

Pozzolana: Active Ingredient in Construction

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ABSTRACT:

Since ancient times, pozzolana natural or synthetic material has been employed in building. Due to its special qualities, it is a useful component in a variety of construction applications, including the manufacturing of cement and soil stabilization. Pozzolana is a substance that can be either natural or artificial that has cementitious qualities when coupled with calcium hydroxide and water. The performance and reactivity of pozzolanic materials in diverse building applications are the subject of this work. We will examine the chapter, key terms, and conclusion in this chapter as they pertain to the action of pozzolana.

KEYWORDS:

Activity, Applications, Classification Pozzolana, Silica Fume.

I. INTRODUCTION

Since ancient times, pozzolana natural or synthetic material has been employed in building. Due to its special qualities, it is a useful component in a variety of construction applications, including the manufacturing of cement and soil stabilization. We shall examine the history, traits, applications, and advantages of pozzolana in the building industry in this essay. The name of the Italian town Pozzuoli, near Naples, where the substance was first found and extensively employed by the ancient Romans, is where the term pozzolana first appeared. The Romans discovered that combining lime and volcanic ash produced an underwater-hardening hydraulic binder, which was a key development in construction technique at the time. After this discovery, pozzolana use gradually became known around the world, revolutionizing how infrastructure and buildings were constructed.

Pozzolana is a siliceous or siliceous-aluminous substance made mostly of fine-grained rocks or volcanic ash. The main ingredients that give it its beneficial features are reactive silica and alumina, which are what make it unique. Volcanic ash, pumice, and certain clay minerals are among the most often used natural pozzolana materials, whereas artificial pozzolanas are made by calcining or grinding materials including fly ash, silica fume, and blast furnace slag. The manufacturing of cement is one of pozzolana's main uses. Pozzolana undergoes a chemical reaction when coupled with lime and water to create compounds that increase the tensile strength and durability of cementitious materials. Additional calcium silicate hydrates (C-S-H), the primary binders in cement, are produced as a result of this process, sometimes referred to as the pozzolanic reaction. Pozzolana improves the performance of cement, lessens shrinkage, and boosts its resistance to sulfate and chemical assault [1], [2]. Pozzolana is further utilized as an ingredient while making concrete. Pozzolana can be added to concrete mixes to increase workability and decrease hydration heat. Additionally, it helps to lessen the permeability of the concrete, increasing its longevity by increasing its resistance to water infiltration. Pozzolana can replace cement entirely or partially in some applications, reducing carbon dioxide emissions and promoting more environmentally friendly building techniques.

Pozzolana is used in geotechnical engineering and soil stabilization in addition to cement and concrete. It increases soil compaction, decreases plasticity, and boosts bearing capacity when used with soil to enhance engineering qualities. Pozzolana-treated soils have enhanced load-bearing capacity and erosion resistance, making them appropriate for a range of construction projects, including the building of roads and embankments. Using pozzolana in building has a number of benefits. The first benefit is that it enables the effective use of industrial by-products like fly ash and blast furnace slag, which lowers waste and encourages sustainable practices. Second, by enhancing the strength, resilience, and chemical resistance of cementitious systems, pozzolanic materials improve their long-term performance. Structures benefit from longer service lives and lower maintenance costs as a result.

Additionally, by incorporating pozzolana into building materials, the environmental issues connected to conventional cement manufacturing may be addressed by lowering carbon dioxide emissions. However, it is crucial to remember that pozzolana's efficiency varies according to elements including its composition, fineness, and reactivity, as well as the particular application and environmental circumstances. Therefore, to guarantee the

required performance and consistency of products comprising pozzolana, thorough testing, quality control, and adherence to pertinent standards are essential. Pozzolana is a versatile material that, in sum, has long had a considerable impact on the building sector. It is a useful ingredient in a variety of applications, such as the manufacturing of cement, concrete mixes, and soil stabilization, due to its special qualities and capacity to improve the performance of cementitious materials. Pozzolana can help us build stronger, more long-lasting structures while having a smaller negative impact on the environment [3], [4].

