

Cement: Composition, Production and Applications

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ABSTRACT:

The growth of infrastructure across the world is greatly aided by cement, an essential component of the building sector. This introduction seeks to provide readers a thorough grasp of cement, including its composition, production method, and many varieties. It also examines how cement manufacturing affects the environment and proposes environmentally friendly alternatives. The chapter closes by highlighting the importance of cement in contemporary society and the necessity of sustainable techniques to lessen its environmental effects.

KEYWORDS:

Cement, Composition, Manufacturing, Properties, Types.

I. INTRODUCTION

Due to its strength, durability, and adaptability, cement is a key component in the building industry. In the construction of constructions like buildings, bridges, dams, and highways, it is essential. An overview of cement is given in this page, along with information on its kinds, uses, and manufacturing method. A binder is anything that hardens and holds other materials together, such as cement. Along with minor levels of calcium aluminates and calcium sulfates, calcium silicates make up the majority of the material. Cement's major ingredients are gypsum, clay, and limestone. To make a raw meal, limestone and clay are mined from quarries and put through a number of procedures, such as crushing, grinding, and mixing. Clinker is created by heating this uncooked meal to high temperatures, generally about 1450 degrees Celsius, in a kiln. Following the grinding of the clinker into a fine powder, cement is created. Cement is combined with other ingredients to create concrete. A number of steps are involved in cement manufacture.

Quarrying is the initial stage, which entails utilizing large gear to remove clay and limestone from quarries. Once at the cement factory, these raw materials are crushed to a size appropriate for further processing. To generate the raw meal, which is subsequently added to a revolving kiln, the crushed ingredients are combined in the proper ratios. The kiln's high operating temperatures enable the chemical processes required for clinker production. Clinker is cooled and processed into a fine powder after exiting the kiln to create cement. There are several cement varieties available, each with unique qualities and uses. The most popular variety, known as ordinary Portland cement (OPC), is used in normal building. Based on its strength, OPC is further divided into distinct classes. The Portland Pozzolana Cement (PPC), which incorporates pozzolanic components such fly ash or silica fume, is another variety. PPC has a reputation for enhancing the durability and workability of concrete. Other cement varieties include sulfate-resistant cement, quick hardening cement, and low-heat cement, each created for a particular purpose [1], [2]. The uses for cement are numerous and varied. In order to keep the aggregates such as sand, gravel, and crushed stone together, cement is primarily used in the creation of concrete. From residential structures to infrastructure projects like bridges and roadways, concrete is employed in a variety of construction projects. Additionally, cement is used to build foundations, walls, floors, and roofs. In order to make precast concrete goods like pipes, tiles, and panels, it is a necessary ingredient. Cement is used for a variety of different things than building.

It serves as a safe containment strategy and is used in the stabilization and solidification of hazardous waste materials. To increase the strength and stability of the soil, cement can also be used in grouting and other soil development procedures. Cement is also used in the production of mortar, which is a binding agent for tiles, stones, and bricks. Cement usage and manufacture, however, have an impact on the environment. The calcination of limestone and the burning of fossil fuels in kilns are the main sources of the production process' considerable carbon dioxide (CO₂) emissions. By using alternative fuels and implementing more environmentally friendly methods, efforts are being undertaken to minimize these emissions. To reduce the negative effects on the

environment, cementitious waste should be disposed of properly. As a result of its critical role in the creation of concrete and several other building uses, cement is a necessary material in the construction sector. Its kinds, production method, and composition all offer adaptability and durability. To reduce its carbon footprint, sustainable techniques must be used due to the environmental effect of cement manufacturing. The industry keeps looking for new ways to enhance cement production and reduce its environmental effect as technology and research advance [3], [4].

