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COMPREHENSIVE INSIGHTS INTO MODERN COMPOSITE BINDERS: TYPES, PRODUCTION BASES, PROPERTIES, AND APPLICATIONS OF PORTLAND CEMENT-BASED COMPOSITES

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A B S T R A C T

This study provides a comprehensive examination of modern composite binders, with a specific focus on Portland cement-based compositions. The research explores the diverse types of composite binders, elucidating their production bases, inherent properties, and versatile applications. Through an in-depth analysis, the study identifies key characteristics that define these composite binders, ranging from their chemical compositions to mechanical properties. The production processes, including raw material selection and manufacturing techniques, are scrutinized to unveil the intricacies of creating these advanced binders. Furthermore, the research sheds light on the specific areas of application where these modern composite binders exhibit superior performance. This includes considerations for construction, infrastructure development, and various industries where the unique properties of Portland cement-based composites find innovative use. The insights garnered from this study contribute to an enhanced understanding of the modern composite binder landscape, offering valuable knowledge for researchers, industry professionals, and practitioners involved in the development and application of advanced construction materials.

K E Y W O R D S

Composite binders, portland cement, construction materials, production processes, material properties, infrastructure development, cement-based composites, advanced binders, manufacturing techniques, mechanical properties, concrete technology, building industry.

Introduction

In the realm of construction materials, the evolution of composite binders has marked a significant stride towards enhancing the performance and versatility of cementitious materials. This introduction initiates an exploration into the multifaceted domain of modern composite binders, with a specific emphasis on those based on Portland cement. As foundational components in construction, these binders play a pivotal role in determining the properties and applications of diverse materials, influencing the quality and sustainability of structures [1,2,3].

The introductory phase delineates the motivation behind delving into this subject, emphasizing the critical need for advanced binders in contemporary construction practices. It sets the stage for an in-depth investigation into the types, production bases, properties, and expansive applications of composite binders, offering a roadmap for understanding their complex composition and potential [4,5].

In a landscape where sustainability, durability, and performance are paramount, comprehending the intricacies of modern composite binders becomes imperative. As such, this exploration seeks to unravel the underlying principles governing their production, assess their diverse properties, and shed light on the innovative applications that propel the construction industry towards a more resilient and environmentally conscious future [6,7,8].

Furthermore, this exploration aims to address the growing demand for sustainable construction practices by examining the role of composite binders, particularly those rooted in Portland cement. The introduction highlights the imperative nature of understanding these binders' types, production processes, and properties as the construction industry endeavours to meet the challenges of the present and future [9,10].

As the global construction landscape evolves, driven by technological advancements and environmental considerations, the utilization of modern composite binders becomes a focal point. This introductory section sets the context for a comprehensive investigation into the intricacies of these binders, considering their potential impact on the efficiency, resilience, and eco-friendliness of construction materials [11,12,13].

By delving into the production bases and properties of Portland cement-based composite binders, this research not only contributes to the academic discourse but also provides practical insights for industry professionals. As we navigate this exploration, the aim is to bridge the gap between theoretical knowledge and real-world applications, fostering a deeper understanding of how modern composite binders can shape the future of construction materials and methodologies [14,15].

Literature Review

Research in the field of composite binders, particularly those based on Portland cement, involves contributions from various scholars, researchers, and institutions. Some notable figures and their contributions include:

Prof. Karen Scrivener:

A renowned materials scientist, Prof. Scrivener has conducted extensive research on cementitious materials, including composite binders. Her work focuses on understanding the microstructure of cement-based materials and developing innovative binders with enhanced properties [16,17].

Prof. Paulo Monteiro:

Prof. Monteiro is recognized for his research in cement chemistry and materials science. His contributions include investigations into the durability of concrete and the development of sustainable composite binders [18,19].

Prof. Gaurav Sant:

Known for his work in sustainable construction materials, Prof. Sant's research explores alternative binders, including those with lower carbon footprints. His contributions aim to reduce the environmental impact of cement-based materials [20,21].

Dr. Victor C. Li:

Dr. Li has conducted research on advanced cement-based materials, emphasizing the use of innovative composite binders for enhanced performance. His work often intersects with the fields of nanotechnology and materials science [22,23].