Historical Significance of Pozzolana: Pozzolana's historical significance may be traced back to the period when its discovery transformed building techniques. The employment of this organic or synthetic substance has significantly influenced the growth of many civilizations, especially during the Roman era. One of the earliest civilizations to discover the advantages of pozzolana was the ancient Romans. They discovered that mixing lime and volcanic ash, or pozzolana, produced a hydraulic binder that solidified underwater. The ability to build buildings in aquatic settings, such as ports, aqueducts, and underwater foundations, made this finding an important scientific advance. The Romans made incredible engineering advancements because to their extensive usage of pozzolana, which are still respected today. The creation of the Pantheon in Rome, a majestic building famous for its enormous concrete dome, stands out as the most remarkable instance. The massive weight of the dome was sustained by a concrete mixture made by the Romans from a combination of pozzolana, lime, and aggregates. The use of pozzolana progressively became known outside of Italy and had an impact on construction methods everywhere else. Pozzolana's use decreased during the Middle Ages in Europe, although it persisted in places like the Middle East and North Africa.

An example of a building that used pozzolanic materials in its construction is the Great Mosque of Kairouan in Tunisia, completed in the ninth century [5], [6]. When architects and builders rediscovered the concepts and methods of ancient Roman construction during the Renaissance, pozzolana attracted new interest. Pozzolana was once again used, and in Europe, it was crucial to the construction of important structures and infrastructure projects. With the rise of industry in the 18th and 19th centuries, artificial pozzolana manufacture began. Fly ash, a fine powder made from coal combustion, is an example of an industrial by-product that has been discovered to have pozzolanic qualities. The use of these minerals in the manufacture of cement resulted in the creation of new varieties of hydraulic cements, including Portland pozzolana cement. Through the 20th century, pozzolanic materials were used more and more frequently as a result of technological developments and the investigation of substitute cementitious materials. The usefulness of pozzolanas in enhancing the performance and sustainability of cement-based products is now acknowledged by the building industry. The transformational effect that pozzolana had on building techniques is what gives it historical relevance. The ancient Romans discovered its special characteristics, which enabled for the construction of strong constructions that defied traditional restrictions. Pozzolana usage had a lasting impact on the construction industry, influencing architectural designs, technical methods, and the creation of new building materials [7], [8].

II. DISCUSSION

The Activity of Pozzolana: The capacity of pozzolana to react with calcium hydroxide to create cementitious compounds when there is water present is referred to as its activity. The pozzolanic reaction, a crucial aspect of pozzolanic materials, is what gives them their advantageous qualities in building applications. Additional calcium silicate hydrates (C-S-H) are produced as a result of a chemical reaction that takes place when pozzolana, lime (calcium hydroxide), and water are mixed. Cementitious materials link to one another and harden as a result of these C-S-H combinations. The pozzolanic reaction increases the strength, durability, and chemical resistance of cement-based systems, which improves performance. A pozzolana material's pozzolanic activity is influenced by a number of elements, including its chemical make-up, degree of fineness, and reactivity. The main elements that contribute to the pozzolanic activity are reactive silica and alumina. In general, pozzolanas with higher silica and alumina concentration are more reactive and effective in enhancing the characteristics of cementitious materials. The pozzolanic material's fineness also has a significant impact on how active it is.

Pozzolanas that have been finely powdered offer a bigger surface area for the reaction to take place on, enabling more widespread and effective pozzolanic activity. Pozzolanas are normally coarsely milled before being added to cement or concrete formulations because of this [9], [10]. Temperature, curing conditions, and the presence of other materials are only a few examples of the variables that might affect pozzolana's reactivity. Under general, curing under wet circumstances is advantageous for the pozzolanic reaction to occur, but higher temperatures can speed up the reaction. Alkaline conditions and the presence of calcium hydroxide can both encourage and improve the material's pozzolanic activity. Pozzolana's activity is a crucial factor to take into account while choosing and utilizing these materials in building. High reactivity and pozzolanic activity pozzolanas are preferred because they improve the overall effectiveness and resilience of cementitious systems. To evaluate a

particular pozzolanic material's pozzolanic activity and make sure it is compatible with the intended use, appropriate testing and quality control procedures are crucial. In conclusion, the capacity of pozzolana to react with calcium hydroxide in the presence of water and produce cementitious compounds is referred to as its activity. A material's pozzolanic activity, which plays a critical role in strengthening the strength, durability, and other advantageous features of cement-based materials, is dependent on elements such its chemical composition, fineness, and reactivity.