Historical Overview of Cement: Cement has a long history, going back thousands of years to the early civilizations that utilised diverse cementitious materials for building. Around 7000 BCE, cement-like substances were first used in ancient Mesopotamia (present-day Iraq and Iran). Building walls were covered with a form of lime plaster derived from gypsum in this area. Cementitious materials were greatly improved by the ancient Egyptians as well. As early as 3000 BCE, they employed a type of lime mortar derived from a combination of limestone and gypsum. This mortar was utilized by the Egyptians to build their spectacular pyramids, temples, and other enormous constructions. Ancient Greece is another renowned civilisation that made a significant contribution to the creation of cement. The natural cementing abilities of volcanic ash, or pozzolana, were discovered by the Greeks.

For their building projects, they combined pozzolana and lime to produce a strong, water-resistant material. The Pantheon in Athens is the most well-known instance of how pozzolana was used in Greek architecture. The understanding and application of cementitious materials were further developed by the Romans. By combining lime and volcanic ash, they created opus caementicium, a material that resembled cement. The great aqueducts, bridges, and iconic buildings the Romans built, such as the Colosseum and Roman Pantheon, were all made of opus caementicium. The Romans were able to build constructions with remarkable strength, toughness, and architectural flexibility because to the usage of opus caementicium. The knowledge of cement usage and manufacture in Europe, however, decreased during the Middle Ages with the fall of the Roman Empire. Construction methods tended to rely more on stone masonry and timber than on cementitious materials [5], [6].

The modern cement business did not start to develop until the 18th century. An underwater-setting hydraulic cement was discovered by English engineer John Smeaton in 1756. Clay and limestone were combined for the burning process to create Smeaton's cement, which was then ground into a fine powder. This finding served as the catalyst for the development of hydraulic cement, which can set and harden even in the presence of water. The creation of Portland cement at the beginning of the 19th century marked another important advancement in cement. An English bricklayer named Joseph Aspdin invented a cement in 1824 that had the same hue as the limestone on the Isle of Portland in England. This cement was created by heating up finely crushed limestone and clay, burning it, and then powdering the clinker that was left over. Due to its increased strength and endurance, Aspdin's development of Portland cement transformed the construction sector. The first cement facilities were established in England in the middle of the 19th century, marking the start of cement manufacture on an industrial scale.

Portland cement's use swiftly extended throughout Europe and eventually to other areas of the world, revolutionizing the construction sector by making it possible to build substantial buildings and infrastructure. Since then, there have been tremendous technological breakthroughs and improvements in the cement business. To fulfill varying building needs, numerous varieties of cement with specialized qualities have been produced as the manufacturing process has grown more efficient. Through the adoption of sustainable methods and the investigation of alternative materials and fuels, the sector has also taken attempts to lessen its negative environmental effect. Cement is currently one of the most commonly used building materials in the world and is essential to the growth of infrastructure and the built environment. Cementitious materials have undergone constant development throughout their long and rich history, which has made them crucial for contemporary building [7], [8].

Importance of Cement in Construction Industry: Due to its significance in building sturdy, long-lasting, and flexible structures, cement plays a significant role in construction. Here are some of the main why cement is necessary in building:

a. **Binding Agent:** When making concrete, cement serves as a binding agent. It combines several building supplies including aggregates sand, gravel, and crushed stone, water, and additives to make a cohesive mass that is solid. This bonding ability enables the construction of strong, sturdy structures.

b. **Strength and Durability:** Cement gives construction projects strength and durability. Excellent compressive strength of cement-based concrete allows it to support enormous loads and resist deformation. Additionally, it

shows strong resistance to age, corrosion, and the effects of the elements, assuring the endurance and durability of buildings.

c. **Versatility:** Cement may be used in a variety of ways in building. It may be molded into a variety of shapes, sizes, and forms, making it appropriate for a variety of constructions. Building foundations, walls, floors, columns, beams, and even bridges may all be constructed with cement, which can be easily modified to meet different architectural specifications.

d. **Fire Resistance:** Materials made of cement, including concrete and mortar, naturally withstand fire. They are crucial for the construction of structures that are resistant to fire, since they can endure high temperatures and aid in containing flames [9], [10].

