



Ultra-High-Performance Concrete (UHPC): A microstructural and particle packing investigation

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ABSTRACT

This study examines into optimizing the composition of dispersed cement systems to reduce inter-particle voids, thereby enhancing solidity and density. The investigated concrete mixtures contain micro silica, granular blast furnace slag that has been finely dispersed, superplasticizer Glenium 430, high-valence hardening accelerator, and two fine aggregate fractions: 10–15 mm granite crushed stone and Portland cement grade 53. Laser analysis was used to analyze the size and shape of the particles, and the structure of the cement block was investigated using X-ray phase analysis, thermographic analysis, and scanning microscopy. The optimized concrete's compressive strength was evaluated at five and twenty-eight days; the results showed values of 52–74 MPa and 128–163 MPa, respectively, at cement utilization levels of 650–750 kg/m³. It was shown that the use of a bimodal clinker component and granulated blast-furnace slag blend was effective. Furthermore, there is empirical data suggesting confirms the optimal amounts of nanoscale additions, such as micro silica, required to get the most favorable outcomes.

Keywords: Cement concrete; Dispersed composition; Mineral modifiers; Strength.

1. INTRODUCTION

High-performance concrete (HPC) and ultra-high-performance concrete (UHPC) have garnered attention for their exceptional compressive strength, yet they face a significant challenge due to their substantial utilization of binder, both in total quantities and specific amounts per unit of strength. While these concrete variants have pushed the boundaries of compressive strength within their respective structural frameworks, their limitations in binder consumption are noticeable. In contrast, reactive powder concrete emerges as a promising alternative, showcasing superior properties such as heightened compressive and flexural strength, coupled with reduced permeability. This advancement surpasses the capabilities of HPC/UHPC, offering a compelling solution in structural applications. Notably, the incorporation of steel and polypropylene fibers contributes significantly to augmenting the mechanical characteristics of concrete and facilitating the dispersion of reinforcing materials. This enhancement opens avenues for a comprehensive exploration of concrete properties even in the absence of reinforcement, broadening the scope of material studies [1].

Extensive research endeavors have underscored the remarkable advantages offered by reactive powder concrete over its HPC/UHPC counterparts. Multiple studies corroborate its enhanced strength and reduced permeability, establishing a robust foundation for its consideration and utilization in various construction contexts [2–4]. The evolution of concrete formulations, especially in the realm of reactive powder concrete, stands as a pivotal stride toward advancing the structural and material capabilities of modern concrete compositions. Self-compacting concrete (SCC) stands as a promising avenue for producing reactive powder concrete, show-casing the potential of this methodology [5–7]. To achieve optimal results, SCC formulations necessitate a delicate balance of high viscosity and fluidity, ensuring the absence of water separation or delamination. Key components such as polycarboxylate superplasticizers, finely dispersed mineral additives, viscosity modifiers, set retarders, and hardening accelerators play pivotal roles in imparting these essential properties. The composition of SCC mixes with reduced yield stress typically incorporates a maximum of 0.5 sand quota, 3–10 mm coarse aggregates, and minimized water content. Manipulating aggregate grain interactions while elevating cement paste content serves to heighten concrete fluidity and enable effective self-compaction [7–10]. However, it's worth noting that concretes with higher cement percentages tend to emit more heat during the mixing process [11]. The bonding of hydrate phase particles during structural formation primarily hinges upon molecular selection, particularly concerning weak flocculation positions [12, 13]. This specific fixation mechanism can accentuate defects, looseness, and micro porosity in cement paste, consequently compromising the overall structural integrity of concrete [14, 15]. Understanding these molecular intricacies is vital in addressing and mitigating potential weaknesses in concrete structures. The interaction between SCC and reactive powder concrete not only highlights the potential for advancements in concrete technology but also underscores the critical importance of molecular-level interactions in shaping concrete properties and performance.

