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Modern approach to the addition of organomineral additives to increase cement brand. A review.

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ABSTRACT

Currently, scientists are researching producing high-quality cement at the expense of various mineral additives without increasing the volume of clinker production. In this article mainly to increase the cement brand, improve the physical-mechanical properties of concrete and increase its strength, study and select the sources of raw materials, which are mineral and watch waste products with pozzolanic properties, as a result of physical-mechanical and chemical processing of raw materials. Also,cement attention is being paid to various studies on increasing the strength of mixtures, resistance to aggressive factors and reducing the cost of cement. To increase the amount of cement required for the construction industry and reduce the cost of clinker production, using various mineral additives. Method is one of the solutions to solve the problems in the construction industry. Also, in this article, the importance of various minerals added to cement was explained in more detail.

1. Introduction

1.1. The importance of mineral additives in the production of Portland cement

Mineral additives into cement significantly alters the characteristics of concrete. Common mineral admixtures include fly ash, microsilica, rice husk ash, ground granulated blast furnace slag, palm oil fuel ash, zeolite, and metakaolin. The effects of these mineral additives on cement vary, particularly concerning the bending and compressive strength of the resulting concrete samples. Additionally, using these additives leads to a reduction in cement consumption, which not only enhances the concrete's properties but also lowers the amount of carbon dioxide emitted during cement production [1,2].

Concrete products have become one of the most widely used building materials globally. However, the declining quality of limestone—the primary raw material for cement production—poses a significant challenge. This issue has driven scientists to explore the use of various mineral additives to decrease cement consumption. Consequently, these efforts lead to more efficient use of raw materials, a reduction in CO_2 emissions, and a positive impact on environmental sustainability. Additionally, the demand for high-quality cement products in modern concrete structures continues to rise.

The novelty of this article from other analytical articles is that in this article, not only the types of additives added to cement and their effects, but also the conditions, temperatures, different mole and mass ratios of the different minerals added, and the results of their effects in different physical It is explained by the fact that learning with the help of chemical analysis is important.

By replacing cement with mineral additives in various combinations, they study the resistance of SEM II/A-I 32.5 N brand cement to bending, compression and aggressive factors. As mineral additives, microsilica, fly

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ash, and combinations of metakaolin and GGBS were replaced with 15% cement, and the strength and durability of cement was studied. As a result, disposal problems have also been solved. Because almost all of these mineral additives are industrial waste products. Due to these additives, the properties of new concrete have increased compared to traditional concrete, its mechanical strength and resistance to aggressive factors. [3,4].

Microsilica is one of the additional materials with high pozzolanic properties among the mineral additives used today. Microsilica has been used as an additive for concrete since the mid-1970s in many countries of the world. The use of microsilica for concrete includes high strength, high chemical resistance, resistance to chloride and sulfate ions. With an increase in concrete strength, the additive has a significant effect on the reduction of portland cement consumption at the expense of microsilica and allows the use of high mixing levels of cement with other additives such as metallurgical slurry, fly ash. It also reduces the energy used for cement production and the harmful gases released into the atmosphere. The resulting high strength is distinguished by its high strength and resistance to external influences compared to ordinary portland cement [5,6].

In the production of microsilica ferrosilicon, as a result of heating quartz at a temperature of up to 2000ºC, vapors of Si and SiO_2 are formed. In this case, SiO_2 condenses in the form of amorphous silicon oxide at low temperature. In order to improve the quality of the obtained microsilica and reduce its contamination, high grade (96.06%) amorphous silicon was obtained by washing in alkali and precipitation in acid [7,8]. The addition of microsilica to concrete products, which is separated as a by-product in the production of ferrosilicon, changes its properties.

In this study, the authors used microsilica (3, 6, 8, and 10%) and fly ash (10, 15, 20, and 25%) in proportions of cement mass in order to reduce the consumption of cement in the construction industry and improve its quality. The water/cement ratio (w/s) in all samples was added in the amount of 0.42. The obtained results showed that the concrete's strength and resistance to external factors increased. Crack intensity of concrete samples decreased. They mentioned that the ideal ratio of added microsilica, which is a by-product, to the mass of cement is 8%. In the second sample obtained, fly ash added as an additive did not significantly affect the cracking intensity of the cement sample, but it helped to increase the strength of concrete [9].