e. **Thermal Resistance:** Excellent thermal mass qualities of cement allow it to absorb, store, and release heat. By controlling temperature changes in buildings, this characteristic creates a cozy interior and uses less energy for heating and cooling.

f. **Sound Insulation:** Cement-based concrete has strong sound-insulating qualities. It helps create a quieter and more serene living or working environment by reducing noise transmission between rooms and from outside sources.

g. **Sustainable Construction:** Cement can help with environmentally friendly construction techniques. The manufacturing of cement has a lower environmental effect when it incorporates different supplementary cementitious materials (SCMs), such as fly ash, slag, or silica fume, which are waste products from other industries. The use of cement-based products in building can also increase sustainability overall, decrease waste, and improve energy efficiency.

h. **Benefits to the Economy:** Cement and concrete products have a large positive impact on the economy. The development of infrastructure by the cement industry fosters economic growth by creating jobs and assisting firms involved in construction.

i. **Repair and Rehabilitation:** Repair and restoration operations frequently include the usage of cement-based products. Existing structures can be strengthened and restored, prolonging their useful lives and enhancing structural integrity.

j. **Aesthetic Possibilities:** Materials based on cement are available in a variety of finishes and architectural configurations. They may be molded, colored, and textured to provide a variety of aesthetic effects, enabling the creation of imaginative and aesthetically pleasing designs.

cement plays a crucial part in construction because of its function as a binding agent, strength, adaptability, fire resistance, thermal mass, sound insulation, sustainability, advantages from an economic standpoint, and capacity for repair and rehabilitation. It is a fundamental substance that makes it possible to build structures that are reliable, beautiful, and safe.

II. DISCUSSION

Composition of Cement: The four primary components of cement are calcium, silicon, aluminum, and iron. The primary compounds in cement are created by mixing these components in a certain ratio. Tricalcium silicate (C3S) and dicalcium silicate (C2S), the two primary substances, both contribute to the strength and early setting time of cement. Depending on the kind and particular requirements of the cement, the composition might change. However, the following are the standard elements included in the majority of cement types:

a. **Calcium Oxide (CaO):** Calcium oxide (CaO), sometimes referred to as lime or quicklime, is the main source of calcium for the manufacture of cement. It is made from limestone, a sedimentary rock that is mostly made of calcium carbonate (CaCO₃). Limestone decomposes at high temperatures in a kiln, generating carbon dioxide (CO₂) and leaving calcium oxide behind.

b. **Silicon Dioxide (SiO₂):** Clay, sand, or other silicon-rich materials are used to create silicon dioxide (SiO₂), sometimes referred to as silica. It is a key element that helps cement become more durable and stronger.

c. **Aluminum Oxide (Al₂O₃):** Bauxite, clay, and other sources of aluminum are used to create aluminum oxide (Al₂O₃). It is in charge of improving the cement's resilience to chemical assaults and offering a limited amount of control over the early setting period.

d. **Iron Oxide (Fe₂O₃):** Made from iron ore or other iron-rich materials, iron oxide (Fe₂O₃) gives cement its color. The characteristics of the cement are not greatly impacted by its little presence.

Minor ingredients that improve certain qualities or meet certain standards may also be present in cement in addition to these basic components. Gypsum, which regulates the cement's setting time, and different admixtures like fly ash, slag, or silica fume, which can increase workability, strength, and durability, are examples of these additions. It is significant to note that depending on the type of cement being manufactured, the content and ratios of these components might change. For instance, the most popular form of cement, Portland, often comprises 60–67% calcium oxide, 17–25% silicon dioxide, 3–8% aluminum oxide, and lower quantities of iron oxide. To attain certain performance qualities, other forms of cement, including blended cements or speciality cements, may have various compositions. Cement's intended qualities, including strength, durability, setting time, and workability, are largely a result of the careful selection and balancing of these elements throughout manufacture.