The attainment of concrete mixtures with a significant cement paste proportion, while concurrently reducing clinker cement consumption, is a viable objective. This can be realized by substituting a portion of clinker cement with finely ground mineral additions such as granulated blast furnace slag, fly ash, microsilica, and similar materials [16]. Incorporating mineral additives into cement requires meticulous attention to factors such as dispersity, content, and the form and size of clinker cement particles. Increasing surface area has the potential to enhance the activity of mineral additives. This concept is investigated through the formulation of thermodynamic and mathematical models aimed at optimizing the composition of composite mixtures [17–19].

Consideration of spatial and geometric characteristics is necessary for optimizing the dispersed composition of concrete with mineral additives. This includes considerations of particle dispersion, geometry, volume, energy state, average void size, fractality, and isometrics, particularly regarding the clinker component and its pozzolanic activity. Spatial and geometric characteristics of both clinker and mineral additives play crucial roles in enhancing concrete strength and other structural properties. Attention to the clinker-to-mineral additive particle size ratio is crucial when substituting cement with mineral additives, emphasizing the need for a well-balanced concrete mix with varied minerals. The evaluation of pozzolanic activity as well as the energy of mineral additions has a substantial impact on the concentration of the solid phase per unit volume in concrete mixtures [20].

Efficient void filling is achieved by placing mineral additive particles of each smaller fraction between grains. Major additions, Coulomb reciprocal action, and the distribution of tessellated small mineral particles on clinker particles cause the bigger particles to naturally align. The phenomenon of self-organization in concrete mixtures decreases the disorder of components, increases the potential energy and viscosity of particles, guarantees a high degree of homogeneity, and reduces the likelihood of delamination in self-compacting concrete [21]. Thus, self-compacting concrete with high-strength grades requires appropriate particle and grain dispersion at each hierarchical structural level. Scanning electron microscopy, thermography, and X-ray phase analysis examine cement paste structure [22]. This method enhances the composition and structure of concrete by utilizing an appropriate proportion of highly dispersed minerals and superplasticizers.

Based on research, there are four major ways to designing the mixture of ultra-high-performance concrete (UHPC) based on the microstructure of reactive powder concrete [23]. This study utilizes close packing methodologies that are based on dry and wet packing densities [23–25]. It investigates the correlation between raw materials and the rheological properties of paste [26, 27]. Additionally, it employs statistical analysis [28], artificial neural network models [29, 30], and solid particle packing to design ceramic processing mixtures [31–37]. Concrete and asphalt, which are also included in this comprehensive study of mixture design for UHPC, are taken into account.

The investigation indicates that there is a substantial amount of empirical data available on the microstructure of reactive powder concrete. Nevertheless, the data failed to yield an accurate mixing theory or design model. This article outlines an easy technique to enhance the dispersion of finely divided clinker particles and mineral additions. This study examines the characteristics of cement paste with many components and enhances the composition of concrete by including mineral additives. Enhancing the density of particles and maximizing the concentration of solid phase per unit volume enhances the strength of concrete. In order to minimize the empty spaces between particles, it is necessary to enhance the concentration of the solid phase per unit volume, hence enhancing its strength.

2. MATERIALS AND METHODS

The study examined the properties as well as the structure of concrete using two different sizes of fine aggregate, specifically 0.250 mm and 0.125 mm. These aggregates were used in proportions of 80% and 20% respectively. Additionally, the concrete included crushed particles of hard blue granite stone with the particle size range from 5-10 mm, Portland cement conforming IS:12269-1987 with 53 grade, the specific surface area of 243 m²/kg, finely dispersed granular blast furnace slag with a specific surface area of 413 m²/kg, micro silica, and a fine fraction of cement. The amount of cement used in concrete, which may include multiple components, ranged

between 460 and 740 kg/m³ depending on the specific research objective. The super plasticizer of gelinium-430 was used in the rage of 0.45-0.55%, the high valance accelerator followed by the rule of Schulze–Hardy rule [13, 38] at the range of 0.08% of the weight of cement.