This paper examines the interface zones in concrete samples that incorporate varying amounts of cement and microsilica as admixtures, comparing their effects. Weak interface zones are inherent in all cement-based products, particularly within the filler and cement-cement composites. Cracks typically propagate along these weak zones, leading to a gradual reduction in strength due to external factors. The inclusion of silica fume as a mineral additive in the mix has notably altered the microstructure of these interface zones, thereby enhancing the physical and mechanical properties of the cement composite[10]. To ensure the long-term performance of cement composites, it is crucial to achieve maximum density in the interface zone. The strength of high-strength silica fume concretes is often linked to a lower water-to-cement (w/c) ratio and improved pore structure. Research on concretes and pastes with and without silica fume shows that the enhanced density of the transition zone significantly contributes to the overall strength, nearly as much as the reduction in the w/c ratio. This effect underscores the impact of silica fume on the microstructure of new concrete[11]. Another research study highlighted the unique physical and chemical properties of silica fume, which enhance the compressive strength and water resistance of cement stone. In this study, silica fume was used as a partial replacement for cement, with replacement levels of 0%, 10%, 20%, and 25% by mass. A total of 120 cement cubes, each measuring 50 × 50 × 50 mm, were cast using steel molds. Two water-cement ratios (w/c) of 0.4 and 0.5 were employed to evaluate water resistance. The water resistance and strength of the samples were assessed after being immersed in water for 3, 7, 28, 45, and 90 days. After 90 days of curing, the samples with a w/c ratio of 0.4 exhibited the highest compressive strength and the lowest moisture loss upon drying. The study concluded that silica fume demonstrates high pozzolanic activity and excellent water resistance.

Addition of metakaolin leads to faster development of strength of concrete at an early age. The use of additional cementitious material such as metakaolin concrete can compensate for environmental, technical and economic problems arising from cement production. According to the authors, the addition of metakaolin (MK) as a mineral additive to concrete increases the strength of concrete and its resistance to chloride ions. In this case, the water/cement ratio and the metakaolin to be added to the cement were taken as appropriate for the preparation of the cement mixture. Different water-cement metakaolin ratios (w/cm) of 0.32, 0.35, 0.4 and 0.5 were studied. held for The proportion of metakaolin was varied from 0 to 15% in 5% increments, and 3 to 90 days were considered in determining the properties of concrete, and experiments were conducted accordingly. The effects of the above mentioned parameters on various properties of concrete such as workability, compressive strength, chloride permeability, pH level of concrete and penetration depth of chloride ions were studied. Compared with metakaolin added concrete, MK concrete is compared with conventional concrete. compared to From the results, it can be seen that MK showed more strength for high w/cm ratios of concrete (0.4 and 0.5) and its chloride ion penetration resistance was similar for all w/cm ratios and MK was optimal who mentioned that the amount was significant in the amount of 10%, 15% [12].

A hybrid support vector regression model was developed by Gilan et al. to predict the strength of concrete with metakaolin addition and the penetration distance of chloride ions [12]. The obtained results showed that the hybrid model was able to predict the strength characteristics of the samples with a high level of accuracy.

2. Natural zeolite

Natural zeolite, known since ancient times and found in volcanic sedimentary rocks, has a variety of modern applications. In the construction industry, natural zeolite is utilized as an additive in cement and concrete due to its pozzolanic properties. When up to 30% of zeolite is added relative to the cement mass, the strength of the samples increases after 28 days, thanks to zeolite's pozzolanic activity. This study, grounded in experimental analysis, explores how adding zeolite as a supplementary material can enhance the properties of cement. Scanning electron microscope (SEM) analysis of the samples revealed that zeolite alters the microstructure of the cement stone by filling micropores and reducing calcium hydroxide (CH) content. Furthermore, cemented sand mixtures containing 20%, 40%, and 60% zeolite, with a base composition of 93% sand and 7% cement, demonstrated an increase in strength by 1.28 to 2.09 times when tested at 14 and 28 days, particularly in samples with 40% zeolite. The authors note that natural zeolite, rich in SiO_2 and Al_2O_3, is widely used as an additive in cement production, especially in countries like China. Similar to other pozzolanic materials, such as microsilica and fly ash, zeolite plays a critical role in enhancing the strength of concrete products through the pozzolanic reaction with CH. This characteristic has made zeolite a subject of significant interest compared to other pozzolanic additives. The study concludes that the strength of cement paste with zeolite increases due to the pozzolanic reaction and the reduction of micropores.