Manufacturing of Cement: Cement is produced through a number of steps, starting with the extraction of raw materials and ending with the creation of cement powder. Here is how it works:

a. **Quarrying:** The first stage in the production of cement is the mining of the raw materials, typically clay and limestone, from mines or quarries. The usual methods for obtaining these basic minerals are drilling or blasting.

b. **Crushing and Grinding:** After being removed, the raw materials are crushed and processed into a fine powder. Typically, clay and limestone are crushed separately and kept in storage facilities.

c. **Mixing and Blending:** To make a raw meal, crushed limestone and clay are combined in the proper ratios. The ratios of clay and limestone are determined by the final cement product's desired qualities. Sand, bauxite, iron ore, and other minerals may be added to change the composition or improve particular qualities.

d. **Preheating:** Hot gases from the kiln are used to warm the raw meal in a preheater tower. In addition to saving energy, this preheating procedure speeds up the chemical processes involved in the creation of clinker.

e. **Clinker Formation:** A rotary kiln, a large, cylindrical furnace, receives the heated raw meal. The raw materials are heated to temperatures in the range of 1450 degrees Celsius (2642 degrees Fahrenheit) or higher in the kiln. Clinker is created as a result of chemical processes that take place at this temperature. Calcium carbonate, which is found in limestone, is converted into calcium oxide in the process, and calcium oxide is then combined with silica, alumina, and iron oxide to generate calcium silicates, aluminates, and ferrites.

f. **Cooling:** To stop additional reactions, the clinker is then quickly cooled using air or water quenching. Clinker that has cooled is fragile and simple to break.

g. **Grinding:** To manage the setting time, a little amount of gypsum (calcium sulfate) is added while the cooled clinker is crushed into a fine powder. A ball mill, vertical roller mill, or other type of grinding machinery may be used during the grinding process.

h. **Storage and packaging:** Before being exported in bulk or being packed in bags, the finished cement powder is kept in silos for storage. The cement will maintain its quality while being stored properly until it is time to utilize it.

Quality control procedures are used throughout the manufacturing process to guarantee the cement's uniformity and intended qualities. These precautions entail routine sampling, testing, and parameter adjustments for raw materials and processes. It should be noted that the production of cement uses a lot of energy and results in large carbon dioxide (CO₂) emissions. In order to lessen the industry's impact on the environment, efforts are being made to improve the process, use less energy, and investigate alternate fuels and raw materials.

Types of Cement: There are several varieties of cement, each with unique qualities and uses. The many cement varieties are made with variables like strength, durability, setting time, and resilience to climatic conditions in mind as they are created to fulfill certain construction needs. The features and uses of a few varieties of cement that are often used are summarized in this article.

1. Ordinary Portland Cement (OPC): The most popular form of cement used in building is known as ordinary Portland cement, or OPC. It is made by grinding clinker, gypsum, and a tiny quantity of other components, and is frequently referred to as gray cement. The strength of OPC is further divided into distinct classes, such as OPC 33, OPC 43, and OPC 53, which represent the cement's compressive strength in megapascals (MPa) after 28 days of curing. OPC is appropriate for a variety of conventional construction tasks, including the construction of homes, businesses, bridges, and pavements.

2. Portland Pozzolana Cement (PPC): Gypsum, pozzolanic ingredients, and OPC clinker are all components of the blended cement known as Portland Pozzolana Cement (PPC). Fly ash, silica fume, volcanic ash, or calcined clay are examples of pozzolanic materials. In comparison to OPC, PPC is easier to work with, has a lower heat of hydration, and is more resistant to chemical assaults. Additionally, it provides longer-lasting durability and is appropriate for constructions located in hostile situations, such as industrial or maritime settings. PPC is frequently utilized in the building of subterranean constructions, dams, and hydraulic systems.

3. Rapid Hardening Cement: Also referred to as high-early-strength cement, rapid hardening cement is intended to acquire more strength more quickly. It is made by employing a larger proportion of tricalcium silicate (C3S) in the clinker and crushing OPC clinker more finely. In applications where early strength is crucial, such as in precast concrete, cold weather concreting, or for quick repairs, rapid hardening cement strengthens more quickly than OPC.