The structure of cement stone was investigated with an Aeris X-ray Diffractometer, malvern panalytical, India. The Q-seris thermal analyzer from TA technologies, New Castle, USA was used for differential thermal analysis. The D4 ENDEAVOR scanning electron microscope (Dynamic Technology Systems, India) was used for structure microanalysis. The particle size distribution aggregates were done followed by the guidelines of IS 460:1962, Th physical and mechanical properties of crushed aggregate particles were examined followed by the guide lines of IS 2386-4 (1963 [39] Determination of particle size distribution of ceramic powders by laser diffraction method [40, 41]. The mobility of the concrete mixture, compressive strength of concert specimen was determined according to IS 456-2000 [42].

3. MATERIALS AND METHODS

Scanning microscopy combined with microanalysis was used to examine the structural composition. The results showed that finely ground granulated blast furnace slag, when used in an appropriate amount and with the proper degree of fineness, is evenly distributed (with a coefficient of variation below 0.5%) within the matrix of a multicomponent cement paste. The finely dispersed clinker component, with a dispersion of 950–1000 m²/ kg, was used in the process of production of the multicomponent cement. Particles with sizes ranging from 1 to 5 microns and less made up a maximum of 50% of the total, whereas particles up to 10 microns accounted for up to 76% of total volume. The fine fraction content and the utilized clinker component were 2.5 times greater than their corresponding quantities in industrial Portland cement (Figure 1). The average particle sizes of conventional Portland cement, fine slag, and fine cement were 35, 20, and 3.5μ mrespectively.

The use of fine cement is essential for the following reasons: firstly, it ensures a uniform reaction between portlandite and silicon dioxide in all microvolumes of the cement paste. A higher degree of consistency in reactions is caused by the uniform distribution of fresh hydro silicate phase formations in each microvolume of cement paste, it leads to the strength enhancement and reduction of damages in inner matrix of cement paste. Furthermore, the second level of concentration corresponds to the concentration of the solid phase per unit volume, This effect results in a decrease in the moisture content of particles in the larger proportion of the clinker component, particularly due to the existence of large and durable remains. Consequently, this substantial rise in the strength of the cement paste and the long-lasting nature of concrete is observed. On other hand it is important to note that the early initiation of the hydration process in slag minerals is a significant factor to consider.



Figure 1: Particle size distrubtion of raw materiels.

The hypothesis is presented by the writers as a means to provide an explanation for the occurrences that are being examined. During the earliest stages of cement hydration, the highly distributed clinker particles undergo practically complete hydration. The particles in question mostly belong to the second hierarchical level within the multi-size cement particle system. The hypothesis is presented by the writers as a means to provide an explanation for the occurrences that are being examined. During the earliest stages of cement hydration, the highly distributed clinker particles undergo practically complete hydration. The particles in question mostly belong to the second hierarchical level within the multi-size cement particle system. Simultaneously, the process of hydration of mineral additions is initiated. The formation of a hydro silicate gel layer occurs on the external surface of the un-hydrated cement particle. This gel layer captures ettringite crystals, leading to the growth of the cement paste's microstructure. As a result, a conglomeration is formed, with clinker particles serving as foci for crystallization. Calcium hydro sulfoaluminates are impurity inclusions that can be found within the microstructure of the potassium silicate hydrate phase. The nanoscale size of these particles and the potential for the creation of chain or cluster percolations lead to an enhanced density and strength of the hydrate phase. Calcium hydro sulfoaluminates are potassium silicate hydrate microstructure impurities. The nanoscale size of these particles and their capacity to form chains/clusters and fabiform, needle-shaped, or hexagonal-prismatic inclusions increase hydrate phase density and strength. The effect is seen when superplasticizer is added to concrete. Figure 2 (a) shows inclusions, and Figures 2(b) and 2(c) show superplasticizer. Ettringite crystals are 1000–3000 nm long and 40-120 nm wide. Crystals can reach 8 µm length and 220 nm cross-sectional diameter.