The obtained results were compared with the results of cement samples with added microsilica and fly ash. According to this, it was concluded that natural zeolite mineral has pozzolanic reactivity like microsilica and fly ash. It reduces the concentration of CH in the cement paste mainly by ion exchange. Thus, the reaction between alkali ions due to the alkali aggregate in the solution in the fine pores of the cement paste also decreases, so the expansion is slowed down due to the reaction of the alkaline aggregate. Generally, cement paste with low water-cement ratio has high strength. When the water-cement ratio is high, the zeolite, which is added, has a high ability to react in the cement paste with a reduced mass. [15,16].

Several studies have analyzed the pore structure and interactive transition zones in concretes containing slag, microsilica, and metakaolin. Experimental results indicate that these mineral additives positively influence the improvement of interactive transition zones by reducing concrete porosity. The microstructural effects of these additives are significant, particularly in the development of compressive strength, which is closely linked to their impact on pore structure and the evolution of the interactive transition zones. The incorporation of metakaolin (MK) as a mineral additive in cement and concrete has been shown to yield favorable outcomes. The properties of cement mixtures and mortars containing MK were investigated based on key chemical parameters of cement, identified as potential activators of MK. The study compared the rheological properties during the initial consolidation process and the development of compressive strength by varying the total sulfate content in the cement, the type of added calcium sulfate, and the free lime content (in the form of portlandite). The findings suggest a balance in strength development depending on sulfate content and type, with a minor addition of portlandite enhancing the stability of the observed properties.

In another scientific study conducted by Liu W and colleagues, the resistance of concrete samples containing microsilica and fly ash to sulfate and acetic acid exposure was evaluated. Specifically, the study examined concrete samples with 10% microsilica and 12% fly ash, subjected to 5% sulfate and 5% acetic acid solutions for 28 days. The resistance of these samples was assessed using XRD and SEM analysis.

The results show that the strength of concrete samples with S10 F12 addition was 29.6%, 40.5% and 28.4% higher at 7, 28 and 56 days, respectively [19].

3. Methods of activation of organomineral additives.

The main task of reducing environmental problems and fuel consumption caused by production is to create a resource-efficient system of disposal and utilization of industrial waste and secondary raw materials, mainly for the production of construction materials and other types of various products. In this study, a group of scientists studied the methods of activating microsilica, a waste product of ferroalloy production, and its use to increase the strength of cement, especially for heavy concrete structures [20]. In 2010, a group of scientists from Mexico studied the activation of metakaolin and damno furnace slurry in an alkaline environment and the statistics of the increase in concrete strength as a result. In this case, the proportions of metakaolin and damno furnace silage (100/0, 80/20, 50/50, 20/80 and 0/100) and sodium silicate solution (5%, 10% and 15%) were taken and the strength of the samples was checked for 365 days. according to 50% addition of metakaolin to blast furnace slurry reduces the strength [21,22]. The effect of metakaolin activated in an alkaline environment on the properties of the product on the direct binder was studied. A JAF calorimeter was used for the synthesis of the reaction of olin kaolin with NaOH solutions. It is said that it is appropriate to change the concentration of NaOH solution from 12 to 18 M [23].