4. Low-Heat Cement: Compared to OPC, Low-Heat Cement is particularly engineered to produce less heat during hydration. It has larger concentrations of dicalcium silicate (C2S) and tricalcium silicate (C3S), and a smaller proportion of tricalcium aluminate (C3A). The likelihood of thermal cracking in big concrete constructions, such as mass concrete components, dams, and foundations, is minimized by the lower heat of hydration. Additionally, low-heat cement offers higher defense against sulfate assaults.

5. Sulfate-Resistant Cement: Also known as sulfate-resistant Portland cement (SRPC), sulfate-resistant cement is made to withstand the negative effects of sulfates found in soil or water. Tricalcium aluminate (C3A), which is vulnerable to sulfate assault, makes up a small portion of its composition. Coastal regions, wastewater treatment facilities, and foundations in sulfates-rich soils are examples of places where SRPC is appropriate for construction due to its high sulfate content.

6. Blended Cements: Blended Cements are made by mixing OPC clinker with additional cementitious materials (SCMs), such fly ash, slag, or silica fume. These materials, which have pozzolanic characteristics, are leftovers from previous industrial operations. In comparison to OPC, blended cements have better workability, durability, a lower heat of hydration, and a smaller carbon footprint. Cements that are mixed often include:

a. **Fly Ash Based Blended Cement:** Blended cement made using fly ash as a partial replacement for OPC. Fly ash is a by-product of coal combustion. It contributes to clinker usage reduction and offers further advantages including enhanced sulfate resistance, decreased heat of hydration, and increased workability.

b. **Slag Based Blended Cement:** Slag-based blended cement is used in place of OPC to some extent. Slag is a by-product of the iron and steel industries. Improved workability, decreased permeability, and better resistance to sulfate and chloride assaults are all features of slag cement. It is appropriate for buildings subject to extreme conditions, such as chemical factories and coastal constructions.

c. **Silica Fume Based Blended Cement:** Silica fume, a waste product of the manufacturing of silicon metal and ferrosilicon alloys, is combined with OPC to create silica fume blended cement. Concrete is strengthened, made to last longer, and is more resistant to chemical assaults when exposed to silica fume. It is frequently employed in the creation of bridges, high-performance concrete, and other constructions requiring long-lasting materials.

7. Colored Cement: Colored Cement is made by incorporating pigments into the cement as it is being ground. It comes in a variety of hues and may be used to give concrete ornamental elements. Architectural concrete, floors, and surfaces that are visually pleasing frequently employ colored cement.

8. Oil Well Cement: Oil Well Cement is a specific kind of cement used in the building of oil and gas wells. It is sometimes referred to as well cement or drilling cement. It must survive extreme downhole conditions, high temperatures, and pressures. Excellent durability, resistance to gas migration, and zonal isolation to stop fluid transfer across various zones in the wellbore are all features of oil well cement formulations.

9. White Cement: Limestone and kaolin clay, two raw materials with low iron contents, are used to make white cement. It is utilized in architectural applications where aesthetics is crucial and has a white hue. In order to produce precast pieces and for ornamental purposes, white cement is frequently employed. It has a crisp, brilliant look.

It is significant to note that depending on the location and nearby manufacturing facilities, certain types of cement may not always be readily available. Additionally, certain applications and specifications could call for the usage of specialized cements or bespoke blends to suit certain performance requirements. To choose the best type of cement for a certain project, it is advised to consult with an experienced engineer or cement supplier.