The energetic interaction of newly formed chains and clusters of calcium hydro-sulfoaluminates with newly formed hydro silicate phases contributes to their fixation in the densest packing. This, in turn, provides a significant contribution to the synthesis of the strength of the cement stone. Their simultaneous presence as an impurity phase in cement stone causes the new hydro silicate phases that are present in cement stone to become more unstable. Therefore, calcium hydro sulfo-aluminates offer a dual benefit to the strength of the cement stone structure in which they are embedded. This is because calcium hydro-sulfoaluminates have both a high and low solubility in water. Because of this, it is advised that high-strength concretes be made with cement that contains



Figure 2: (a) Ettringite structure like thread, (b) Ettringite structure like hexagonal prismatic structure, (c) Tricalcium aluminate.

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a low percentage of tricalcium aluminate. The rationale for this is so that the concrete can better withstand the force of impact.

When the calcium silicate minerals that make up clinker are hydrated, calcium hydroxide is produced as a byproduct. Calcium hydroxide interacts with silica fume to generate an amorphous polymorph of silicon dioxide and other silicious components, primarily in an amorphous state. These components compose strong calcium hydro silicates with a low basis strength. In this scenario, the hydration processes of the clinker minerals C_3S and C_2S are sped up, resulting in a faster final product. After some time has passed, the pozzolanic reaction of the particles with lower kinetic energy that are found in the hydrate phases will produce a product that has substantially less deficiency, a higher degree of structure ordering, high density, and strength due to the tight coagulation of these particles.

The compressive strength can exceed 1000 MPa even with only a moderate amount of disorder in the material. The chemically bonded water content of this product is 1.5–2 times lower than the water content found in primary neoplasms of hydrosilicate phases [19]. Later on, the products of hydration of the calcium silicate phases of clinker, slag, and the pozzolanic reaction will eventually consolidate into a structure of a conglomerate or composite type that is long-lasting, homogenous, and has a high dispersity. The majority of the pores in such a compact lattice are of the helium size. The durability of this structure is ensured by the presence of C–S–H with varying stoichiometry, residuals of clinker and slag, as well as the hard particles of mineral additions.

Therefore, in order to achieve a substantial enhancement in the strength of reactive powder concrete, it is necessary to employ a multilevel particle packing approach in the formulation of a multicomponent concrete mixture, ensuring a consistent distribution of particle sizes. The achievement of full hydration of the minerals present in clinker particles is not necessary in order to guarantee the attainment of high structural strength. The self-consolidating concrete (SCC) mixture, which was made in accordance with the previously mentioned guidelines, has a low yield stress, high deformability, and demonstrates the lack of water gain, gravity segregation, and separation stability. Additionally, the SCC mixture possesses a cone flow diameter of 88 cm. The concrete mixture exhibits the presence of equally dispersed coarse aggregate grains on its surface, hence validating the aforementioned features (refer to Figure 3).



Figure 3: SCC mix spred.



Figure 4: SEM image of (a) control composition, (b) with fine slag, (c) with fine slag and floured cement, (d) with fine slag, floured cement, and micro silica.

The experimental experiments revealed that the ideal proportion of highly distributed cement was determined to be 6%, while the optimal amount of microsilica was found to be 3%. The study also revealed that the ideal proportion of the superplasticizer GleniumACE 430 in relation to the cement mass ranges from 0.45% to 0.56%. Additionally, it was determined that the high-valence hardening accelerator AC should be present at a concentration of 0.07%. The optimal composition of the hardening accelerator AC was found, considering the Schulze-Hardy rule [22]. The use of a hardening accelerator resulted in a synergistic outcome when combined with Glenium 430, enabling a further reduction in the water content of the concrete mixture by up to 20%. The addition of a hardening accelerator to a concrete mixer should be performed after the plasticizer has been mixed for a duration of 8–10 seconds, but before the concrete mixture preparation is completed. This timing allows for the adsorption of the hardening accelerator onto the grafted side chains of the polycarboxylate superplasticizer. Consequently, it leads to a substantial enhancement of the plasticizing reduction effect, primarily attributed to the amplified repulsive forces within the concrete that has been modified with mineral additives.

