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The Properties and Latest Application of Geopolymers

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Abstract. With unique and favorable performances, geopolymer have attracted extensive attention in recent years. It combines some characteristics of organic polymers,cements and ceramics for its special poly-condensed network structure. This paper introduced the synthesis and performance of geopolymer, and mainly reviewed its application in recent years.We can see that the geopolymer has a great development future in many fields like civil engineering,innovative geopolymer binder, rapidly-repair and dealing with poisonous and radioactive waste material, geopolymer-type coatings, novel ceramic materials and so on. In addition, the existing problems and several suggestions according to personal researches are put forward.

1. Introduction

Geopolymer (GP) is a kind of new cementitious material with high-temperature ceramics, fire-resistant coatings, radioactive and toxic waste encapsulation, medicinal applications and environmental friendliness [1–4]. And the application of geopolymer (GPs) involves many scientific fields: geology, mineralogy, colloid science, physical chemistry, modern inorganic chemistry and other engineering process technologies. In recent years, extensive studies have been done on geopolymerization chemistry, geopolymeric applications as binders and cements [5–7].

There are many literatures about the study of GPs and the reaction mechanism is still controversial, which brought a certain degree of complexity to the late-stage study. Therefore, the preparation, properties and applications of GP are systematically reviewed, and the future research is prospected in this paper.

2. Synthesis and Properties of Geopolymers

2.1. Geopolymers Synthesis

GP materials are usually synthesized using an aluminosilicate raw material and an activating solution which is mainly composed of alkalis of sodium or potassium and waterglass [8]. A GP contains a variety of semicrystalline or amorphous phases and it is a three-dimensional aluminosilicate mineral polymer, futher more, the network structure of GP consists of $Si(OH)_4^-$ and $Al(OH)_4^-$ linked alternately by sharing oxygen [9,10].

In recent years, researchers have done a lot of research on the GP material synthesis for further improving its performance. J.J. Trochez used a spent fluid catalytic cracking catalyst as precursor to prepare GPs, and the study found that increased SiO_2/Al_2O_3 was beneficial to the formation of GPs, but the mechanical strength was reduced [11]. In addition, there are many researches on the preparation process of GPs. Jean Noël Yankwa Djobo studied the effects of different preparation process conditions on the reactivity of volcanic ash [12]. Results showed that the reactivity of volcanic ash in alkaline solution is lower than that of other aluminosilicate, but the reaction activity increases slightly with the increase of concentration and curing temperature. Prinya Chindaprasirt has found that the use of outdoor heat exposure (OHE) for curing polypropylene (PP) fiber-reinforced GP composite can achieve the purpose of saving energy [13]. Solar energy is a sustainable and renewable energy for OHE-curing of GP composites leading to strong bridging properties between the PP fiber and the matrix, and strong composites.

2.2. The Properties of Geopolymers

2.2.1. Environmental friendliness. GPs, an environmental protective silicon aluminate inorganic material, whose products can significantly reduce the carbon footprint in their preparation and application process. And in the nature world, various containing silicon and aluminum oxide can be used to synthesize GP. For instance, GP concrete is a building material with high application potential. It can reduce the amount of CO_2 emissions to a large extent, and the maximum can be 86% lower than that of standard ordinary portland cement [14].

2.2.2. Rapid hardening and high strength. GP has the characteristics of high early strength and fast setting time. In recent years, researchers have done a lot of research on GP owing to its high mechaincal strength. Du revealed that using SiC can obviously enhance the compressive strength of GP composites. When the content of SiC is 10 wt %, the compressive strength of GP composites can reach 155 MPa, which is equivalent to increasing 100% on the basis of unfilled GP [2].

2.2.3. High temperature resistance and heat insulation. The oxidation reaction and decomposition reaction of the GP products between 1000-1200 ℃ are not possible, and they are stable under high temperature. The linear shrinkage at 400 ℃ and 800 ℃ are 0.2% to 1% and 0.2% to 2%, respectively, and the original strength above 60% can be maintained [15]. This shows better mechanical strength at elevated temperature.

2.2.4. Good corrosion resistance and durability. GPs show good stability in acidic solutions and in various organic solvents. In 5 wt.% hydrochloric acid and sulfuric acid solution, the decomposition rate of GP were only 1/13 and 1/12 of it of portland cement, respectively. GP can form compact structure with high strength and excellent impermeability.

2.2.5. Strong interfacial bonding ability. At the interface between the traditional portland cement and the aggregate, the transition zone of calcium hydroxide enrichment and preferred orientation is easy to occur, resulting in weak interfacial bonding force. And for GP, the transition zone does not appear due to the reason that the hydration reaction of calcium silicate does not exist, and the final product is a three-dimensional network of gel, which combined with the aggregate interface.

2.2.6. Immobilizing toxic metal ions. Mallowc and others believe that metal ions are also involved in the formation of GP structures, so that metal ions in the system can be more effectively fixed .

3. The Application of GPs

The excellent properties of GPs determine their broad application and development prospects, and the main applications are as follows.

