of the coarse aggregate are further filled in the stirring process, so that the mechanical strength of the prepared concrete is improved, and the application field of the recycled concrete is widened.

JP2024097144 (A) - GEOPOLYMER COMPOSITION AND GEOPOLYMER CURED BODY

To provide a geopolymer composition with which it is possible, while minimizing an added quantity of silica fume, to achieve both good fluidity over a long time and high strength development in a cured body thereof in a short time by using a simple method.SOLUTION: Provided is a geopolymer composition comprising an active filler, an aggregate, an activator, a dispersant, and added water, the geopolymer composition being characterized by: not comprising silica fume or comprising less than 1 mass% of silica fume relative to the total mass of the geopolymer composition; the total moisture content of the geopolymer composition being 10-13 mass%; the active filler comprising at least 35 mass% of blast-furnace slag powder relative to the total mass of the active filler and coal ash that has not undergone treatment to meet the standards for fly ash for concrete as defined by JIS A 6201; and the dispersant being a polycondensation product-based

dispersant comprising a polyalkylene glycol monophenyl ether as a partial structure.

SA521421910 (B1) - ADDITIVES FOR GEOPOLYMER CEMENTS

The present disclosure is directed to chemical additives for geopolymer cements that can improve the rheological properties of geopolymer cements. These chemical additives include sulfates and selenates of a specific formula as well as hydroxycarboxylic acid salts of Li, Na, and K including but not limited to glycolic, lactic, citric, mandelic tartaric, and malic acids. The chemical additives for geopolymer cements disclosed herein can facilitate the uniform mixing, increase the time mixtures can be transported, and improve the ability to place and finish concrete and mortars made with the geopolymer cements.

CN118311092 (A) - Real-time non-sampling detection method for moisture content of 3D printing concrete

The invention relates to the technical field of 3D printing concrete. The invention discloses a real-time non-sampling detection method for the moisture content of 3D printing concrete. The real-time non-sampling detection method comprises moisture content chart making and concrete moisture content actual measurement The invention provides a method for obtaining the real-time moisture content of a wet concrete material by measuring and calculating the real-time specific heat capacity of the wet concrete material, and the method is used for accurately measuring local moisture content data of the concrete in real time in the continuous configuration and continuous output process of the concrete and correcting the process state of the 3D printing concrete according to the local moisture content data. The method is suitable for the fly ash-based geopolymer 3D printing material containing fly ash and regenerated micro powder, the process consistency of the material in 3D printing can be greatly improved, the related manufacturing quality is improved, and the rejection rate is reduced.

Today we found about 750 patents of USA, China, Japan and other countries. The patents analysis showed that geopolymer mortar and composite had been assessed in different applications, including heavy metal adsorption, fire resistance, strengthening, 3D printing, repair, and marine coating. In the last five years, more patents have emerged on the usage of geopolymer mortars for 3D printing, grouting, sewage lining, and wastewater treatment.

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