Classification of Pozzolana: Pozzolana materials come in a variety of varieties that are utilized in building. Natural and manufactured pozzolanas are the two basic groups into which these may be divided. Let's investigate a few of the frequently occurring kinds under each category:

1. Organic Pozzolanas

a. **Volcanic Ash:** One of the earliest and best-known natural pozzolanas is volcanic ash. It is made of pyroclastic material or hardened volcanic lava. The ash has been utilized since antiquity, especially by the Romans, and is high in reactive silica and alumina.

b. **Pumice:** Pumice is a lightweight, very porous volcanic rock that can be used as a pozzolanic component naturally. It is created when bubbly, frothy volcanic lava rapidly cools and captures them. Pumice is frequently utilized as an ingredient in soil stabilization and lightweight concrete.

c. **Diatomaceous Earth:** Diatomaceous earth is a sedimentary rock that forms naturally and is made up of the fossilized remnants of a single-celled algae called a diatom. It may be utilized as a pozzolanic material in some applications and has a high silica concentration.

d. **Rice Husk Ash:** Due to its high silica concentration, rice husk ash, a by-product of the milling of rice, is regarded as a natural pozzolana. It can be used in addition to other cementitious materials for making concrete, which will increase strength and durability.

2. Synthetic Pozzolanas

a. **Fly Ash:** A byproduct of the burning of coal in thermal power plants is fly ash. Due to the high concentration of silica and alumina in it, it is a frequently used artificial pozzolanic material. The characteristics and sustainability of the materials are improved by the frequent use of fly ash as a partial substitute for cement in the manufacturing of cement and concrete.

b. **Silica Fume:** Microsilica, commonly referred to as silica fume, is a by-product of the manufacturing of silicon and ferrosilicon alloys. It is made up of very tiny amorphous silica particles. High-performance concrete uses silica fume, a highly reactive artificial pozzolanic ingredient, to increase strength, durability, and chemical resistance.

c. **Blast Furnace Slag:** Slag from a blast furnace is a by-product of the iron that is produced in these furnaces. Due to the high concentrations of silica, alumina, and calcium in it, it is frequently employed as an artificial pozzolanic material. In the manufacturing of cement and concrete, blast furnace slag can be crushed and utilized as an additional cementitious ingredient.

d. **Metakaolin:** Kaolin clay is calcined at high temperatures to form metakaolin, a highly reactive pozzolanic substance. It is utilized as an artificial pozzolan in cement and concrete applications because of its high proportion of reactive silica and alumina, which improves strength and durability.

These are only a few illustrations of the various pozzolana materials that may be used in building. The best pozzolana choice is determined by a number of variables, including availability, particular application requirements, and desired performance qualities.

Effects of Natural Pozzolana: Natural pozzolanas have a variety of impacts on building supplies and uses. The effectiveness and longevity of cementitious systems are influenced by these factors. Examining some of the main results of natural pozzolanas is as follows:

a. **Pozzolanic Reaction:** The capacity of natural pozzolanas to undergo the pozzolanic reaction is their main impact. Natural pozzolanas chemically react with lime and water to produce more calcium silicate hydrates (C-S-H). This process aids in cementitious materials' binding and hardening, increasing their strength and longevity.

b. **Strengthening:** Natural pozzolanas can increase the cementitious systems' compressive strength. Denser and more interlocked cementitious matrices are produced as a result of the increased C-S-H that is formed during the pozzolanic process. The materials get stronger as a result, increasing their resistance to compressive stresses.

c. **Reduced Permeability:** Natural pozzolanas have a beneficial impact on cement-based materials' permeability. Pore size and connectivity are decreased as a result of the pozzolanic reaction, which also creates a finer, more compact microstructure. The material's permeability is reduced by the denser microstructure, increasing its resistance to chemical and water incursion.

d. **Improved Durability:** Natural pozzolanas are used in building projects to increase the materials' long-term durability. The pozzolanic reaction results in greater strength, decreased permeability, and better microstructure, which improves resistance to chemical assaults such as sulfate and chloride intrusion as well as other environmental elements that can damage cementitious systems.