Dr. Waltraud M. Kriven:
Dr. Kriven has contributed to the understanding of cement chemistry and composite binders. Her research often explores the microstructure and properties of alternative binders, contributing to the broader field of advanced construction materials [24,25].
Contributions to the field include advancements in understanding the chemistry, microstructure, and mechanical properties of composite binders. Researchers have explored alternative materials, production techniques, and sustainable practices to improve performance and reduce the environmental impact of cement-based materials. Their work has implications for the construction industry, offering insights into the development of more durable, efficient, and eco-friendly building materials [26,27,28].
It's recommended to explore academic journals, conference proceedings, and institutional publications for the most current and specific contributions by these and other researchers in the field.
Russian scientists have made significant contributions to the field of materials science and construction materials, including research on composite binders and cement-based materials. Some notable Russian scientists and their contributions include [29,30,31]:
Prof. Viktor K. Ivanov:
Prof. Ivanov is a prominent Russian scientist known for his research in the field of construction materials, specifically cement and concrete technology. His work has contributed to the understanding of the properties and behaviour of cement-based materials under different conditions.
Prof. Vyacheslav R. Lesovik:
Prof. Lesovik has made contributions to the study of composite binders and the development of novel construction materials. His research often explores the mechanical and durability aspects of cement-based composites.
Prof. Irina V. Kuznetsova:
Prof. Kuznetsova is recognized for her work in materials science, with a focus on cementitious materials. Her contributions include investigations into the microstructure of composite binders and the improvement of their properties.
Prof. Sergey Sobolev:
Prof. Sobolev is known for his research on alternative cementitious materials and sustainable construction practices. His work includes studies on the utilization of industrial by-products in composite binders to reduce environmental impact.
Prof. Andrey Pustovgar:
Prof. Pustovgar has conducted research on cement chemistry and the development of advanced construction materials. His contributions extend to the understanding of hydration processes in composite binders [32,33,34,35].
These scientists have played roles in advancing the knowledge of cement-based materials, composite binders, and sustainable construction practices. Their work often involves interdisciplinary approaches, combining expertise in materials science, chemistry, and engineering. Contributions from Russian scientists include insights into the optimization of binder formulations, exploration of alternative materials, and improvements in the mechanical and durability properties of construction materials.

Gypsum-based composite binders

Substances obtained by burning gypsum rocks are considered traditional mineral binders and have been known to mankind for several thousand years. Gypsum binders are widely used not only in plastering but also in the production of bulky construction materials. Natural bedrock (gypsum rocks, anhydrite) and production waste containing calcium sulfate (phosphogypsum, borogypsum, sulfur production waste) are used as raw materials for obtaining binders.

Approximately 35-40 million tons of gypsum binders are produced globally, with 90% of this output utilized in construction projects. The leading countries in gypsum binder production include the USA, France, England, Spain, and Russia.

In Uzbekistan, gypsum binder production is well-established in the Bukhara and Fergana regions. Furthermore, significant efforts are underway in Tashkent, Fergana, and Samarkand regions to utilize production waste for gypsum production.

Production of gypsum binder

The gypsum binder is a powdered mineral substance primarily resulting from the dehydration of aqueous calcium sulphate. Dehydration involves the gradual loss of chemical and physical water within the material, leading to the decomposition of its components.

Gypsum binders are manufactured through three distinct processes:

- Crushing and baking gypsum stone.
- Crushing gypsum stone, subjecting it to a cooking process until it attains a sand-like consistency.
- Crushing gypsum stone, treating it with high-pressure steam, followed by thorough drying.

The cooking of gypsum stone is predominantly carried out in rotary kilns, steam boilers, or autoclaves. A common practical method involves cooking gypsum in pots. Powdered gypsum is placed in a pot, comprising a steel cylinder and an upright guard, where it undergoes the cooking process. Four heating pipes pass through the cauldron's diameter, facilitating the cooking of the raw gypsum. The finished product is then collected in the gypsum collection room through a chute at the boiler's bottom.

Upon heating calcium sulphate, containing two molecules of water, at temperatures ranging from 120-180 °C, its properties transform as water gradually evaporates, leading to dehydration. During this process, gypsum stone loses 1.5 molecules of water and transforms into half a molecule of aqueous gypsum, as represented by the following reaction:

$$CaSO_4 x2H_2O = CaSO_4 x0,5H_2O + 1,5H_2O \qquad (1)$$

The types of baked plaster vary based on the period and temperature of the baking process, resulting in distinct categories:

- Hemihydrate: Formed in a dry environment at temperatures of 120 to 180 °C, typically cooked in rotary kilns and large boilers (brands G-2 to G-7).
- Hemihydrate: Formed in an aqueous environment at temperatures of 80 to 180 °C, commonly cooked in an autoclave (brands G-10 to G-25).

When baked in a dry environment at temperatures exceeding 150 °C, a crystalline hemihydrate with fibrous, cracked surfaces is produced. Gypsum binders used in construction primarily consist of v-hemihydrate, capable of containing up to 1% water by weight. This type exhibits rapid water absorption and hardening properties. Although melding gypsum possesses a well-crystallized structure, the initiation period of the process is slower.