In another scientific study, the effect of adding sodium sulfate and microsilica to cement on the formation of stratlingite and hydrogarnet crystals was studied. The mechanism of statlingite formation is approximately CAH10 or C2AH8 due to dissolved silicon oxides. The presence of sodium ions accelerates the dissolution of silicon oxides necessary for the formation of stratlingite [24]. Russian scientists studied the effect of thermally modified peat on concrete strength. Peat was activated by heat treatment at 600ºC, and when 4 and 8% was added to the cement mass, the fluidity of the mixture, waterproofing and strength of the 21-day samples were studied. It was found that the bending strength of the concrete sample with 8% activated peat was 23% higher than the 9% compressive strength [25]. Three factors were taken into account in the alkaline activation of slag and microsilica:

1. Increasing the mixing time improves mechanical properties.
2. Depending on the amount of water, the concentration of the activator accelerates the hydration process and increases mechanical properties by reducing porosity.

When mixing 3-Shlar and microsilica in a ratio of 1:1, a great effect on the mechanical properties is given [26]. According to the authors, mechanically activated fly ash-added cement samples actively participate in the hydration process compared to non-mechanically activated fly ash-added cement samples. It was noted that mechanically activated fly ash contributes to the growth of CSH in the cement mixture and increases the rate of pozzolanic reaction [27]. Other scientific researchers have activated fly ash by physical, thermal and chemical methods and added 10%, 20%, 30% and 40% to the mass of cement, increasing the corrosion resistance and strength of concrete. In physical activation, fly ash was first sieved in sieves and ground in a ball mill to 40 and 90 μm size. In thermal activation, crushed fly ash is heated to 900-1000 °C to release carbon, sulfur and other substances. Finely ground fly ash was chemically activated by adding sodium hydroxide solution, filtered and dried. In addition, during the preparation of the mixture, 5% of calcium oxide was added to the mass of cement. According to the obtained results, the corrosion resistance and strength of concrete with 30% activated fly ash was more effective than others [28]. A new method of fly ash activation is presented with the addition of $Ca(OH)_2$ and a small amount of another method of fly ash activation. The activity of fly ash activated by this method is high, which ensures early hydration of cement. According to the authors, the amount of active groups increases, calcium silicate hydrates with a low Ca/Si ratio, as well as calcium aluminate hydrates are formed, and the ability to absorb CaO increases. At the same time, it increases early hydration of cement and puzalan activity. Addition of 5% to 10% active fly ash ensures higher cement strength in 1 day. Therefore, the combined use of activated fly ash and fly ash as cement additives leads to high results [29].

4. Effectiveness of active mineral additives and superplasticizers added to Portland cement

In another scientific study, the addition of graphene oxide and polycarboxylate superplasticizer to the cement mass increased the corrosion resistance of steels to improve concrete strength [30]. Metakaolin (30; 40 and 51%) by weight was added to portland cement and its hydration, strength and water demand were studied based on the amount of PCE superplasticizer. In this case, when the cement metakaolin ratio of cement composite is 70:30, a high result was obtained with the participation of PCE superplasticizer. According to the results of the experiment, the increase in the amount of metakaolin increases the pouzalon and the compressive strength of the 14-day sample, but it does not change significantly at 28 days. In addition, it increases the demand for water, which increases the consumption of superplasticizer. In such a composite, the water demand of cements and PCE superplasticizer dosage are closely related to metakaolin content and fineness of particles. PCE superplasticizer dosages generally increase with increasing metakaolin content in calcined clay blended cement [31,32,33].

5. Effect of active mineral additives on portland cement hydration.

The high demand for energy in the cement production industry and the high carbon dioxide emission, which is a global problem, are urgent issues. At the same time, the strength of cement is important in the resumption of its hydration process. The progress of research on the mechanism of cement hydration has been reviewed since the work of Le Chatelier and Michaelis at the end of the 19th century. Many years of research have shown that inhibition of portlandite crystal growth by silicate ions is an important factor and may provide a mechanism for the formation of calcium silicate hydrate (C-S-H) crystals, supporting theories that suggest that C-S-H and portlandite grow from the same nuclei. Therefore, reducing the consumption of ordinary portland cement and increasing the hydration of cement by adding active mineral additives with puzalan properties is an important issue today. The authors studied the effect of partial replacement with blast furnace slag and microsilica to overcome this problem. The study used 10% damno mortar and 0-16% microsilica relative to 0.42 water cement mass. To study the effect of these mineral additives, the compressive strength of all cement samples was studied at 3, 7, 28 and 56 days. According to the results of the analysis, it is said that the addition of 10% of blast furnace slag and 12% of microsilica compared to the mass of cement gives a positive result in terms of its strength, microstructure of concrete and the high concentration of CSH crystals as a result of pouzalon reaction [34,35].

