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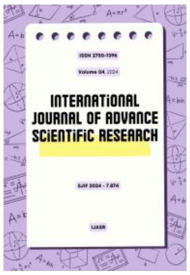

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Research Article

DEVELOPMENT OF ADVANCED COMPOSITIONS INCORPORATING WOLLASTONITE, THERMOVERMICULITE, SILICON IV OXIDE, AND AEROSIL

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ABSTRACT

This study presents the development of innovative composite materials by incorporating wollastonite, thermovermiculite, silicon IV oxide (SiO_2), and aerosil. The primary objective was to formulate high-performance materials with enhanced mechanical, thermal, and structural properties suitable for industrial and construction applications. Wollastonite and thermovermiculite, known for their excellent reinforcing properties, were combined with SiO_2 and aerosil to create a hybrid matrix. The materials were synthesized and characterized using techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM), and thermal gravimetric analysis (TGA). Experimental results revealed that the new compositions exhibited superior heat resistance, improved strength, and enhanced durability compared to traditional materials. The inclusion of aerosil, with its fine particle size and high surface area, contributed to improved dispersion and homogeneity within the matrix, resulting in enhanced thermal stability and mechanical performance. These advanced composites hold great potential for applications in areas requiring robust thermal and structural integrity, including insulation, construction materials, and high-temperature industrial components. Future work will focus on further optimizing these formulations and exploring their use in specialized engineering fields.

KEYWORDS

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Wollastonite, thermovermiculite, silicon IV oxide (SiO_2), aerosil, composite materials, thermal stability, mechanical strength, high-temperature applications, material synthesis, structural integrity.

Introduction

In modern construction and materials science, the development of high-performance cement-based compositions has become a focal point due to their widespread application in infrastructure, industrial, and high-temperature environments. Cement-based materials, including concrete, are valued for their strength, durability, and versatility. However, enhancing their thermal and mechanical properties is essential to meet the growing demands for specialized construction materials that offer improved fire resistance, thermal insulation, and long-term stability.

It is widely recognized that one of the most effective methods to improve the composition, structure, and thermal resistance properties of cement-based materials is through the addition of various additives and fillers. These supplementary materials can significantly modify the physical and chemical properties of the cement matrix, leading to improved performance characteristics. For instance, by carefully selecting additives and fillers based on their chemical composition, porosity, and thermal properties, cement-based compositions can achieve specific mechanical strengths, flexibility, thermal conductivity, and enhanced fire resistance [1].

Fillers such as wollastonite, thermovermiculite, and aerosils offer unique advantages in optimizing cement-based materials. Wollastonite, a calcium silicate mineral, is known for its reinforcing properties and ability to enhance the strength and durability of composite materials [2]. Thermovermiculite, a hydrous silicate mineral, is valued for its thermal stability and low thermal conductivity, making it an excellent choice for improving fire resistance in cement composites [3]. Aerosil, a highly dispersed silica, contributes to the material's homogeneity, reducing the porosity of the cement matrix and improving its overall structural integrity [4,5].

Methods

Based on this, at the initial stage of this research, experiments were conducted to produce various fine fractions of wollastonite, thermovermiculite, and aerosils, which were chosen as the primary fillers for the formulation of new cement-based compositions. These fillers were selected due to their promising potential to improve the physico-mechanical and thermal properties of cement composites, such as strength, flexibility, and fire resistance. The goal of this study is to further explore and optimize the impact of these fillers on cement-based materials, focusing on enhancing their performance under extreme conditions.

In preliminary studies, wollastonite and vermiculite minerals were ground into different dispersed fractions in two stages (Table 1).

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Table 1. Various dispersed fractions of wollastonite and vermiculite minerals

No Fraction / Mineral	1	2	3	4	5	6
Wollastonite	3.0-4.0 мм	0.50-1.0 мм	0.5-0.25 мм	3.5-4.0 мкм	0.50-1.5 мкм	smaller than 0.16 µm
Vermiculite	3.0-4.0 mm	0.50-1.0 mm	0.5-0.25 mm	3.5-4.0 µm	0.50-1.5 µm	smaller than 0.16 µm

Based on the results of the step-by-step grinding processes, the technological stages of separating wollastonite and thermovermiculite minerals into fractions of the required fineness were developed (Fig. 1).