e. **Alkali-Silica Reaction Mitigation:** Natural pozzolanas have the ability to reduce the potentially harmful consequences of the alkali-silica reaction (ASR). Concrete expands and cracks as a result of ASR, a chemical reaction between alkalis in cement and certain reactive forms of silica in aggregates. Natural pozzolanas can assist to lessen the alkalinity of the pore solution in concrete mixes, which can help to prevent the development of ASR.

f. **Sustainable Construction:** Natural pozzolanas provide advantages for the environment when used in building. Utilizing these resources will reduce the demand for cement and the accompanying carbon dioxide emissions from cement manufacture. Locally accessible materials, such as natural pozzolanas, can cut down on the need for transportation and increase regional sustainability.

It's crucial to remember that the impacts of natural pozzolanas might change based on elements like their precise composition, degree of fineness, degree of reactivity, and the ratios utilized in cementitious combinations. The desired outcomes and performance of natural pozzolanas in building applications must be ensured by appropriate testing, quality control, and adherence to pertinent standards.

Applications of Pozzolana: Due to their advantageous qualities and capacity to improve the performance of cementitious materials, pozzolanas are used in a wide range of construction-related applications. Let's examine a few of the typical uses for pozzolanas:

a. **Cement Production:** Pozzolanas are a common ingredient used in the manufacture of cement. They go through the pozzolanic process when combined with lime and water, producing more calcium silicate hydrates (C-S-H) thus strengthening and preserving the cement. Pozzolanas can substitute some cement, reducing carbon dioxide emissions and promoting more environmentally friendly cement manufacturing.

b. **Production of Concrete:** Pozzolanas are added to concrete mixes to enhance a variety of qualities. They make new concrete more workable and less dependent on a high water content. Pozzolanas enhance concrete's durability over the long term, boost its resistance to chemical assault, and help concrete acquire strength over time.

c. **Soil Stabilization:** Pozzolanas are employed in the stability and enhancement of soil. They can improve the engineering qualities of soil, such as compaction, decreased plasticity, and improved load-bearing capacity, when combined with soil. The use of pozzolana-treated soils in road construction, embankments, and other geotechnical applications results in increased stability and erosion resistance.

d. **Mortar Applications:** Pozzolanas are used in mortar to increase the mix's workability, tensile strength, and durability. Cement, sand, and water are combined to make mortar, which is used to bond bricks, stones, and other construction components. Pozzolanas improve mortar's performance by increasing its resistance to cracking, shrinkage, and chemical deterioration.

e. **Repair and Restoration:** Repair and restoration of concrete buildings frequently include the use of pozzolanic materials. To offer compatibility with pre-existing concrete, strengthen bonding, and increase the long-term durability of treated areas, they can be added into repair mortars or grouts.

f. **Shotcrete and Sprayed Concrete:** In shotcrete and sprayed concrete applications, where the substance is pneumatically projected onto surfaces, pozzolanas are employed. Shotcrete and sprayed concrete benefit from the inclusion of pozzolanas since it enhances their cohesion, adhesion, and overall performance, making them appropriate for uses including tunnel linings, slope stabilization, and quick construction.

g. Products Made from Precast Concrete: Pozzolanas are Used to Make Blocks, Pipes, And Panels from Precast Concrete. They increase the precast elements' strength and longevity, reduce permeability, and improve the overall quality and performance of the products.

It's important to keep in mind that the precise application and dose of pozzolanas might change based on the substance type utilized, the demands of the project, and regional laws. To guarantee the intended performance and consistency of pozzolanic materials in diverse building applications, proper testing, quality control, and adherence to pertinent standards are crucial.

Fly Ash: In coal-fired power plants, the burning of pulverized coal produces fly ash, a thin, powdery residue. It is one of the most prevalent kinds of industrial waste since it is a by-product of coal combustion. However, due to its potential to be a useful resource in a variety of applications, fly ash has attracted considerable interest and utility. The kind of coal used, the combustion process, and the effectiveness of pollution control systems in the power plant all affect the fly ash's composition. Fly ash typically consists of spherical particles with lower quantities of calcium oxide, iron oxide, and other minor components. The main constituents of fly ash are silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and silicon dioxide (CaO). Class F and Class C fly ash are the two categories into which it is commonly divided. Burning anthracite or bituminous coal results in Class F fly ash, which has a low calcium oxide level. It is well recognized for having pozzolanic characteristics, which means that it may combine with water and calcium hydroxide to create cementitious compounds.