The use of microsilica, which is a by-product of the ferrosilicon and silicon production industry, as an additive to cement is economically and ecologically highly effective. Temperature dependence of water-cement ratio and strength of cement with microsilica addition was studied. According to the obtained results, the strength of the concrete sample containing 6% and 10% microsilica at 600ºC was reduced by 6.7 and 14.1% compared to normal concrete. does not glaze, causes a decrease in compressive strength at temperatures above 300 ºC. Microsilica water/cement and the optimal dosage of 6% and 0.35 gives a positive result [36,37]. The presence of microsilica in the cement causes a decrease in aggregate and weak zones in the cement matrix. It turns out that the higher the concentration of silicon, the smaller the interphase transition zones. According to the authors, cracks in concrete propagate through these interphase transition zones. It gives a conclusion on the influence of short-term and long-term characteristics of concrete strength in these zones over the years. A weak interphase transition zone can seriously affect the physico-mechanical properties of concrete, water and harmful ions easily penetrate into concrete, as a result, it has a negative effect on concrete strength. Therefore, for the long-term performance of concrete, the interfacial zone should be as dense as possible and have a strong connection between the aggregate and the cement matrix [38,39]. According to Dale P.B. and his co-authors, the interphase transition zones in the concrete composite play an important role in concrete strength. microstructure is significantly different. It is concluded that the weakness of interphase transition zones ensures the strength of concrete [40].

High strength of concrete depends on products formed as a result of cement hydration. The effectiveness of the pouzalon reaction in cement hydration depends on the amount of microsilica. The addition of microsilica in the appropriate amount improves the microstructure of cement paste, because compared to ordinary cement, it leads to an increase in the amount of CSH crystals and a decrease in the amount of $Ca(OH)_2$ due to the pozzolanic reaction. The size of microsilica particles affects cement hydration depending on the alkalinity environment and the amount of replacement with cement [41].

The addition of excess microsilica to the cement mass causes SiO_2 to form a filler in the cement paste, because the amount of $Ca(OH)_2$, which reacts pozzolanally with SiO_2, is reduced. This causes the strength of cement to decrease. According to the authors [42], early hydration of cement paste containing active mineral additives depends on the activity of mineral additives and water/cement ratio of 0.45, cement consisting of 90% and 10% mineral additives. it goes normally. The rate of crystallization of the CSH phase on the surface of the cement grains depends on the amount of active mineral additives added to the cement composition. [43] Fine particles added to cement accelerate the rate of hydration for hydrate growth. An increase in the surface area of mineral additives increases the number of active centers for the formation of CSH crystals, and as a result, has a positive effect on cement hydration and mechanical properties. Compared to the control sample, the strength of cement with fine particle mineral added is higher. The effect of microsilica on the mechanism of hydration and kinetics of the cement mixture obtained by adding microsilica to Portland cement (20ºC W/S=0.5) was studied. In this, the authors quantitatively determined the calcium hydroxide (CH) formed as a result of hydration and calculated the percentage of hydration.