Studies have shown that the optimized and self-organized interparticle void content at four dispersed levels of concrete modified with mineral additives decreases by 12–14% or more due to the optimal spatial, geometric, and quantitative parameters of mineral additives and the almost mosaic energy state of the original powder components' surface. Concrete strength increases by more than twofold. This is because mineral additives have excellent spatial, geometric, and quantitative properties.

The theoretical value of 8 percent and nine point nine % is supported by the fact that finely dispersed slag reduces the interparticle void content of real concrete modified with mineral additives by more than 9 % to less than 9%, depending on the material. The compressive strength of concrete after 2 days after hardening under normal conditions was 52, 63, and 74 MPa, and at 28 days it was 128, 137, and 163 MPa, with 650, 700, and 750 kg/m³ multicomponent cement consumption. Concrete was tested at three ages to ascertain this. The quality assessment of the concrete specimens was conducted through the utilization of scanning electron microscopy, as depicted in Figure 4.

The inclusion of mineral additives, whose dispersion and content are selected based on the findings of this study and earlier research [21], has a substantial positive impact on the structural integrity of concrete. This improvement may be shown at a nano-modified level, as depicted in Figure 5 and Images 3 and 4. Thermal imaging and X-ray analysis were conducted on concrete samples containing mineral additions. These samples

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Figure 5: Particle distrubtion of clinker and mineral additives.

SL. NO	MINERAL ADDITIVES (%)	WIGHT LOSS (%)			METHOD	9/ OF	DEGREE OF	
		125– 150°C	500– 525°C	800– 825°C	OF CURING	% OF Ca(OH) ₂	HYDRATION OF (%)	CURING
1	Control specimen	16.4	22.6	27.1	Water curing	20.7	64	28
2	Specimen with 20% fine slag	13.9	20.2	25.4	Water curing	16.9	78	28
3	Specimen with Fine slag of %, 5% micro silica and fine faction of cement	14.2	17.7	21.2	Water curing	13.2	87	28
4	Control specimen	14.8	20.6	24.6	Steam Curing	22.4	62	28
5	Specimen with 20% fine slag	12.3	17.2	20.5	Steam Curing	16.3	74	28
6	Specimen with Fine slag of %, 5% micro silica and fine faction of cement	9.8	13.6	17.2	Steam Curing	11.1	81	28

Table 1: Results of thermographic and radiographic analyses.

were examined at the 28-day mark after being hardened under both normal settings and steam curing. The results of these experiments are presented in Table 1.

The concrete structure, when modified with mineral chemical modifiers that possess optimal parameters, exhibits a notable reduction in portlandite content. Additionally, the hydration level of Portland cement reaches 83–85%, surpassing the corresponding value of the control composition by 20–27%, thereby confirming its enhanced strength.

4. DISCUSSION

The packing density-based close parking approach for UHPC mixture design defines the ratio of solid volume to the cement and additive system's total volume [22–24]. The authors suggest a physical model of concrete microstructure and particle packing using spherical particles to explain the results. Figure 5 depicts the expected particle distribution of clinker and mineral additives. A similar hypothesis was originally proposed in [15] without experimental validation. Figure 5, Image 1 shows the unit cell of clinker particles as a simple pseudo-cubic packing of particles of the same dimension. The clinker matrix is considered to be a simple cubic packing with 48% voidness and particles of the same dimension. The notion is supported by the 55–58% voidness of genuine cement particles. Additionally, sedimentation and laser tests revealed that up to 85% of the distribution of cement and mineral additives occurs within a $12–15 \,\mu$ m range.