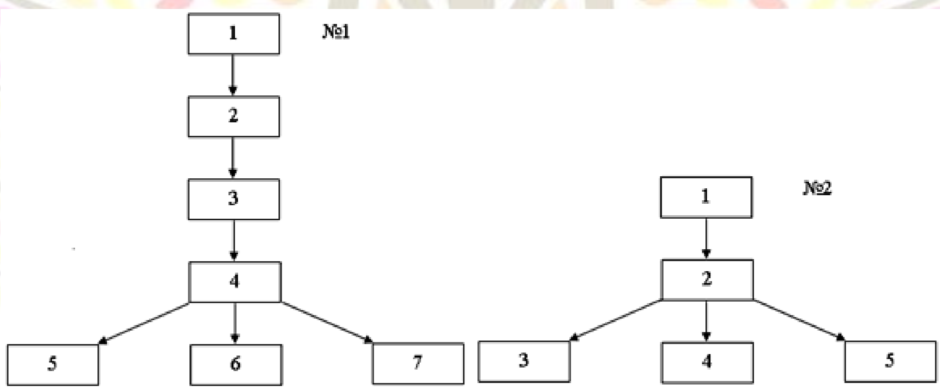

Figure 1. #1 - technological stages of grinding wollastonite and vermiculite minerals #2 - scheme of dividing crushed minerals into 3 fractions according to the level of fineness.

The block diagram No. 1 shown in the picture consists of the following elements: 1 - a warehouse for minerals (wollastonite and vermiculite), 2 - a bunker for minerals, 3 - a mill, 4 - a vibrating sieve, 5, 6 and 7 - crushed finished product. At this stage, block #1 was divided into relatively coarse fractions - according to the diagram. These are fractions with grain sizes of 5 – (0.5-0.25) mm, 6 – (0.50-1.0) mm and 7 – (0.5-0.25) mm.

In Phase 2 of these experiments:

As a result of practical research work, a full cycle of technological processes for obtaining effective multifunctional new compositions based on wollastonite, vermiculite minerals and aerosil nanoparticles was developed.

The technology of obtaining these contents includes several stages. In the first stage of the process, the vermiculite concentrate was ground

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in a traditional mechanical way (block diagram 1) and divided into fractions (block diagram 2),

Results and Discussion

Based on the above, in this research work, compositions were developed by adding different fractions of wollastonite mineral to cement binder concrete compositions.

Table 2. Compositions based on highly dispersed wollastonite mineral and aerosil nanoparticles (mass ratios)

Substance and materials / No. Contents	Cement	Gravel	Sand	Wollastonite	Aerosil
№1	1.43	4.75	1.60	0.10	0.10
№2	1.43	4.75	1.60	0.10	0.30
№3	1.43	4.75	1.60	0.10	0.50
№4	1.43	4.75	1.60	0.10	1.00
№5	1.43	4.75	1.60	0.10	3.00
№6	1.43	4.75	1.60	0.10	5.00
№7	1.43	4.75	1.60	0.10	10.00

Table 3. Highly dispersed wollastonite mineral and aerosil nanoparticle compositions (mass ratios)

Substance and materials / No. Contents	Cement	Gravel	Sand	Wollastonite	Aerosil
№1	1.43	4.75	1.60	0.10	0.10
№2	1.43	4.75	1.60	0.15	0.10
№3	1.43	4.75	1.60	0.20	0.10
№4	1.43	4.75	1.60	0.25	0.10
№5	1.43	4.75	1.60	0.5	0.10
№6	1.43	4.75	1.60	1.0	0.10
№7	1.43	4.75	1.60	1.5	0.10

Based on this, concrete samples were taken for testing by adding crushed fractions of wollastonite mineral.

Conclusions

This research has demonstrated the potential for developing advanced cement-based compositions by incorporating wollastonite, thermovermiculite, and aerosil as key additives and fillers. Through a series of experiments, it was confirmed that these materials significantly enhance the physico-mechanical, thermal, and fire resistance properties of cement composites. Wollastonite contributed to improved mechanical strength and durability, while thermovermiculite provided superior thermal stability and fire resistance. Aerosil played a crucial role in reducing the porosity of the cement matrix, ensuring better homogeneity and structural integrity.

The results suggest that the combination of these fillers allows for the formulation of cement-based materials with tailored properties, making them suitable for use in high-temperature environments and applications requiring enhanced fire protection and durability. Future research should focus on further optimizing the ratios of these additives to achieve even greater performance outcomes, as well as exploring their application in specific engineering fields, such as fireproof construction materials and thermal insulation systems.

In conclusion, the incorporation of wollastonite, thermovermiculite, and aerosil into cement-based compositions presents a promising avenue for creating high-performance materials with specialized properties, paving the way for innovations in construction technology and material science.

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