In ordinary portland cement, the formation of CH takes 8-10 hours after the start of hydration. In the conducted research, the addition of microsilica, which is more than 8% compared to the mass of cement, causes an acceleration of the hydration of the cement mixture. Pouzalon reaction of microsilica and CH formed as a result of initial hydration occurs after three days of hydration [44]. In a study conducted by a group of scientists, the compressive strength of cement mixtures with microsilica and the characteristics of the interphase transition zone in a hardened cement sample were studied. According to the authors, microsilica can significantly increase the hydration of the cement mixture and improve the interfacial bond strength between the cement mixture and the aggregate. The amount of calcium hydroxide in the interphase transition zones is reduced by adding microsilica [45]. In the hydration of ordinary portland cement with microsilica, 100 ml of deionized water was added to the cement mixture with microsilica content of 0, 5, 10, 15 and 20% and mixed for 7 days. The filtered solution was analyzed for pH, silicon and calcium ions. In this case, the main part of calcium hydroxide formed during cement hydration reacted with microsilica in 7 days. According to the results of X-ray diffraction and SEM analysis, the amount of $Ca(OH)_2$ decreased due to the reaction with microsilica. They concluded that the optimal addition amount of microsilica is 20%. [46]. According to another group of scientists, a large amount of amorphous SiO_2 reacts with calcium hydroxide (CH), a product of the initial hydration of Portland cement. At the same time, due to the small size of the particles, microsilica fills the spaces between cement grains, which increases strength and reduces permeability. Due to the pouzalon reaction of microsilica with CH, it increases the strength of the cement mixture and, as a result, significantly densifies the interface transition zone and reduces water accumulation [47].

A number of scientific works have been carried out on the mixing of nanoparticles in cement-based materials. When studying the properties of the cement mixture with nano SiO_2, the pouzalon reaction of amorphous silicon with $Ca(OH)_2$ formed as a result of the initial hydration of cement was determined. In this case, the speed of the pulsar reaction depends on the surface area of the reacting particle. Therefore, it is advisable to use nano SiO_2 particles to obtain concrete with high strength. According to the conducted experiments, the strength of 7- and 28-day samples of cement mixture with nano SiO_2 is higher than micromagnesium, but it is more expensive than microsilica. At the same time, nano SiO_2 is used as a filler and pozzolanic reaction activator to improve the microstructure. Based on the obtained results [48], the authors concluded that it is effective to add Nano SiO_2 particles to cement mixtures to increase the strength of concrete.

A group of scientists tested local kaolinite from the Tabarka region of Tunisia as a pozzolanic material. Thermal treatment was carried out as a means of mineral activation. Phase identification before and after heat treatment was investigated by X-ray diffraction and differential thermal analysis / thermogravimetric analysis (DTA / TGA). In this study, the pozzolanic ability of native kaolinite clay, calcination temperature, fineness of calcined clay and its percentage in cement are investigated to optimize the properties of blended cement using Box-Behnken experimental methodology. Finally, a blended cement composition was developed, which achieves optimal results at a calcination temperature of 700°C and a Blaine fineness of 7700 cm 2 /g in 30% calcined clay soil [49]. Addition of metakaolin to Portland cement (PC) can increase chloride binding but decrease carbonation. Durability issues with this added effect remain unclear, but chloride intrusion and carbonation may occur simultaneously. This study investigated the effect of carbonation on chloride resistance in PC mixed with metakaolin through thermodynamic modeling. The results showed that in the absence of carbonation, chloride binding increased with metakaolin substitution. However, as carbonation increased, chloride binding decreased with metakaolin replacement. This is because (1) metakaolin substitution reduces the calcium content of the binder and (2) the formation of calcite also results in a lack of calcium for further Friedel salt formation. According to the authors, cement mixed with metakaolin definitely loses its ability to bind chloride with carbonation, which points out that the durability performance of metakaolin mixed cement should be carefully considered [50]. The reaction of metakaolin with limestone produces more hemicarboaluminate and monocarboaluminate than other mixed cements. In this study, the formation of carboaluminate phases mainly occurs in the "third" hydration peak after the alite and aluminate peaks. The effect of metakaolin composition, sulfate addition rate, and water binding ratio on the position and magnitude of this peak was studied. The formation of monocarboaluminate has a significant effect on improving porosity and increasing strength. In addition, aluminum in metakaolin has been observed to contribute to the precipitation of ettringite if sufficient sulfate is present [51]. Metakaolin (MK) is widely used in cement, lime and concrete due to its unique pozzolanic activity, which significantly improves long-term mechanical strength, permeability, corrosion resistance and other properties. At the same time, the high adsorption and low dispersion of MK lead to an increase in the demand for water and superplasticizers to achieve the required workability, which makes MK a little difficult to produce cement products. In this study, the authors proposed the use of local solid waste titanium slag (TS) as a low-hydration active filler and water-reducing mineral admixture to mitigate the adverse effects of Portland cement and MK.