Assuming three types of mineral addition dispersion to increase concrete density: a) Mineral additive dispersion is optimal when particles cover spaces between clinker particles (Figure 5, Image 2). Mineral additions enhance cement paste density by 8.09% compared to without them (Figure 5, Image 1). b). Clinker and mineral additive particles disperse similarly. The addition of mineral additive does not alter the density of the cement paste (Figure 5, Image 5–8). b) Dispersion of mineral additive particles is substantially higher than clinker particles (Figure 5, Image 3). A finely disseminated mineral addition like microsilica has a specific surface area of 18,000–21,000 m²/kg. Mineral additions may enhance cement paste density more than without them. Large aggregates of mineral additions can decompact clinker particles (Figure 5, Image 4), increase interparticle voidness, and negatively affect concrete characteristics. Cement systems with a conglomerate or composite structure may have two or more distributed mineral additives forming a distinct aggregate [2, 19].

In microvolumes of cement systems, the pozzolanic reaction is rare. The microvolumes are pseudopores measuring 5–7 μ m for three particles and 0.5–1.5 μ m for two particles. Large particle numbers and aggregates can loosen the matrix component by distributing particles in interparticle gaps of elementary cells (Figure 5, Image 2). Concrete containing mineral additives will have weaker strength, frost resistance, and deformation due to structural faults such as pseudopores. Increased mineral additive content may cause stable aggregates of tiny microsilica particles with high binding energy.

Accurately determining the appropriate quantities of mineral additives in the composition of concrete is of utmost importance in comprehending their impacts, both beneficial and detrimental, on the overall structure and properties of the material. In the initial scenario, it is deemed fair to incorporate mineral additions ranging from 18% to 25%. In the second scenario, achieving a uniform distribution of clinker and mineral additives requires the inclusion of mineral additives at levels of 25%, 50%, or 75%. In the third scenario, the quantity of mineral additives is limited and calculated using empirical methods. Mineral additives' pozzolanic activity affects clinker mineral hydration, hydrate phase products, contact zones between mineral additive particles and neoplasms, and concrete strength. Inactive mineral additives reduce cement substitution while boosting mineral additive concentration. When replacing cement with highly active mineral additives to increase concrete strength compared to the control composition, the cement and mineral additive content must be reduced in a specific ratio. For mineral reinforcement through independent hydraulic hardening, scatter slag particles finely and distribute them primarily in the interparticle gaps of the clinker component. Cement mixtures should have between 35 and 70 percent slag [11]. This quantity exceeds the volume of clinker component interparticle voids. It is recommended to use a slag or clinker component with a bimodal particle size distribution when making high-density concrete with dispersed mineral additives. High-density concrete modified with scattered composition mineral additives can be made by incorporating slag or clinker into the concrete distribution. In Figure 5, Image 2, the data illustrates the presence of bimodal clinker dispersion and the utilization of mineral methods involving the incorporation of 40% (by volume) slag alongside an equal-dispersion clinker component, or alternatively, a higher-dispersion component with 20% slag. Bimodal particle size finely dispersed granular blast furnace slag has the capability to occupy a range of 60% to 80% of the mineral-added concrete. In the latter scenario, it is necessary to utilize blast furnace slag that possesses a singular granulation mode, alongside clinker that exhibits a more homogeneous particle size distribution and an optimal specific surface area, by adding highly distributed nanosized minerals such carbon fibers, fullerenes, and nanosilica, self-compacting concrete can be strengthened. Their content should be unimportant. Agglomeration of nanosized particles may reduce the benefits of nanosized mineral additions.