Class F fly ash is frequently utilized as an ingredient in the creation of cement and concrete, where it improves the products' strength, use, and longevity. Additionally, it aids in lowering the heat of hydration and shrinkage, enhancing the concrete's overall functionality. In contrast, Class C fly ash is produced by burning lignite or sub-bituminous coal and has a greater calcium oxide percentage than Class F fly ash. It has both pozzolanic and self-cementing characteristics, meaning it may form cementitious characteristics without the addition of further calcium hydroxide. Class C fly ash is used in similar ways as Class F fly ash, but it is especially well suited for projects that need for quick strength growth, such building roads. There are various advantages to using fly ash in the manufacture of cement and concrete. First of all, it lessens the demand for conventional cement components, preserving natural resources and lowering carbon dioxide emissions related to cement manufacture. Utilizing fly ash, a byproduct that would otherwise be dumped in landfills, helps reduce waste disposal problems. Additionally, adding fly ash to concrete makes it easier to work with and pump, uses less water, and is more resistant to sulfate and chemical assault, making for longer-lasting and more sustainable constructions.

Fly ash has uses outside of cement and concrete applications as well. It may be used as a filler material to lower manufacturing costs and improve the mechanical qualities of ceramics, bricks, and blocks. Fly ash may also be used to stabilize soils, increasing their tensile strength, decreasing swelling, and increasing their resistance to erosion. However, while employing fly ash, it is crucial to take a few things into account. Fly ash's characteristics can change depending on where it comes from and how it is burned, thus it is essential to do quality control tests to guarantee that it is suitable for a certain use. Furthermore, due to the tiny particle size and potential for trace element leaching of fly ash, care must be taken to reduce occupational and environmental exposure during handling and storage. In conclusion, fly ash, a by-product of coal combustion, has been well recognized for its beneficial qualities and uses. Its use in soil stabilization, cement, concrete, ceramics, and other building materials has several benefits, including improved strength, sustainability, and durability. Fly ash may be efficiently used as a valuable resource, contributing to more ecologically friendly and effective construction techniques, with sufficient quality control and responsible management.

Calcined Clay Pozzolana: charred clay Pozzolana is a term used to describe a specific kind of pozzolanic material created by calcining clay minerals. Due to its pozzolanic qualities, which help cement and concrete perform better and last longer, it is a commonly used ingredient in cement and concrete manufacturing. Clay minerals like kaolinite or montmorillonite are heated in a controlled atmosphere to high temperatures (between 600 and 900 degrees Celsius) in order to produce calcined clay pozzolana. The clay minerals undergo structural changes as a result of this heat treatment, which give rise to the pozzolanic characteristics. After being calcined, the clay is crushed into a fine powder that may be used to cementitious systems. When added to cement and concrete, calcined clay pozzolana has several benefits. First, it improves the development of calcium silicate hydrates (C-S-H) during the hydration process, which increases the strength and durability of concrete. The creation of extra C-S-H gel as a result of the pozzolanic reaction between the calcined clay and calcium hydroxide created during cement hydration increases concrete's strength and lowers its permeability. The service life of concrete structures is increased as a consequence of greater resistance to chemical assault, sulfate attack, and other harmful elements. The use of calcined clay pozzolana in the manufacture of cement also benefits the environment.

As a result, the demand for conventional cement materials declines and the carbon dioxide emissions linked to cement production decrease. Calcined clay is an additional cementitious ingredient that can substitute Portland cement in some construction projects, reducing the carbon footprint. The cement industry may support environmentally friendly practices and the reduction of greenhouse gas emissions by using calcined clay pozzolana. Additionally, adding calcined clay pozzolana to cementitious systems can make concrete easier to work with. It enables a more even distribution of water throughout the mixture, improving pumpability and making it simpler to pour the concrete during construction. For projects that need for pouring concrete in challenging or crowded regions, this can be very useful.