The hydration process and performance of blended cements containing ordinary portland cement (OPC), MK and/or TS were analyzed. According to the authors, MK actively participates in the process of cement hydration and its strengthening. The addition of TS to cement containing OPC and MK effectively reduces the water demand, resulting in slightly higher compressive strength compared to OPC consistency. The addition of TS did not change the hydration products [52]. The hydration reactions of cement are highly complex, and no single method can fully characterize these reactions. Consequently, this study investigated the various properties and hydration behaviors of a Portland cement composite containing silica ash, limestone, and metakaolin using several complementary approaches. Initially, the physical, chemical, mineralogical, and molecular characteristics of metakaolin and the Portland cement composite (including silica ash and limestone) were analyzed. Subsequently, the physical and mechanical properties of the Portland cement composite were evaluated with metakaolin replacements at 0%, 5%, 10%, 15%, and 20% of the total cement mass. Finally, the hydration reactions of the metakaolin-replaced cement mixture were examined over a 28-day period using spectroscopic techniques such as X-ray diffraction, infrared spectroscopy, and scanning electron microscopy. The results indicated that increasing the proportion of metakaolin reduces the amount of portlandite released during hydration. Moreover, both the physical and mechanical properties of the Portland cement composite, as well as those of the metakaolin-replaced samples, were found to be dependent on the metakaolin content. Metakaolin also demonstrates a chemical reactivity known as pozzolanicity, which is primarily influenced by the material's fineness. Increased fineness of metakaolin enhances its chemical reactivity, leading to greater consumption of lime during the chemical reactions.

Reducing the amount of reactive phases and small particles in MK reduces chemical reactivity and compressive strength. For several years, MK has been widely used in inorganic binders due to its ability to react strongly with calcium hydroxide (CH_3). In humid environments, a number of main hydrated phases are formed, namely tetracalcium aluminate hydrate (C_4AH_{13}), calcium silicate hydrates (CSH), and calcium aluminum silicate hydrates (stratlingite C_2ASH_8). The obtained results showed that the compositions of lime / MK pastes show different reaction kinetics during solidification, the composition of the pozzolan product is directly proportional to the rate of exchange of lime with MK. A decrease in the ratio of lime replacement of MK leads to a decrease in the strength of the formed hydraulic crystal phases [55].

Another group of scientists proposed to obtain cement composites with dolomite and metakaolin in order to reduce waste from the cement industry and obtain concrete structures with high strength. According to the obtained results, hydrotalcite was formed as a result of cement composite hydration. Unlike many other hydrated phases, hydrotalcite is highly resistant to leaching and carbonation [56]. Like silica fume (SF), metakaolin (MK) is a valuable additive to improve the performance of cementitious composites through its high pozzolanic properties. Although SF is distinguished by improving the mechanical properties of concrete, concrete containing MK has a relatively lower cost and higher strength. In this study, cement composites with MK and SF were compared based on different experiments. The results of these tests show that the addition of 20% MK to cement is effective. The concretes were tested for slump, compressive strength, free compression, confined compression cracking and chloride diffusion absorption. Concrete modified with metakaolin showed better workability than concrete modified with silica fume. The obtained results show that the durability of concrete containing MK was higher than that of concrete containing SF [57,58]. Other scientists have conducted scientific work on the connection of mechanical and durability properties of metakaolin (MK) and silica fume (SF) concretes with their microstructure properties. The compressive strength and chloride permeability of concrete with MK or SF were studied when the water-cement ratio was 0.3 and 0.5. The effect of MK and SF on interfacial porosity is discussed based on the test results.