The suggested physical model for concrete microstructure and particle packing is supported by experimental findings [15, 16]. Development criteria for mineral-added self-compacting concrete: You need 5–10 millimeters of coarse material. To limit ultimate shear stress, the concrete mixture should not exceed 0.5 sand fraction in coarse aggregate [9, 43]. Fine aggregate should consist of two or three fractions: 80% coarse 0.3 mm and 20% fine 0.12 mm. A fractional fine aggregate composition in concrete reduces intergranular voids and air entrainment. Use absolute volume to calculate multicomponent binder volume. Three-stage multicomponent binder dispersion. Portland cement with 220–250 m²/kg dispersion may be used first. Over time, coarse cement fraction keeps strong clinker particles with high modulus of elasticity in concrete. To fill Portland cement's first interparticle gaps, add 20–25% finely distributed blast furnace slag at 380–450 m²/kg. At the second level, use 4–12% finely dispersed Portland cement with 900–1100 m²/kg dispersion. This dispersion allows a consistent pozzolanic response in all micro volumes with mineral modifiers, preventing aggregation of particles.

In the case of the third level, it is recommended to incorporate microsilica at a concentration ranging from 2.% to 6%, accompanied by a dispersion level falling within the range of 18,000 to 21,000 m²/kg. Microsilica exhibits migration between larger particles. The hydration phase neoplasms exhibit molecular selection and strong flocculation, resulting in the fixation of particles at a distance of 10–9 m [12, 43]. The augmentation of mineral additives in conjunction with effective flocculation has been found to significantly enhance the

density and strength of concrete. Furthermore, the pozzolanic reaction gives rise to the formation of robust dendrite-shaped secondary hydrosilicate phases with low basicity. During the manufacturing process of concrete mixtures, the combination of highly dispersed amorphous silicon dioxide and calcium hydroxide leads to the formation of fibrous and tubular nanosized calcium hydrosilicates. Agglomerations of calcium hydro-silicates facilitate the dense packing of neoplasmal particles within hydrate phases. In this particular instance, the quantity of microsilica utilized is small and determined using empirical means. In order to achieve a multi-component binder with a highly dispersed structure, the inclusion of polycarboxylate-type superplasticizers and high-valence hardening accelerators is required.

Furthermore, it is worth noting that when the cement concentration is high, there is a possibility for the total alkali content in different components of the concrete composition to surpass the critical threshold of 3 kg/m³. The presence of a high concentration of alkali necessitates the use of aggregates that include reactive silica in order to facilitate alkaline corrosion of the aggregates. As a result, the utilization of limestone and dolomite flour in concrete that has been altered with mineral additions demonstrates lower efficacy compared to mineral additives that contain reactive silica.

5. CONCLUSION

This study found that heterogeneous mineral additions are essential for a consistent, tightly packed cement stone structure with few flaws. These additives must have surface area and content that match the spatial geometry and energetic properties of the matrix component's interparticle void particles. The following conclusion has been made based on this experiment.

- Ideal geometric and quantitative parameters and mineral additions can reduce mineral-modified concrete's initial interparticle void content by 12–14% or more. Mineral additives double or more the strength of concrete. Using finely distributed slag reduces interparticle void volume by 9%.
- Using clinker particles of various sizes increases solid phase concentration, and promotes homogeneous pozzolanic and hydration reactions in all microvolumes of concrete with mineral additives. A significant rise in cement stone density and the presence of big, powerful clinker particles later on contribute to the strength and durability of concrete.
- Complex polycarboxylate-type superplasticizer and high-valence hardening accelerator AC work well. According to the Schulze-Hardi rule, cement should include 0.07% hardening accelerator AC by mass. The superplasticizer
- Glenium 430 works better with a high-valence hardening accelerator. This method can reduce concrete water content by 20%. When mixing concrete, apply the hardening accelerator 8–10 seconds after the plasticizer. Maximum 20% water reduction in concrete mixtures is recommended. Following the plasticizer, add the hardening accelerator to the concrete mixer 8–10 seconds before mixing.

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