Properties of Cement: Because of its many unique qualities, cement is a flexible and necessary material in the building sector. Physical, chemical, and mechanical qualities of cement may all be categorized. Cement has the following important qualities:

a. **Setting and Hardening:** Cement has the capacity to go through a chemical process called hydration, which causes the cement paste to set and harden. The term setting time describes the amount of time needed for the cement paste to transition from a flexible, workable condition to a solid, rigid one. While the ultimate setting time is when the cement paste is totally firm, the initial setting time is when the cement paste first begins to harden.

b. **Compressive Strength:** The capacity of cement to endure compressive stresses without failing is one of the material's most important characteristics. Compression tests on concrete cubes or cement mortar are used to determine it. As the hydration process proceeds, the compressive strength of cement grows over time, reaching its maximum strength after around 28 days. Cement strength plays a critical role in determining the longevity and load-bearing capacity of concrete structures.

c. **Flexural Strength:** The capacity of cement to withstand bending or flexural loads is referred to as flexural strength, also known as the rupture modulus. It calculates the highest stress that a material can bear before cracking when bent. Since cement has a lower flexural strength than compressive strength, it is more likely to break under bending or tensile pressures.

d. **Workability:** This term describes how simple it is to mix, lay, compress, and finish cement. It is affected by elements including the amount of water present, the distribution of cement particle sizes, and chemical admixtures. Workability has an impact on the simplicity of construction as well as the ability to consolidate and compact concrete properly. Good workability in cement makes it simple to handle and apply without segregation or excessive bleeding.

e. **Heat of Hydration:** Heat is produced during the hydration of cement, which takes place when water is supplied. The quantity of heat generated during the hydration process is known as the heat of hydration. Thermal cracking can be brought on by excessive heat production, especially in big concrete constructions. The composition of the cement, its fineness, the water-to-cement ratio, and the curing circumstances all have an impact on the heat of hydration.

f. **Durability:** Cement's capacity to endure a variety of environmental factors and prevent degradation over time makes it one of its most important properties. A cement that is durable demonstrates resistance to corrosive substances, weathering, abrasion, and other types of degradation. The composition of the cement, the presence of admixtures, curing techniques, and exposure circumstances are all factors that affect durability.

g. **Control of Setting Time:** Different setting times for cement may be created, giving building flexibility. When speedy strength development is necessary, such as during cold weather concreting or emergency repairs, rapid-setting cement is employed. When longer workability and setting time are needed, on the other hand, delayed-setting cement is employed.

h. **Shrinkage:** Known as drying shrinkage, cement experiences a certain degree of shrinkage throughout the drying and curing process. In concrete constructions, shrinkage can lead to cracking and distortion. Shrinkage and accompanying difficulties can be reduced with proper curing and the use of auxiliary materials.

i. **Adhesion:** Cement has strong adherence to a variety of construction materials, which enables it to bind with aggregates, reinforcing steel, and other substrates efficiently. This characteristic guarantees the stability and structural integrity of concrete components.

j. **Color and Aesthetics:** Because cement can be made in a variety of hues, it may be used in architectural applications that are pleasant to the eye. For instance, colorful cements allow design flexibility, while white cement offers a clear and brilliant appearance.

These characteristics of cement help explain both its extensive usage in building and its capacity to satisfy the various demands of various applications. When choosing the right kind of cement for a particular project, it's crucial to take these features into account.

III. CONCLUSION

In conclusion, cement is a crucial component of the building sector since it acts as a binder in the creation of concrete and mortar. Calcium, silica, aluminum, and iron make up the majority of its composition, with other chemicals added to improve certain qualities. Limestone and clay are two examples of raw materials that must be

mined before being precisely proportioned, ground, and heated in a kiln. To make cement, the clinker that results is finely pulverized. The release of carbon dioxide during the calcination process, which occurs during cement manufacture, has a considerable negative influence on the environment. Its large environmental impact is also a result of its high water, energy, and raw material consumption. Sustainable options like blended cements, which include additional cementitious ingredients, are becoming more popular as a response to these worries. These options save natural resources while lowering their carbon footprint. Cement is still essential to the building sector, enabling the expansion of infrastructure and urbanization despite environmental difficulties. However, in order to reduce the negative consequences of cement manufacturing, stakeholders must embrace sustainable practices. The industry can work towards more environmentally friendly and sustainable cement manufacturing, ensuring the lifespan of our built environment while protecting the planet's resources for future generations, through embracing innovation, research, and collaboration.

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