It was found that MK concrete has high strength and chloride resistance similar to SF concrete. According to the obtained results, the differences between the concrete porosity of MK and SF added concrete are smaller than the control concrete, which indicates the improvement of the interactive microstructure with the addition of pozzolans. To some extent, this difference had a positive effect on concrete strength and chloride permeability [59]. In order to increase the physical mechanical properties and corrosion resistance of concrete in lightweight concrete structures, the results were analyzed by adding metakaolin in the ratio of 5%, 10%, 15% and 20% to the cement mass. According to the results of this study, the strength and corrosion resistance of lightweight cement structures with 15% metakaolin addition increased [60]. The chloride diffusion coefficient of concrete depends on the quality of concrete, external factors and time. Chloride diffusion coefficient was studied in cement with metakaolin and cement mixtures with a water-cement ratio of 0.3-0.5 and

0-25% [61,62]. Chloride diffusion was investigated under various external factors. The resulting changes in chloride diffusion were studied by the pozzolanic effect of metakaolin and the change of the interphase transition zone (ITZ) as a result of the increase and decrease of the aggregate volume. Reduction of the rate of chloride diffusion through the hydrated cement matrix of metakaolin also caused an increase in the resistance of the ITZ material to chloride transport in solutions. According to the authors, the hydration process of lime or concrete can be increased with active pozzolanic additives. In this study, the effect of metakaolin on heat of hydration was compared with other pozzolans, fly ash and silica fume. The results show that the pozzolanic activity of MK is lower than that of SF and significantly higher than that of FA [63]. The presence of metakaolin in cement can increase the dissolution of cement phases and provide additional well-dispersed sites for the formation of hydration products. Intensification of some calorimetry data also indicates the occurrence of some additional exothermic reactions, which may be related to the reactivity of the calcium aluminate phases in the cement as well as the reaction of metakaolin [64]. The authors studied the activity of additives with two artificial and one natural pozzolanic properties, natural pozzolanic Milos soil (soil of Milos island in Greece), artificial pozzolanic ceramic powder (baked brick powder) and metakaolin samples under standard conditions. (RH = 98%, T = 25℃) was tested for 3, 7, 14 and 28 days. According to the obtained results, different pozzolans have different reactivity according to their mineralogical, physical and chemical properties. In particular, lime/metakaolin samples present the highest reactivity of all materials investigated. This fact can be attributed to its physical and chemical composition [65-66]. The presence of hydrated gelenite and the relative decrease in the amount of calcium hydroxide in the OPC pastes mixed with metakaolin observed by DTA when analyzing the addition of metakaolin in the amount of 0 and 20% compared to the cement mass indicate the pozzolanic reaction of metakaolin. An increase in the amount of metakaolin increases the resistance to the effects of chloride ions [66]. According to M. Frias and J. Cabrera, the pozzolanic reaction and CH consumption in cement samples mixed with metakaolin MK are higher than those of SF or FA-mixed cement pastes [67-68].

Scanning electron microscope micrographs of the samples showed the formation of a denser microstructure for the hardened OPC-MK10 sample compared to the pure OPC pastes after 28 days of hydration[69-75].

6. Conclusion

In this article, based on the analysis of the literature, the process of cement production and the extraction of various organic and inorganic mineral additives used in the preparation of concrete, as well as their various physico-chemical and mechanical properties, were studied. It was studied how many minerals used as additives should be added to cement, useful sources of these minerals for clinker and cement based on industrial waste. Physical-mechanical and chemical activation methods for adding microsilicon, zeolite, natural zeolite, slags, metakaolin, silica fume and other additives to clinker and cement were investigated. The effect of mineral additives on the cement brand and the effect of pozzolanic additives on the hydration process of cement in increasing the strength of concretes are analyzed by various methods such as X-ray diffraction, differential thermal analysis / thermogravimetric analysis (DTA / TGA), Box-Behnken experimental methodology, SEM analysis. the importance of the analysis is presented.

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The authors declare no conflict of interest.

We hereby confirm that all the figures and tables in the manuscript are ours.

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Authors' Contribution Statement

Mukimov A.S. Conducted the drafting, Turaev Kh.Kh: Completed the conception, design, drafting, Tojiev P.J**:** responsible for the acquisition of data Nabiev D.A: data interpretation; Nomozov A.K.: Participated in the conception, design, drafting, Nomozov A.K.: Took part in revision and proof reading.

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