It is significant to remember that the performance of calcined clay pozzolana might change based on elements such the mineral makeup of the clay, the calcination temperature, the fineness, and the particular application. To guarantee the intended performance and uniformity of products using calcined clay pozzolana, proper testing and quality control are vital. In conclusion, calcined clay pozzolana is an important component in the creation of cement and concrete. Its pozzolanic qualities help these materials be stronger, more resilient, and more sustainable. Calcined clay pozzolana can be used to improve cementitious systems' long-term performance, increase workability, and minimize carbon dioxide emissions. Construction techniques can become more efficient and ecologically beneficial by employing calcined clay pozzolana.

Silica Fume: Microsilica, sometimes referred to as silica fume, is a highly reactive pozzolanic substance that is created as a by-product of the manufacturing of silicon and ferrosilicon alloys. It is categorized as an amorphous silica substance and is made up of exceedingly small particles with an average diameter of less than 1 micron. High-purity quartz or quartzite is reduced in an electric arc furnace to produce silica fume, which causes the vaporization of silicon compounds. The subsequent rapid cooling of these gases causes them to condense into small, spherical particles. A high-purity product is produced by collecting the resultant silica fume and further processing it to eliminate contaminants. In the manufacturing of concrete, silica fume is typically employed as an additional cementitious ingredient. When applied to concrete, silica fume fills the spaces between cement grains and improves packing density, creating a matrix that is both denser and stronger. Because of its large surface area and chemical reactivity, it may chemically react with calcium hydroxide, a by-product of cement hydration, to create more calcium silicate hydrates (C-S-H), which increase strength and durability.

There are several advantages of adding silica fume to concrete. First off, compared to concrete without silica fume, it greatly boosts the compressive strength of the material. As a result, buildings with greater load-bearing capacity may be built. Additionally, silica fume improves the flexural strength, abrasion resistance, and impact resistance of concrete, enabling it to be used in hard environment applications such as bridges, high-rise structures, and infrastructure. Additionally, concrete becomes less permeable due to silica fume, increasing its resistance to chemical corrosion, sulfate attack, and chloride ion penetration. This increases the resilience of concrete structures, especially in commercial or industrial settings. Alkali-silica reaction (ASR), a chemical process that can cause the expansion and degeneration of concrete, is also lessened as a result of silica fume. Silica fume has uses in a variety of industries in addition to concrete. To increase their resistance to high temperatures and chemical assault, it is used in refractory materials. Additionally, silica fume is employed in shotcrete applications to increase adhesion and lessen rebound.

To increase the tensile strength and longevity of wellbore cement, silica fume is used in the oil and gas sector during well-cementing procedures. It is crucial to remember that silica fume addition to concrete necessitates careful mix design, handling, and quality control. Due to its highly reactive nature, appropriate safety measures should be implemented when handling it in order to limit the danger of respiratory problems for employees and to prevent excessive exposure. To maximize the performance of silica fume in concrete, modifications to the concrete mix design, such as the use of superplasticizers and increased curing, can also be required. In conclusion, silica fume is an important auxiliary cementitious element that improves the performance, strength, and longevity of concrete. Due to its special qualities, it is especially ideal for applications that call for great strength and durability to hostile conditions. Silica fume offers substantial benefits in construction and helps create more resilient and sustainable concrete buildings when handled carefully and under quality control.

III. CONCLUSION

Pozzolanic materials have shown tremendous promise for improving the characteristics and functionality of cement-based materials. The capacity of pozzolana to react with calcium hydroxide, which is commonly present in Portland cement, to create new cementitious compounds is referred to as its activity. Pozzolanic materials can increase strength, durability, and permeability qualities when added to concrete or mortar mixtures. Pozzolana's reactivity is influenced by its chemical make-up, degree of fineness, and curing conditions used during hydration.

Numerous pozzolanic substances, including fly ash, silica fume, and metakaolin, have been thoroughly investigated and have been shown to be efficient in raising the general performance of cement-based systems. Future studies should concentrate on improving the use of various pozzolanic materials, creating uniform testing procedures, and investigating their potential in green building techniques. Overall, the use of pozzolana contributes significantly to the development of cementitious materials and has the potential to increase the sustainability and durability of construction projects.

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