Baking gypsum stone at temperatures ranging from 350 to 800 °C results in the formation of anhydrite

($CaSO_4$). Anhydrite solidifies only when an activator, which enhances solidification, is added to its composition. Activators such as potassium sulphate, sodium sulphate, zinc sulphate, aluminium sulphate (3% by weight), and Portland cement or calcium oxide (5% by weight) are commonly added. During heating, decomposition of calcium sulphate commences when the temperature exceeds 600 °C.

$$CaSO_4 xCaO + SO_2 + 1/2O_2 \tag{2}$$

The resulting substance is called matrix gypsum, which contains calcium oxide from CaSO4. It will have a very high strength and can be more than 19 MPa.

Hydration (hardening) is the process of binding gypsum binders with water. In this case, the semi-molecular aqueous gypsum turns back into two-aqueous gypsum in the crystalline state:

$$CaSO_4 * 0,5H_2O + 1,5H_2O = CaSO_4 + 2H_2O \tag{3}$$

As a result, the crystals of the resulting two-water gypsum collide with each other, due to which its density increases. According to academician AA Baikov's theory, the following physical and chemical processes mainly occur during the hardening of gypsum. The solidification process consists of three stages: dissolution of calcium sulphate, formation of new crystals, and crystal growth.

Gypsum particles turn into a gluey state called gel. As a result, a gypsum paste consisting of very small particles in a colloidal state is formed and begins to crystallize rapidly. Needle-like crystals growing from two hydrous gypsum particles condense and become solid crystals. The formation of a colloidal solution and its crystallization process continue until half-molecular water gypsum turns into full two-molecule water gypsum. The use of gypsum binder is highly dependent on its crystallization rate. Curing gypsum binder is an exothermic (heat release) process.

When the gypsum binder is mixed with water (the gypsum is sprinkled into the water during mixing), a flowable liquid paste is formed. It begins to thicken quickly but is still in a plastic state. This indicates that the gypsum has begun to thicken; the beginning of solidification is the period from the moment of mixing plaster and water to the time when the Vika tool is less than 1 mm under the Vika needle dipped in the plaster paste in the public container; and the end of hardening is the period when the needle of the Vika tool has sunk in only 1 mm.

Table 1. Compressive strength of gypsum binder

Brands of gypsum binders	Strength limit after 2 hours of gypsum rod with dimensions 40x40x160 mm			
	To squeeze		To bend	
	MPa	kgs/cm^2	MPa	kgs/cm^2
G-2	2	20	1.2	12
G-3	3	30	1.8	18
G-4	4	40	2	20
G-5	5	50	2.5	25
G-6	6	60	3	30
G-7	7	70	3.5	35
G-10	10	100	4.5	45
G-13	13	130	5.5	55
G-16	16	160	6	60
G-19	19	190	6.5	65
G-22	22	220	7	70
G-25	25	250	8	80

There are the following types of gypsum binders depending on the curing time (Table 2):

Table 2. Types of gypsum binder

Type depending on the hardness of the binder	Index depending on the duration of hardening	Hardening times, minutes	
		Beginning	The end
Quick hardener	A	2	15
Average hardener	B	6	30
Slow hardener	V	20	not specified

Gypsum binders find extensive applications in various construction materials, including curtain walls, plasterboard (crafted from gypsum and wood shavings), and "dry plaster" boards (plasterboard enclosed between two sheets of paper). Their significance extends to furniture manufacturing, where they play a crucial role in ensuring operational durability.

Moreover, gypsum binders are widely employed for plastering the interiors of building walls, as well as in painting and crafting decorative items. The fire-resistant nature of plaster makes it a preferred material for constructing ventilation devices, elevator cages, and other fireproof structures. The versatility of gypsum binders underscores their importance across a spectrum of construction and design applications.

Conclusions

In conclusion, the production of gypsum binders involves diverse processes and types, each influenced by specific baking conditions. The distinction between hemihydrate formed in dry and aqueous environments, at varying temperatures, results in a range of plaster types, each possessing unique properties.

V-hemihydrate, a crystalline form formed in a dry environment at temperatures above 150 °C, serves as a key component in gypsum binders used in construction. Its rapid water absorption and hardening capabilities make it well-suited for molding applications, despite a slower initiation period in the process.

Furthermore, the transformation of gypsum stone into anhydrite at temperatures between 350 and 800 °C presents an opportunity for enhanced solidification. The addition of activators, such as potassium sulfate, sodium sulfate, zinc sulfate, aluminium sulfate, portland cement, or calcium oxide, influences the solidification properties of anhydrite.

This comprehensive understanding of the various processes and resulting plaster types contributes to the optimization of gypsum binder production. The utilization of specific baking conditions and additives allows for the tailoring of binders to meet diverse construction needs, emphasizing efficiency, durability, and applicability across different contexts.

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