3.1. Innovative GP Binder and Sustainable Repair Material

Utilization of GP binder has been extensively investigated for its low shrinkage, high early strength, sulfate attack and corrosion, high resistance to thawing and freezing. Used in civil engineering, it can greatly shorten the stripping time, speed up the template operation cycle, and improve the construction speed. One-part GP mixtures is a new type of geopolymeric binders, which can be used to simplify the process of activating GPs in silicate solution. At the temperature of 950 ℃, Peng has performed thermal treatment of low-quality kaolin, and the strength of the corresponding binders is up to 47MP, which could reach comparable strength with two-part mix systems [16]. Nasvi revealed that GP cement is suitable for storage wells under deep down-hole stress conditions and carbon capture owing to its good acid resistance, high mechanical strength, durability and low permeability [17]. GP cement is regarded as potential replacement of portland cement. This is mainly based on the properties and sustainability criteria.

3.2. GP-Type Coatings
The GP can be connected into the network structure of film material through the aluminum tetrahedral and silicon tetrahedral, so as a kind of inorganic coating, with non-toxic environmental protection, low cost, fire proof and water proof etc. Various proportions of β-SiC were used to prepare the GP-type paints by A. Khosravanihaghighi, and the results show that, by increasing the proportion of nano-SiC, the porosity is reduced, and the corrosion resistance and wear resistance are improved [18]. In addition, reflective heat insulation GP coating was synthesized from metakaolin and sodium silicate solutions as main initial raw material, and talcum powder, hollow glass microspheres and sericite powder are added as fillers [19]. The properties of two hybrid type GP concrete composed of alkaline-activated metakaolin and fly ash has been studied by Ana María Aguirre-Guerrero, and it was treated as protective coatings against chloride-induced corrosion in its application [20].

3.3. Novel Ceramic Materials
Compared with the hydrothermal and the sol-gel methods, GP technology provides a new method for the direct synthesis of final structural ceramics. GPs can form a structure comparable to those of high temperature sintered ceramics, and the low temperature GP ceramic is convenient for forming products of various complex shapes and has good overall performance.

3.4. Sealing Materials for Industrial Toxic Waste Residue
Harmful heavy metals can be produced from modern industry, agriculture, disposal of waste and others. GP technology can transform industrial solid waste containing aluminosilicates into useful products thanks to the flexibility and capability to immobilize and stabilize the wastes inside the GP network. Metals such as Co, Cu, Pb, Cd, Ni, Zn, Pd, As, Ra and U can be incorporated in the 3 dimensional GP network decreasing the mobility of the heavy ions through metal hydroxide precipitation, ion substitution or physical encapsulation [21].

3.5. GP Based Self-Cleaning Concrete Materials
Severe air pollution is mainly caused by industrial production, natural disasters, engineering construction and automobile exhaust, etc. Thus building facilities will become dirty when exposed to the pollute air. This problem has forced the industries to develop alternative materials for supporting the sustainable development. GP based self-cleaning concrete material is green alternative for solving the problem owing to their unique properties. And the self-cleaning performance of GP based concrete are studied by introduction of photocatalytic materials such as ZnO and TiO_2 [22].

3.6. GP Biological Materials
GP composite has the advantages of non-toxic, biocompatibility, good drug carrying capacity and sufficient mechanical strength, etc., which can be used as oral drug delivery carrier. Metakaolin-based Na GP has been reported as an appropriate carrier for the powerful synthetic the sedative drug zolpidem and opioid analgesic drug fentanyl [23]. Further more, the ion exchange property of GP has been developed into germicidal material with potential application prospect of water purification, and it has a great application prospect in water-scarce countries.

3.7. The Applications of Other Fields
GPs have a wide variety of applications in other fields owing to its excellent properties. For example, there are some of the following:
- Thermal shock refractories;
- Fire-resistant materials, thermal insulation, foams;

- Environmentally friendly adhesive for wood based panels and modern biotechnology;
- High-tech carbon fiber materials used inside and outside of aircraft;
- Dielectric materials for electronic packaging and molecular sieve catalysts material.

4. Conclusion and Recommendations

GPs have many advantages, such as rich raw materials, simple process, saving resources and energy, and they also have excellent properties of organic polymers, ceramics and cement, so that more and more attention has been paid to them. In this paper, the properties and applications of GP have been comprehensively reviewed. At the same time, with the development of GP research, the sources of sustainable raw materials will be expanded, the performance of GPs will continue to be enhanced, and some new potential applications will be found.

Based on this review, some recommendations on future research can be provided. On the basis of the existing literature review, the future research of GP should be focused on the following aspects. On the one hand, the research time of GPs is relatively short, and many properties required long time monitoring are not clear, such as volume stability, long-term durability and so on. In addition, toughening modification and mechanism of GP should be studied further owing to its brittleness. On the other hand, NaOH and Na_2SiO_3 and other alkaline activator resources are limited, the price is expensive, and may pollute the environment, which affected the popularization and application of this material to some degree.

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